REPORT OF GEOGRAPHIC INFORMATION SYSTEM DATABASE DEVELOPMENT AND INVESTIGATIONS TO SUPPORT COMPLIANCE DETERMINATION METHOD DEVELOPMENT-HYDROLOGY FY94

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ABSTRACT

Nuclear Regulatory Commission (NRC) and Center for Nuclear Waste Regulatory Analyses (CNWRA) staffs are in the process of developing Compliance Determination Methods (CDMs) to ensure a timely review of the U.S. Department of Energy (DOE) License Application (LA) for Yucca Mountain (YM). For the purposes of developing the necessary background to evaluate DOE submittals, it is possible to use current levels of understanding to identify broad types of data that will be needed to complete the compliance reviews of the LA in the mandated time. Many of the required data, such as site geology, precipitation, and hydrostratigraphy, are site-specific in nature. Given the recent initiation of site characterization activities at YM, while it is possible to make a preliminary identification of specific data sources, much of the data currently available is sparse. Presumably many of the gaps will be filled in through ongoing and future site characterization activities. For several types of data, such as water and gas properties, there is little need to acquire site-specific data, and current data sources can be identified readily. Even in these cases, however, certain systems or parameters may be poorly characterized and subject to change as research proceeds and levels of understanding increase. This report is an initial attempt to identify specific data needs for each of the CDMs related to hydrological and climatological issues, and currently available sources for these data. Although developed separately, there is generally good agreement between the data needs identified here, and those cited in the Format and Content Regulatory Guide (FCRG).

Many of the hydrological and climatological data that will be generated during DOE site characterization will be site-specific to YM and the surrounding area. For this reason, these data are most useful when tied to a geographic and geologic framework. Geographic Information Systems (GIS) such as ARC/INFO are powerful tools designed for presenting and interpreting data in a geographic context. By incorporating hydrological and climatological data in a GIS database, it is possible to analyze the data for spatial trends, identify relations among other geographic and geologic data, and identify gaps in the data collection. By superimposing different coverages such as geology, other geochemical and hydrologic data and political and regulatory boundaries, it is possible to develop figures and maps that can transmit a wide range of information. Future efforts in this task will focus on obtaining selected data identified in this report and combining site-specific information with the GIS database currently in development at CNWRA.

CONTENTS

Section | Page

TABLES iv
ACKNOWLEDGEMENTS v

1 INTRODUCTION 1-1
1.1 REGULATORY BASIS 1-1
1.2 OVERALL REVIEW STRATEGY AND THE LICENSE APPLICATION REVIEW PLAN (LARP) 1-2

2 COMPLIANCE DETERMINATION METHOD DATA NEEDS, METHODS, AND ANALYSES 2-1
2.1 DATA NEEDS FOR DIFFERENT LEVELS OF COMPLIANCE REVIEW 2-1
2.2 CODES, METHODS, AND ANALYSES 2-2

3 SPECIFIC DATA NEEDS AND EXISTING DATA SOURCES 3-1

4 SUMMARY AND CONCLUSIONS 4-1
4.1 CURRENT STATUS 4-1
4.2 FUTURE EFFORTS 4-2

5 REFERENCES 5-1

APPENDIX A LIST OF ABREVIATIONS

TABLES

Table		Page
1-1	Compliance Determination Methods for Hydrology, and Climatology/Meteorology Individual Systems	1-4
2-1	Broad data needs for Compliance Determination Methods in Hydrology Individual System	2-3
2-2	Broad data needs for Compliance Determination Methods in Climatology/Meteorology Individual System	2-4
2-3	Codes, methods, and analyses for Compliance Determination Methods in the Hydrology Individual System.	2-5
2-4	Codes, methods, and analyses for Compliance Determination Methods in the Climatology/Meteorology Individual System	2-6
3-1	LARP Section 3.1.2 — Hydrologic Systems Description (FY94)	3-3
3-2	LARP Section 3.2.2.5 — (PAC) Flooding (FY94)	3-5
3-3	LARP Section 3.1.4 — Climatological and Meteorological Systems Description (FY94)	3-7
3-4	LARP Section 3.2.4.1 — (FC) Precipitation that is a Small Percentage of Annual Potential Evapotranspiration (FY94)	3-10
3-5	LARP Section 8.1.2 — Performance Confirmation: Hydrologic System (FY95)	3-15
3-6	LARP Section 8.1.4 — Performance Confirmation: Climatologic System (FY95)	3-18
3-7	LARP Section 3.1.5 — Integrated Natural System Response to Maximum Design Thermal Load (FY96)	3-20
3-8	LARP Section 3.2.2.1 — (FC) Nature and Rates of Hydrologic Processes (FY96)	3-25
3-9	LARP Section 3.2.2.7 — (PAC) Natural Phenomena and Groundwater (FY97)	3-29
3-10	LARP Section 3.2.2.11 — (PAC) Potential for Unsaturated Zone Saturation (FY97)	3-32
3-11	LARP Section 3.2.2.4 — (FC) Unsaturated Zone Hydrogeologic Conditions (FY98)	3-36
3-12	LARP Section 3.2.2.10 — (PAC) Complex Engineering Measures (FY98)	3-38
3-13	LARP Section 3.2.2.9 — (PAC) Changes in Hydrologic Conditions (FY99)	3-42
3-14	LARP Section 3.3 — Assessment of Compliance with the Groundwater Travel Time Performance Objective (FY00).	3-47

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QUALITY OF DATA

DATA: Sources of data are referenced in this report. CNWRA-generated laboratory and field data cited in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Data from other sources however, is freely used. Data from non-CNWRA sources, their referenced sources should be consulted for determining their level of quality assurance.

1 INTRODUCTION

Tertiary ash-flow tuffs at Yucca Mountain (YM), Nevada are currently being considered as a potential location for a high-level radioactive waste (HLW) geologic repository. To maintain the public health and safety, the ability of this repository to isolate the waste from the accessible environment is of critical importance. Because a multiple-barrier design is reflected in the regulatory requirements, the geologic setting will be relied upon to provide isolation of the waste beyond the engineered barrier system. The different subsystems of the geologic setting, including the hydrologic, geochemical, and climatology/meteorological systems all contribute to controlling the isolation capabilities of the site.

Many of the hydrological and climatological data that will be generated during U.S. Department of Energy (DOE) site characterization will be site-specific to YM and the surrounding area. For this reason, these data are most useful when tied to a geographic and geologic framework. Geographic Information Systems (GIS) such as ARC/INFO are powerful tools designed for presenting and interpreting data in a geographic context. By incorporating hydrological and climatological data in a GIS database, it is possible to analyze the data for spatial trends, identify relations among other geographic and geologic data, and identify gaps in the data collection. By superimposing different coverages such as geology, geochemical and hydrologic data, and political and regulatory boundaries, it is possible to develop figures and maps that can transmit a wide range of information.

1.1 REGULATORY BASIS

The Nuclear Waste Policy Act of 1982 (NWPA), as amended in 1987 charges the DOE, the Nuclear Regulatory Commission (NRC), and the Environmental Protection Agency (EPA) with particular responsibilities in the siting, licensing, construction, operation, and permanent closure of a HLW geologic repository. The NRC regulations governing waste isolation in a geologic repository are given principally in 10 CFR Part 60, while the limits imposed on radionuclide release to the accessible environment are established by the EPA in 40 CFR Part 191. The EPA standards are currently under evaluation by the National Academy of Sciences (NAS) in the context of the Energy Policy Act of 1992.

Through site characterization activities designed to meet the requirements in 10 CFR Part 60 and described in detail elsewhere (e.g., U.S. Department of Energy, 1988), the License Application (LA) submitted by DOE is required to provide general information on the ability of the YM to meet overall performance objectives. The LA must also include a Safety Analysis Report (SAR)[10 CFR 60.21(c)] containing a description and assessment of the hydrogeology, geochemistry, climatology, and meteorology of the site. The analyses and evaluations of individual systems required for the SAR are covered in 10 CFR 60.21(c)(1)(ii)(A) through (C). Hydrogeologic, geochemical, and climatology/meteorology considerations are also identified in several places in the siting criteria identified in 10 CFR 60.122(b) and 10 CFR 60.122(c) as both favorable (FAC) and potentially adverse (PAC) conditions, respectively.

The overall system performance objective for the geologic repository after permanent closure is defined in 10 CFR 60.112 and requires that "...releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events," [10 CFR 60.112]. Performance objectives for the engineered barrier and the geologic setting are described in 10 CFR 60.113. In 10 CFR 60.113(a)(2), the performance of the geologic setting with regard to hydrology is described such that "...pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years...," [10 CFR 60.113(a)(2)]. The role of hydrology and climatology/meteorology in performance assessment is described in 10 CFR 60.113(b) and is dependent on the ability of the repository to satisfy the overall system performance objective [10 CFR 60.112] as it relates to anticipated processes and events. For unanticipated processes and events, it may be necessary to specify additional requirements to satisfy the overall performance objective [10 CFR 60.113(c)].

1.2 OVERALL REVIEW STRATEGY AND THE LICENSE APPLICATION REVIEW PLAN (LARP)

The general nature of the review strategies that will be followed by NRC for the LA are described in Overall Review Strategy for the Nuclear Regulatory Commission's High-Level Waste Repository Program (Johnson, 1993). Stated simply, upon receiving the LA from DOE, NRC will be charged with evaluating the application and making a recommendation as to whether or not to grant a license for construction of the HLW repository. As described in 10 CFR 60.31, the decision to authorize construction will be based on consideration of three factors:

- Reasonable risk to the health and safety of the public [10 CFR 60.31(a)]
- Noninimicability to the common defense and security [10 CFR 60.31(b)]
- Protection of environmental values [10 CFR 60.31(c)]

The statutory time period mandated by the NWPA, for review of the LA is 3 years. It is expected that only 18 months of that time will be available for NRC staff to review the LA and prepare its safety evaluation report (SER).

Because of the complex nature of the technical issues that are to be addressed in the LA and the relatively short review time mandated by the NWPA, NRC has developed guidance to help streamline the review process. One such guidance document is the Draft Regulatory Guide DG-3003: Format and Content for the License Application for the High-Level Waste Repository (FCRG) which provides guidance to DOE concerning what NRC staff considers acceptable format and content for the LA.

Additionally, NRC is iteratively developing the License Application Review Plan (LARP). The LARP consists of more than 90 individual review plans that provide guidance relevant to the review of procedural and technical requirements contained in 10 CFR Part 60. As described in the License Application Review Plan for a Geologic Repository for Spent Nuclear Fuel and High-Level Radioactive Waste, Draft Review Plan (NRC, 1994), the LARP is comprised of three parts. Part A describes the overall review strategy. Part B consists of eight individual review plans developed for review of general information in the LA. The final section (Part C) contains all other individual review plans for the technical information required as a part of the SAR [10 CFR 60.21(c)].

The individual review plans contained in the LARP follow a standard format. The first part identifies the applicable parts of 10 CFR Part 60 (regulatory requirements). The second part consists of the compliance determination strategies (CDSs) developed by NRC and Center for Nuclear Waste Regulatory Analyses (CNWRA) staff to assess the compliance of DOE with the applicable 10 CFR

Part 60 regulatory requirements. The review plans also contain specific procedures and acceptance criteria to be used in evaluating DOE demonstrations of compliance, review plan interfaces and integration information example evaluation findings, and references.

NRC and CNWRA staffs have completed the initial development of the CDSs. To streamline the review process and assure that important issues associated with the regulatory requirements are given appropriate emphasis, the review strategies specify review types of varying complexity. The following definitions are abstracted from the Technical Operating Procedure (TOP) for CDS development (TOP-001-11).

- A Type 1 Acceptance Review is designed to determine if the LA is complete and acceptable for further compliance reviews. It is not designed to determine the adequacy of the data in the LA. This type of review is required in all of the individual review plans.

- A Type 2 General Information Review is designed to determine the adequacy of compliance with the general information requirements of 10 CFR Part 60.

- A Type 3 Safety Review is the first level of review of the compliance demonstrations and systems descriptions related to radiological health and safety or waste isolation. The focus of the review is on the contents of the LA itself and is not designed to require detailed independent analysis beyond the use of standard formula or simple "back-of-the-envelope" calculations.

The most detailed types of review (Types 4 and 5) are associated with key technical uncertainties (KTUs), which are those technical issues that the staff believes pose the highest risk of noncompliance with a performance objective of 10 CFR Part 60. All of the review plans requiring Type 4 and/or 5 reviews also require a Type 3 Safety Review.

- A Type 4 review requires the detailed review of selected information, supported by analyses performed by the technical staff using "...methods, developed by DOE or other parties, that have been reviewed and found acceptable by the staff." (Johnson, 1993).

- A Type 5 review is given the highest priority, and requires the application of methods and analyses independently developed by the technical staff to those technical issues considered to be the most difficult to resolve.

Compliance Review Types 2 through 5 all require some evaluation of the technical adequacy of DOE compliance demonstrations. For this reason, these types of review will all require some technical expertise on the part of NRC and CNWRA staff. This may include general expertise in a relevant field such as hydrology or geochemistry, as well as knowledge of information that is site-specific to YM or related to the repository design. The types of expertise and information that will be necessary to evaluate the adequacy of the LA are described in Section 4 of the Compliance Determination Methods (CDMs).

NRC and CNWRA staff have begun development of the CDMs that will contain the review procedures and acceptance criteria to be used by NRC in determining the compliance of DOE's license application with the performance objectives given in 10 CFR Part 60. It is this part of the LARP review plans that deals specifically with the technical criteria for siting a repository. As part of the LARP, 28 of the more than 90 individual review plans are related to issues in hydrology, geochemistry, and climatology/meteorology. A listing of the different hydrology and climatology/meteorology CDMs and the current schedule for their completion is given in Table 1-1. The schedule may be modified in response to DOE program changes.

Table 1-1. Compliance Determination Methods for Hydrology, and Climatology/Meteorology Individual Systems.

CDM		Individual System	Review Type	Schedule
3.1.2	Description of Hydrologic System	Hydrology	Types 1 and 3	FY94
3.1.4	Description of Climate/Meteorology System	Climate/Meteor	Types 1 and 3	FY94
3.2.2.5	(PAC) Flooding	Hydrology	Types 1 and 3	FY94
3.2.4.1	(FC) Potential for Evapotranspiration	Climate/Meteor	Types 1 and 3	FY94
8.1.2	Performance Confirmation: Hydrology	Hydrology	Types 1 and 3	FY95
8.1.4	Performance Confirmation: Climatology/Meteor	Climate/Meteor	Types 1 and 3	FY95
3.1.5	Integrated Natural System Response: Thermal Loading	Hydrology	Types 1 and 3	FY96
3.2.2.1	(PAC) Nature and Rates: Hydrologic Processes	Hydrology	Types 1,3,4,5	FY96
3.2.2.6	(PAC) Human Activity and Groundwater	Hydrology	Types 1,3,4	FY96
3.2.2.3	(FC) Groundwater Travel Time > 1000 yrs	Hydrology	Types 1 and 3	FY97
3.2.2.7	(PAC) Natural Phenomena and Groundwater	Hydrology	Types 1 and 3	FY97
3.2.2.11	(PAC) Potential for Unsaturated Zone Saturation	Hydrology	Types 1 and 3	FY97
3.2.2.4	(FC) Unsaturated Zone Hydrogeologic Conditions	Hydrology	Types 1 and 3	FY98
3.2.2.10	(PAC) Complex Engineering Measures	Hydrology	Types 1 and 3	FY98
3.2.4.2	(PAC) Changes to Hydrologic System from Climate	Climate/Meteor	Types 1,3,4	FY98
3.2.2.8	(PAC) Structural Deformation and Groundwater	Hydrology	Types 1,3,4	FY99
3.2.2.9	(PAC) Changes in Hydrologic Conditions	Hydrology	Types 1,3,4,5	FY99
3.2.2.12	(PAC) Perched Water Bodies	Hydrology	Types 1,3,4,5	FY99
3.3	Assessment of Compliance with Groundwater Travel Time (GWTT) Objective	Hydrology	Types 1,3,4,5	FY00

2 COMPLIANCE DETERMINATION METHODS DATA NEEDS, METHODS, AND ANALYSES

2.1 DATA NEEDS FOR DIFFERENT LEVELS OF COMPLIANCE REVIEW

An important part of CDM development is inclusion of rationales for the different procedures and acceptance criteria which are being used to determine compliance. To aid in developing these criteria and rationales, it is desirable that NRC and CNWRA staff identify as early as possible technical data that will be necessary for the timely review of the license application. For many of the individual review plans the staff has considered the issue relatively well understood and has assigned only a Type 1 acceptance review and a Type 3 Safety Review. For these review plans, the review can be largely confined to evaluating the information present in the LA.

Although a Type 3 Safety Review will rely on information provided with the LA, there are advantages to identifying data needs within the context of CDM development and establishing a database of limited amounts of site specific data to prepare NRC/CNWRA staff for reviewing the license application. By allowing staff to become familiar with existing data well in advance of receiving the LA, the Safety Review would be enhanced by allowing the staff to become familiar with DOE approaches and the existing data as they become available through reports by DOE and its contractors. In addition, information that either is pre-existing or is gathered outside of the DOE program through state and federal (other than DOE or NRC) agencies, international programs, universities, and private companies may be very useful in developing an understanding of the hydrologic, geochemical, and meteorological systems present at YM. This understanding is important in identifying the uncertainties and limitations of these data and the effect on the computations that use them.

For those review plans that require the more detailed analysis of a Type 4 or 5 review, it may be more difficult to identify data needs at this point in time. It is possible, however, to identify potential approaches that may be adopted by DOE through documents like the Site Characterization Plan and DOE study plans. In addition, the Total System Performance Assessments (e.g., Barnard et al., 1992; Eslinger et al., 1993; Wilson et al., 1994) provide details on the types of information that are currently available, the likely focus of DOE site characterization, and the types of information DOE is likely to use in future performance assessments. In addition to data needs, it is important to identify computer codes that are either likely to be used by DOE or even those codes that may provide an independent alternative to DOE codes.

For the purposes of developing the necessary background, it is possible to use current levels of understanding to identify broad types of data that will be needed to complete the compliance reviews of the LA in a timely manner. Many of the required data, such as site geology, precipitation, and hydrostratigraphy, are site-specific in nature. Given the recent initiation of site characterization activities at YM, while it is possible to make a preliminary identification of specific data sources, much of the data currently available is sparse. The gaps will be filled in through ongoing and future site characterization activities. For many of these types of data, such as radionuclide thermodynamic data, there is no need to acquire site-specific data, and current data sources can be identified readily. Even in these cases, however, certain systems or parameters may be poorly characterized and subject to change as levels of understanding increase.

Tables 2-1 and 2-2 are an attempt to identify the broad data needs for the different individual review plans related to hydrology, and climatology/meteorology. Examining Tables 2-1 and 2-2, there are three types of data at this relatively high level that are important to CDM development:

- Basic data that are applicable to systems outside of YM, but are necessary for calculations such as water and gas properties.

- Site specific data that are necessary to define the boundary and initial conditions at YM, such as matrix porosity, groundwater chemistry, and regional precipitation. These data are currently being generated as part of the YM Site Characterization, and will presumably become available in online DOE databases such as the Automated Technical Data Tracking System (ATDTS) and the Technical Data Base (TDB) being developed by the Yucca Mountain Project Office (YMPO) (Harloe, 1993). These are the data that carry information in a geographic context and are effectively stored and displayed in a GIS database.

- Design data that are necessary to define the effects of the repository itself such as repository design criteria and man-made materials to be used. Many of these design issues are still in development and final design decisions have not yet been made. In addition, most of these data do not have a specific geographic context, and are not well suited to a GIS format.

It is important to note that there are several areas of data overlap, and computer codes that may be used for more than one LARP section. As will be shown in Section 3, each LARP section may require a specific type of data such as fault slip history or plant respiration that is unique to that particular issue. In most cases, however, data such as hydraulic conductivities or fracture densities will be applicable to more than one section and these sections of the databases can be shared.

2.2 CODES, METHODS, AND ANALYSES

Much of the LA will be based on computer analyses. Many of these codes are complex and require significant knowledge on the part of the user to develop a conceptual model and identify the appropriate boundary and initial conditions. To evaluate model results, the reviewer must be familiar with the assumptions and limitations of the models. For KTUs, the reviewer should also be familiar either with the computer code(s) used by DOE in the analysis, or similar types of codes. Much in the same way that early identification of data will enhance the review of the LA, there is an advantage in the early identification of methods and computer codes, and to the extent possible, the exercise of these codes. Tables 2-3 and 2-4 are a preliminary effort to identify methods that are likely to be used by DOE and for those CDMs/LARP Sections that require a Type 4 or 5 review, a tentative listing of existing codes that address these issues.

In many cases, due to the complexities of natural systems, expert elicitation will be necessary to provide key information that is unavailable by more direct means. In all cases, conceptual and mathematical models are likely to be required, even for those CDMs/LARP sections that do not have KTUs. Thorough evaluation of DOE submittals will require that the reviewer is familiar with the assumptions and approximations that are made in constructing the models. It is important to note that the computer codes that are listed are meant only as examples of the types of codes that currently exist. In most cases, DOE has not yet identified the code(s) that it will use for the different sections of the LA, and in some cases, the codes that will be used have not yet been developed.

Table 2-1. Broad data needs for Compliance Determination Methods in hydrology individual system

CDM\Data Needs: HYDROLOGY	Hydro-geologic Framework	Physical Boundaries	Matrix Hydrologic Properties	Fracture Hydrologic Properties	Rock Thermal Properties	Hydraulic Head/ Gradient	Recharge/ Infiltration-Discharge	Groundwater Chemistry	Geologic Structure	Repository Design	Human Activity
3.1.2 Description of Hydrologic System	X	X	X	X		X	X				
3.2.2.5 (PAC) Flooding	X	X					X				
8.1.2 Performance Confirmation: Hydrologic	X	X	X	X	X	X	X	X	X	X	X
3.1.5 Integrated Natural System Response: Thermal Loading	X	X	X	X	X	X	X	X	X	X	
3.2.2.1(PAC) Nature & Rates-Hydrology	X	X	X	X		X	X	X	X		
3.2.2.6 (PAC) Human Activity and Groundwater	X	X	X	X		X	X				X
3.2.2.3 (FC) Groundwater Travel Time 1000 years	X	X	X	X		X	X	X	X		
3.2.2.7 (PAC) Natural Phenomena and Groundwater	X	X					X		X		
3.2.2.11 (PAC) Potential for Unsaturated Zone Saturation	X	X	X	X		X	X	X	X		
3.2.2.4 (FC) Unsaturated Zone Hydrogeologic Conditions	X	X	X	X			X	X	X		
3.2.2.10 (PAC) Complex Engineering Measures	X	X	X	X		X	X		X	X	X
3.2.2.8 (PAC) Structural Deformation and Groundwater	X	X	X	X		X	X	X	X		
3.2.2.9 (PAC) Changes in Hydrologic Conditions	X	X	X	X		X	X	X	X	X	X
3.2.2.12 (PAC) Perched Water Bodies	X	X	X	X		X	X	X	X		
3.3 Assessment of Compliance with GWTT Objective	X	X	X	X	X	X	X	X	X	X	

Table 2-2. Broad data needs for Compliance Determination Methods in the Climatology/Meteorology Individual System

CDM\Data Needs: CLIMATE/METEOROLOGY	Annual Precip.	Seasonal Precip.	Temperature	Geography (Physical setting)	Topography	Evapotrans-piration/ Plants	Paleoclimate	Infiltration	Singularities
3.1.4 Description of Climate/Meteorology System	X	X	X	X	X	X	X		X
3.2.4.1 (FC) Potential for Evapotranspiration	X	X	X	X	X	X	X	X	X
8.1.4 Performance Confirmation-Climate/Meteorology.	X	X	X			X			
3.2.4.2 (PAC) Changes to Hydrologic System from Climate	X	X	X	X	X	X	X	X	X

Table 2-3. Codes, methods, and analyses for Compliance Determination Methods in the hydrology individual system

CDM\Possible Methods: HYDROLOGY		Expert Elicit.	Concept. Models	Math. Models	Computer Codes (Types, examples)
3.1.2	Description of Hydrologic System	X	X	X	Type 1 and 3 — No KTUs
3.2.2.5	(PAC) Flooding	X	X	X	Type 1 and 3 — No KTUs
8.1.2	Performance Confirmation-Hydrologic	X	X	X	Type 1 and 3 — No KTUs
3.1.5	Integrated Natural System Response-Thermal Loading	X	X		Type 1 and 3 — No KTUs
3.2.2.1	(PAC) Nature & Rates - Hydrology	X	X	X	Flow — MODFE (DOE); MODFLOW (USGS); BIGFLOW (CNWRA) Transport — PORFLOW (ACRI/CNWRA); 2-Phase — VTOUGH (LLNL); SUTRA (USGS)
3.2.2.6	(PAC) Human Activity and Groundwater	X	X	X	Flow — MODFE (DOE); MODFLOW (USGS)
3.2.2.3	(FC) Groundwater Travel Time > 1000 years	X	X	X	Type 1 and 3 - No KTUs
3.2.2.7	(PAC) Natural Phenomena and Groundwater	X	X	X	Type 1 and 3 — No KTUs
3.2.2.11	(PAC) Potential for Unsaturated Zone Saturation	X	X	X	Type 1 and 3 - No KTUs
3.2.2.4	(FC) Unsaturated Zone Hydrogeologic Conditions	X	X	X	Type 1 and 3 — No KTUs
3.2.2.10	(PAC) Complex Engineering Measures	X	X	X	Type 1 and 3 - No KTUs
3.2.2.8	(PAC) Structural Deformation and Groundwater	X	X	X	Type 1 and 3 - No KTUs
3.2.2.9	(PAC) Changes in Hydrologic Conditions	X	X	X	Flow — MODFE (DOE); MODFLOW(USGS); BIGFLOW (CNWRA) Transport — PORFLOW (ACRI/CNWRA); 2-Phase — VTOUGH (LLNL); SUTRA (USGS)
3.2.2.12	(PAC) Perched Water Bodies	X	X	X	Flow — MODFE (DOE); MODFLOW (USGS); BIGFLOW (CNWRA)
3.3	Assessment of Compliance with Groundwater Travel Time Objective	X	X	X	Flow — MODFE (DOE); MODFLOW(USGS); BIGFLOW (CNWRA) Transport — PORFLOW (ACRI/CNWRA); 2-Phase — VTOUGH (LLNL); SUTRA (USGS)

Table 2-4. Codes, methods, and analyses for Compliance Determination Methods in the Climatology/Meteorology Individual System

CDM\Possible Methods: CLIMATE/METEOROLOGY		Expert Elicitation	Concept. Models	Math. Models	Computer Codes (Types, Examples)
3.1.4	Description of Climate/Methorology Sytem	X	X	X	Type 1 and 3 No KTUs
3.2.4.1	(FC) Potential for Evapotranspiration	X	X	X	Type 1 and 3 No KTUs
8.1.4	Performance Confirmation-Climate/Metheorology	X	X	X	Type 1 and 3 No KTUs
3.2.4.2	(PAC) Changes to Hydrologic System from Climate	X	X	X	Global Climate Model GENESIS (NCAR) Flow Model MODFE (DOE); MODFLOW (USGS)

3 SPECIFIC DATA NEEDS AND EXISTING DATA SOURCES

In the matrices discussed in Section 2, broad data needs were outlined for those sections of the LARP related to technical issues in hydrology and climatology/meteorology. While these matrices show areas of overlap and similarities in data needs between the different LARP sections, there is also interest in "zooming in" on the cells of these matrices to identify more specific data needs, existing data sources, and the status of these data in the GIS database being developed at CNWRA.

Tables 3-1 through 3-14 are an initial effort to identify specific data needs and focus on hydrologic and climatologic (and other) data that are *currently* available from the different DOE programs and from the general literature. Since site characterization at YM will continue up until license submittal (and beyond), much of this information should be viewed as preliminary and subject to change. The tables will be modified and updated as additional site characterization data become available. In addition, although most of the data referenced in Section 3 have been selected from the peer-reviewed literature, many of the datasets that are identified precede the development of approved procedures and have not been collected under DOE Quality Assurance (QA). It is expected that much of this will change as DOE Studies and Activities, conducted under DOE QA procedures, progress and additional data become available. Under these conditions, to the extent possible, DOE will bring existing data under QA control, or new data generated with the appropriate QA "pedigree" will supersede those data sources listed here.

The format of Tables 3-1 through 3-14 includes:

- Column 1 — Broad and Specific Data Needs: These represent specific types of data that the analyst believes are necessary to addressing this issue in developing the LARP section/CDM. These subdivisions are typically constrained by the CDS developed by NRC/CNWRA staffs.

- Column 2 — Data Source(s): These are the references for the data identified in Column 1. Although some references identify DOE study plans that are designed to provide these types of data, emphasis has been placed on those data that are known to exist currently. Additional data may be added or supersede the data given here as site characterization proceeds. In some cases, data needs may be identified, but no sources have been found.

- Column 3 — Data Obtained?: This column simply indicates whether or not the current data have been acquired by NRC/CNWRA. In the current version, this is usually "Yes" since most of the data sources identified by the staff were based on hardcopies in their possession. It is expected that as electronic reference databases come on line (e.g., ATDTS), data sources will be identified that exist in the DOE program, but have not been obtained.

- Column 4 — Entered in GIS?: This column indicates whether data have been entered in an electronic form into the GIS ARC/INFO database. As discussed in Section 2, only some of these data have the geographic context appropriate for GIS format. At present, only two data sets have been entered in ARC/INFO: the compilation of saturated water chemistry of McKinley et al. (1991), and the mineral chemistry data of Broxton et al. (1986).

- Column 5 — QA Status: Most of the data identified have been generated and gathered outside of the QA program developed by DOE for the YM Project. Where no indication is made in the report of the QA status, a question mark is entered next to the agency or laboratory that produced the data. It is assumed that as data are developed under the DOE program, many of these uncertainties in QA status can be updated. The abbreviations are identified in Appendix A.

The final row under each broad data need gives a short summary of why the specific data types are important in evaluating these parts of the LA. This type of information is useful in developing the rationale language for the CDM.

Table 3-1. LARP Section 3.1.2 — Hydrologic Systems Description (FY94)

Broad Data Need — Hydrogeologic Framework and Physical Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Delineation of the hydrologic framework and physical boundaries is required in order to conduct a rational investigation and analysis of the proposed repository. Water levels are required to determine groundwater flow directions and travel times.				
Broad Data Need — Matrix Properties	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b) 2. Anderson (1992) 3. Craig and Reed (1991) 4. Flint and Flint (1990) 5. Lahoud et al. (1984) 6. Rush (1983) 7. Whitfield et al. (1985)	Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
2. Porosity	1. Anderson (1981a,b) 2. Anderson (1992) 3. Flint and Flint (1990) 4. Lahoud et al. (1984) 5. Rush et al. (1983) 6. Thordarson (1983)	Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes No	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	1. Anderson (1981a,b) 2. Anderson (1984) 3. Kume and Hammermeister (1991) 4. Lahoud et al. (1984) 5. Loscot and Hammermeister (1992) 6. Rush et al. (1983) 7. Whitfield et al. (1990) 8. Whitfield et al. (1993)	Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE
These data are required to estimate groundwater travel times, in the rock matrix, in the saturated and unsaturated zones.				

Table 3-1. LARP Section 3.1.2 — Hydrologic Systems Description (FY94) (Cont'd)

Broad Data Need — Fracture Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			

These data are required to estimate groundwater travel times, in fractures, in the saturated and unsaturated zones. Fracture properties are poorly characterized at YM, leading to a lack of information on such properties as In-Situ water content and van Genuchten parameters.

Broad Data Need — Hydraulic Head Gradient	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Regional Hydrology Models	1. Rush (1971) 2. Burbey and Prudic (1991) 3. Winograd and Thordarson (1975) 4. Montazer and Wilson (1984)	Yes Yes Yes Yes	No No Yes No	?USGS ?USGS ?USGS ?USGS
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS

Hydraulic gradients are necessary to determine directions of fluid flow and flow paths from the repository to the accessible environment. Regional hydrology models can be used to provide boundary conditions for the controlled area surrounding the repository.

Broad Data Need — Infiltration, Recharge/Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Long-Term Net Infiltration	1. Flint et al. (1993) 2. Gauthier (1993) 3. Gauthier and Wilson (1994) 4. Hevesi and Flint (1993)	Yes Yes Yes Yes	No No No No	?DOE ?DOE ?DOE ?DOE

This information is required to predict the rate of flow and amount of water that will pass through the proposed repository.

Table 3-2. LARP Section 3.2.2.5 — (PAC) Flooding (FY94)

Broad Data Need — Hydrogeologic Framework and Physical Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Topographic Maps	1. USGS topographic maps (1 to 24,000 - 9 quadrangles covering the site area)	Yes	Yes	?USGS
2. Topographic Data	1. USGS digital elevation data (DEM format - 30 pixel resolution)	Yes	Yes	?USGS

Procedures used to estimate the hydraulics of overland flow routing and hydrography development require a knowledge of site topography. Recently, the CNWRA has developed a digitized topographical model of the YM site using available USGS data. This data can be used to locate probable flood plains based on analysis of data on precipitation, infiltration, and runoff.

Broad Data Need — Infiltration, Recharge/Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Precipitation Records	1. Hevesi et al. (1992)	Yes	No	?USGS
	2. Hevesi and Flint (1993)	Yes	No	?USGS
	3. Hevesi et al. (1994)	Yes	No	?USGS
	4. Bowen and Egami (1983)	Yes	No	DOE
	5. Chu (1986)	Yes	No	?NOAA
	6. Eglinton and Dreicer (1984)	Yes	No	?SNL
	7. Hershfield (1961)	Yes	No	?DOC
	8. Nichols (1986)	Yes	No	?USGS
	9. Quiring (1983)	Yes	No	?DOC
	10. Karl (1990)	Yes	No	?ORNL
	11. Quinlan et al. (1987)	Yes	No	?ORNL
	12. French (1986)	Yes	No	?DRI
	13. NOAA (1993)	Yes	No	?NOAA
	14. Ambos and Flint (1994)	Yes	No	?USGS
	15. Klein and Bloom (1987)	Yes	No	?
	16. Czarnecki (1990a,b)	Yes	No	?USGS
	17. McKinley and Oliver (1994)	Yes	No	?USGS
	18. DOE (1991b,g)	Yes	No	DOE
	19. DOE (1993f)	Yes	No	DOE
2. Long-Term Net Infiltration	1. Flint et al. (1993)	Yes	No	?DOE
	2. Gauthier (1993)	Yes	No	?DOE
	3. Gauthier and Wilson (1994)	Yes	No	?DOE
	4. Hevesi and Flint (1993)	Yes	No	?DOE

Table 3-2. LARP Section 3.2.2.5 — (PAC) Flooding (FY94) (Cont'd)

Broad Data Need — Infiltration, Recharge/Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
3. Historical Maximum Flood Estimates	1. Glancy (1993)	Yes	No	?USGS
4. Probable Maximum Precipitation	1. NOAA (1960) 2. Hansen et al. (1977) 3. DeWispelare et al. (1993)	Yes Yes Yes	No No n/a	?NOAA ?NWS CNWRA
This information is required to predict the rate of flow and amount of water that will pass through the proposed repository. The occurrence of groundwater at locations or depths other than that currently present, in addition to the hydraulic properties of the subsurface media, will depend upon the rates of precipitation, infiltration, percolation and recharge.				

Table 3-3. LARP Section 3.1.4 — Climatological and Meteorological Systems Description (FY94)

Broad Data Need — Annual and Seasonal Precipitation	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Precipitation Records	1. Hevesi et al. (1992)	Yes	No	?USGS
	2. Hevesi and Flint (1993)	Yes	No	?USGS
	3. Hevesi et al. (1994)	Yes	No	?USGS
	4. Bowen and Egami (1983)	Yes	No	DOE
	5. Chu (1986)	Yes	No	?NOAA
	6. Eglinton and Dreicer (1984)	Yes	No	?SNL
	7. Hershfield (1961)	Yes	No	?DOC
	8. Nichols (1986)	Yes	No	?USGS
	9. Quiring (1983)	Yes	No	?DOC
	10. Karl (1990)	Yes	No	?ORNL
	11. Quinlan et al. (1987)	Yes	No	?ORNL
	12. French (1986)	Yes	No	?DRI
	13. NOAA (1993)	Yes	No	?NOAA
	14. Ambos and Flint (1994)	Yes	No	?USGS
	15. Klein and Bloom (1987)	Yes	No	?
	16. Czarnecki (1990a,b)	Yes	No	?USGS
	17. McKinley and Oliver (1994)	Yes	No	?USGS
	18. DOE (1991b,g)	Yes	No	DOE
	19. DOE (1993f)	Yes	No	DOE
Historical precipitation records are necessary to determine current net infiltration in the vicinity of the proposed repository. Estimates of net infiltration will be used as boundary conditions in groundwater flow analyses.				

Broad Data Need — Temperature	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Air Temperature Data	1. Karl (1990)	Yes	No	?ORNL
	2. Quinlan et al. (1987)	Yes	No	?ORNL
	3. NOAA (1993)	Yes	No	?NOAA
	4. Bowen and Egami (1983)	Yes	No	?NOAA
	5. Eglinton and Dreicer (1984)	Yes	No	?SNL
	6. Nichols (1986)	Yes	No	?USGS
	7. Church et al. (1985)	Yes	No	?SNL
	8. Church et al. (1986)	Yes	No	?SNL
	9. Czarnecki (1990a,b)	Yes	No	?USGS
	10. McKinley and Oliver (1994)	Yes	No	?USGS
Air temperature will have an effect on evapotranspiration and other processes related to infiltration in the vicinity of the proposed repository. Estimates of net infiltration will be used as boundary conditions in groundwater flow analyses.				

Table 3-3. LARP Section 3.1.4 — Climatological and Meteorological Systems Description (FY94) (Cont'd)

Broad Data Need - Geography (Physical Setting) and Topography	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Topographic Maps	1. USGS topographic maps (1 to 24,000 - 9 quadrangles covering the site area)	Yes	Yes	?USGS
2. Topographic Data	1. USGS digital elevation data (DEM format - 30 pixel resolution)	Yes	Yes	?USGS
Geographic and topographic information will help control climate variability. For example, the high relief of the Sierra Nevada mountains helps to create a rain shadow which can control precipitation in the area of the repository, and therefore have an effect on infiltration.				
Broad Data Need — Evapotranspiration	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Humidity	1. Bowen and Egami (1983) 2. Britch (1990) 3. Church et al. (1985) 4. Church et al. (1986)	Yes Yes Yes Yes	No No No No	DOE ? ?SNL ?SNL
2. Wind Speed	1. Bowen and Egami (1983) 2. DOC (1986) 3. Eglinton and Dreicer (1984) 4. Quiring (1968)	Yes Yes Yes Yes	No No No No	DOE ?DOC ?SNL ?DOC
3. Solar Radiation	1. Flint and Childs (1987) 2. Flint and Flint (1987) 3. McKinley and Oliver (1994) 4. Eglinton and Dreicer (1984)	Yes Yes Yes Yes	No No No No	?USGS ?USGS ?USGS ?SNL
4. Potential Evapotranspiration	1. Flint and Childs (1991) 2. Czarnecki (1990b) 3. DOE (1993f,q)	Yes Yes Yes	No No No	?USGS ?USGS DOE

Table 3-3. LARP Section 3.1.4 — Climatological and Meteorological Systems Description (FY94) (Cont'd)

Broad Data Need — Evapotranspiration	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
5. Plants	1. Czarnecki (1990b)	Yes	No	?USGS
	2. Leary (1990)	Yes	No	?
	3. O'Farrell and Emery (1976)	Yes	No	?DRI
	4. Robinson (1957)	No	No	?
	5. Spaulding (1985)	Yes	No	?USGS
	6. Wallace and Romney (1976)	Yes	No	?
Meteorological data are required to determine potential evapotranspiration, which in turn is necessary to estimate current net infiltration in the vicinity of the proposed repository. Estimates of net infiltration will be used as boundary conditions in groundwater flow analyses.				
Broad Data Need — Paleoclimate	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Models of Quaternary Climate	1. Winograd et al. (1988)	Yes	No	?USGS
	2. Winograd et al. (1992)	Yes	No	?USGS
	3. Spaulding (1983)	Yes	No	?USGS
	4. Spaulding (1985)	Yes	No	?USGS
	5. Whelan et al. (1994)	Yes	No	?USGS
	6. Long and Childs (1993)	Yes	No	?
	7. Benson and Klieforth (1989)	Yes	No	?USGS
The long-term climate in a given region is important in determining what are likely to be the extreme climate conditions experienced by the region during the regulatory period. Paleoclimate information is also valuable in determining whether historical trends represent short-term excursions from long-term trends. Such trends may be less likely to be important during the relatively long regulatory period.				
Broad Data Need — Singularities	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Climate and Potential Climatic Variability	1. DeWispelare et al. (1993)	Yes	No	CNWRA
	2. Crowley and North (1990)	Yes	No	?
	3. Giorgi et al. (1992)	Yes	No	?
	4. Flint et al.(1993)	Yes	No	DOE
	5. Imbrie et al. (1984)	Yes	No	?
	6. Long and Childs (1993)	Yes	No	?
	7. McMahon (1985)	Yes	No	?
	8. Winograd et al. (1988)	Yes	No	?USGS
	9. Winograd et al. (1992)	Yes	No	?USGS
Information on climatic variability is needed to estimate future net infiltration rates. These estimates will be used as boundary conditions in groundwater flow analyses. This information can also include short-term excursions from long-term trends [e.g., volcanic eruptions, effects of El Niño Southern Oscillations (ENSO)]				

Table 3-4. LARP Section 3.2.4.1 — (FAC) Precipitation that is a Small Percentage of Annual Potential Evapotranspiration (FY94)

Broad Data Need — Annual and Seasonal Precipitation	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Precipitation Records	1. Hevesi et al. (1992)	Yes	No	?USGS
	2. Hevesi and Flint (1993)	Yes	No	?USGS
	3. Hevesi et al. (1994)	Yes	No	?USGS
	4. Bowen and Egami (1983)	Yes	No	DOE
	5. Chu (1986)	Yes	No	?NOAA
	6. Eglinton and Dreicer (1984)	Yes	No	?SNL
	7. Hershfield (1961)	Yes	No	?DOC
	8. Nichols (1986)	Yes	No	?USGS
	9. Quiring (1983)	Yes	No	?DOC
	10. Karl (1990)	Yes	No	?ORNL
	11. Quinlan et al. (1987)	Yes	No	?ORNL
	12. French (1986)	Yes	No	?DRI
	13. NOAA (1993)	Yes	No	?NOAA
	14. Ambos and Flint (1994)	Yes	No	?USGS
	15. Klein and Bloom (1987)	Yes	No	?
	16. Czarnecki (1990a,b)	Yes	No	?USGS
	17. McKinley and Oliver (1994)	Yes	No	?USGS
	18. DOE (1991b,g)	Yes	No	DOE
	19. DOE (1993f)	Yes	No	DOE
In order to determine whether historical precipitation is a small fraction of potential evapotranspiration, historical precipitation records are necessary.				
Broad Data Need — Temperature	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Air Temperature Data	1. Karl (1990)	Yes	No	?ORNL
	2. Quinlan et al. (1987)	Yes	No	?ORNL
	3. NOAA (1993)	Yes	No	?NOAA
	4. Bowen and Egami (1983)	Yes	No	?NOAA
	5. Eglinton and Dreicer (1984)	Yes	No	?SNL
	6. Nichols (1986)	Yes	No	?USGS
	7. Church et al. (1985)	Yes	No	?SNL
	8. Church et al. (1986)	Yes	No	?SNL
	9. Czarnecki (1990a,b)	Yes	No	?USGS
	10. McKinley and Oliver (1994)	Yes	No	?USGS
Air temperature will have an effect on evapotranspiration and other processes related to infiltration in the vicinity of the proposed repository. Estimates of net infiltration will be used as boundary conditions in groundwater flow analyses.				

Table 3-4. LARP Section 3.2.4.1 — (FAC) Precipitation that is a Small Percentage of Annual Potential Evapotranspiration (FY94) (Cont'd)

Broad Data Need — Geography (Physical Setting) and Topography	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Topographic Maps	1. USGS topographic maps (1 to 24,000 - 9 quadrangles covering the site area)	Yes	Yes	?USGS
2. Topographic Data	1. USGS digital elevation data (DEM format - 30 pixel resolution)	Yes	Yes	?USGS
Geographic and topographic information will help control climate variability. For example, the high relief of the Sierra Nevada mountains helps to create a rain shadow which can control precipitation in the area of the repository, and therefore whether or not precipitation is a small percentage of potential evapotranspiration.				
Broad Data Need — Evapotranspiration	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Humidity	1. Bowen and Egami (1983) 2. Britch (1990) 3. Church et al. (1985) 4. Church et al. (1986)	Yes Yes Yes Yes	No No No No	DOE ? ?SNL ?SNL
2. Wind Speed	1. Bowen and Egami (1983) 2. DOC (1986) 3. Eglinton and Dreicer (1984) 4. Quiring (1968)	Yes Yes Yes Yes	No No No No	DOE ?DOC ?SNL ?DOC
3. Solar Radiation	1. Flint and Childs (1987) 2. Flint and Flint (1987) 3. McKinley and Oliver (1994) 4. Eglinton and Dreicer (1984)	Yes Yes Yes Yes	No No No No	?USGS ?USGS ?USGS ?SNL
4. Potential Evapotranspiration	1. Flint and Childs (1991) 2. Czarnecki (1990b) 3. DOE (1993f,q)	Yes Yes Yes	No No No	?USGS ?USGS DOE
5. Plants	1. Czarnecki (1990b) 2. Leary (1990) 3. O'Farrell and Emery (1976) 4. Robinson (1957) 5. Spaulding (1985) 6. Wallace and Romney (1976)	Yes Yes Yes No Yes Yes	No No No No No No	?USGS ? ?DRI ? ?USGS ?
In order to determine whether historical precipitation is a small fraction of potential evapotranspiration, historical records of meteorologic data are necessary to estimate potential evapotranspiration. The comparison of potential evaporation to precipitation is a surrogate for infiltration and potential evapotranspiration is a bound for actual evapotranspiration, thus direct comparisons are useful. One component of evapotranspiration depends on plant respiration.				

Table 3-4. LARP Section 3.2.4.1 — (FAC) Precipitation that is a Small Percentage of Annual Potential Evapotranspiration (FY94) (Cont'd)

Broad Data Need — Paleoclimate	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Models of Quaternary Climate	1. Winograd et al. (1988)	Yes	No	?USGS
	2. Winograd et al. (1992)	Yes	No	?USGS
	3. Spaulding (1983)	Yes	No	?USGS
	4. Spaulding (1985)	Yes	No	?USGS
	5. Whelan et al. (1994)	Yes	No	?USGS
	6. Long and Childs (1993)	Yes	No	?
	7. Benson and Klieforth (1989)	Yes	No	?USGS
The long-term climate in a given region is important in determining what are likely to be the extreme climate conditions experienced by the region during the regulatory period. Paleoclimate information is also valuable in determining whether historical trends represent short-term excursions from long-term trends. Such trends may be less likely to be important during the relatively long regulatory period.				
Broad Data Need — Infiltration	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Infiltration	1. DOE (1993f,q)	Yes	No	DOE
	2. Hevesi et al. (1994)	Yes	No	?USGS
	3. Flint and Flint (1994)	Yes	No	?USGS
	4. Savard (1994)	Yes	No	?USGS
The comparison of potential evaporation to precipitation is a surrogate for infiltration and potential evapotranspiration is a bound for actual evapotranspiration, thus direct comparisons are useful.				
Broad Data Need — Singularities	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Climate and Potential Climatic Variability	1. DeWispelare et al. (1993)	Yes	No	CNWRA
	2. Crowley and North (1990)	Yes	No	?
	3. Giorgi et al. (1992)	Yes	No	?
	4. Flint et al.(1993)	Yes	No	DOE
	5. Imbrie et al. (1984)	Yes	No	?
	6. Long and Childs (1993)	Yes	No	?
	7. McMahon (1985)	Yes	No	?
	8. Winograd et al. (1988)	Yes	No	?USGS
	9. Winograd et al. (1992)	Yes	No	?USGS
Information on climatic variability, including short-term singular behavior such as perturbations due to volcanic activity, is needed to estimate future potential evapotranspiration and precipitation rates. These estimates can be used to examine possible changes in the ratio of potential evapotranspiration to precipitation over time.				

Table 3-5. LARP Section 8.1.2 — Performance Confirmation: Hydrologic System (FY95)

Broad Data Need — Hydrogeologic Framework and Physical Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework Physical Boundaries	1. Stirewalt et al. (1994)	Yes	Yes	CNWRA
	2. Schenker et al. (1994)	Yes	No	?SNL
2. Current Water Levels	1. Robison (1984)	Yes	No	?USGS
	2. Robison et al. (1988)	Yes	No	?USGS

Delineation of the hydrologic framework and physical boundaries is required in order to conduct a rational investigation and analysis of the proposed repository. Water levels are required to determine groundwater flow directions and travel times.

Broad Data Need — Matrix Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b)	Yes	Yes	?USGS
	2. Anderson (1992)	Yes	Yes	?USGS
	3. Craig and Reed (1991)	Yes	Yes	?USGS
	4. Flint and Flint (1990)	Yes	Yes	?USGS
	5. Lahoud et al. (1984)	Yes	Yes	?USGS
	6. Rush et al. (1983)	Yes	Yes	?USGS
	7. Whitfield et al. (1985)	Yes	Yes	?USGS
2. Porosity	1. Anderson (1981a,b)	Yes	Yes	?USGS
	2. Anderson (1992)	Yes	Yes	?USGS
	3. Flint and Flint (1990)	Yes	Yes	?USGS
	4. Lahoud et al. (1984)	Yes	Yes	?USGS
	5. Rush et al. (1983)	Yes	Yes	?USGS
	6. Thordarson (1983)	Yes	No	?USGS
3. *In-Situ* Water Content	1. Anderson (1981a,b)	Yes	Yes	?USGS
	2. Anderson (1984)	Yes	Yes	?USGS
	3. Kume and Hammermeister (1991)	Yes	Yes	?USGS
	4. Lahoud et al. (1984)	Yes		
	5. Loscot and Hammermeister (1992)	Yes	Yes	?USGS
	6. Rush et al. (1983)	Yes	Yes	?USGS
	7. Whitfield et al. (1990)	Yes		
	8. Whitfield et al. (1993)	Yes	Yes	?USGS
			Yes	?USGS
			Yes	?USGS

Table 3-5. LARP Section 8.1.2 — Performance Confirmation: Hydrologic System (FY95) (Cont'd)

Broad Data Need — Matrix Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE
These data are required to estimate groundwater travel times, in the rock matrix, in the saturated and unsaturated zones. This information will be required for both site characterization and performance assessments. Hydraulic characterization information can and should be consistent when used interchangeably for these analyses.				

Broad Data Need — Fracture Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			
These data are required to estimate groundwater travel times in fractures in the saturated and unsaturated zones. Fracture properties are poorly characterized at YM, particularly for such properties as *In-Situ* water content and van Genuchten parameters. This information will be required for both site characterization and performance assessments.				

Broad Data Need — Rock Thermal Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Thermal Conductivity	1. DOE (1990a)	Yes	No	DOE
2. Density	1. DOE (1990a) 2. Schwartz (1990)	Yes Yes	No No	DOE ?SNL
3. Specific Heat	1. DOE (1990a)	Yes	No	DOE
Overall performance of the geologic setting may be affected by the thermal load imposed on the system by the radioactive waste, particularly during repository operation. Rock thermal properties are necessary to predict thermal perturbations and temperature gradients as a function of time.				

Table 3-5. LARP Section 8.1.2 — Performance Confirmation: Hydrologic System (FY95) (Cont'd)

Broad Data Need — Hydraulic Head Gradient	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Regional Hydrology Models	1. Rush (1971) 2. Burbey and Prudic (1991) 3. Winograd and Thordarson (1975) 4. Montazer and Wilson (1984)	Yes Yes Yes Yes	No No Yes No	?USGS ?USGS ?USGS ?USGS
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Hydraulic gradients determine flow paths from the repository to the accessible environment. Regional hydrology models can provide boundary conditions for the repository and the controlled area.				

Broad Data Need — Infiltration, Recharge/Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Long-Term Net Infiltration	1. Flint et al. (1993) 2. Gauthier (1993) 3. Gauthier and Wilson (1994) 4. Hevesi and Flint (1993)	Yes Yes Yes Yes	No No No No	?DOE ?DOE ?DOE ?DOE
This information is required to predict the rate of flow and amount of water that will pass through the proposed repository. Changes in the current water table and hydraulic properties of the subsurface media, will depend upon the rates of precipitation, infiltration, percolation and recharge.				

Broad Data Need — Groundwater Geochemistry	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Zone Waters	1. McKinley et al. (1991) 2. Kerrisk (1987) 3. White et al. (1980) 4. Claassen (1985)	Yes Yes Yes Yes	Yes No No No	?USGS ?LANL ?USGS ?USGS
2. Unsaturated Zone Waters	1. Yang et al. (1988) 2. White et al. (1980) 3. Yang et al. (1993) 5. Kerrisk (1983)	Yes Yes Yes Yes	No No No No	?USGS ?USGS ?USGS ?LANL
Groundwater chemistry is an important means for tracing groundwater flow and establishing the hydrogeologic framework.				

Table 3-5. LARP Section 8.1.2 — Performance Confirmation: Hydrologic System (FY95) (Cont'd)

Broad Data Need — Geologic Structure	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Fault Maps and Data	1. Frizzell and Shulters (1990) 2. Scott and Bonk (1984) 3. DOE (1988) 4. DOE (1990b) 5. DOE (1991a) 6. DOE (1993a-e) 7. Dohrenwend (1982) 8. Dohrenwend and Moring (1991a-c) 9. Dohrenwend and Moring (1993) 10. Dohrenwend et al. (1991a-f) 11. Dohrenwend et al. (1992a,b) 12. Jennings (1992)	Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes No No No No Yes Yes Yes Yes Yes Yes	?USGS ?USGS DOE DOE DOE DOE ?USGS ?USGS ?USGS ?USGS ?USGS ?CDMG
2. Fault Slip History Data	1. Young et al. (1992) 2. Ferrill et al. (1994) 3. Rogers et al. (1987)	Yes Yes Yes	No Yes No	CNWRA CNWRA DOE

Geologic structure and stratigraphy provides significant control on hydrologic processes, through providing conduits and barriers to hydrologic flow. Changes in these structures may alter the subsurface hydrology. Much information on geologic structure is subject to interpretation, and conceptual models may change as additional data become available

Broad Data Need — Repository Design	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Rock/Soil conditions (along shafts/ramps)	1. DOE (1990a) 2. DOE (1992a)	Yes Yes	No No	DOE DOE
2. Repository Heating	1. O'Neal et al. (1984) 2. Buscheck and Nitao (1993a-c) 3. Pruess and Tsang (1993) 4. Wilson et al. (1994)	Yes Yes Yes Yes	No No No No	?LLNL ?LLNL ?LBL ?SNL
3. Water Infiltration	1. Wilson et al. (1994) 2. Dodge and Green (1994)	Yes Yes	No No	?SNL CNWRA
4. Source Term Models	1. Manaktala (1993) 2. Codell and Weller (1994) 3. Ahola et al. (1994) 4. Wilson et al. (1994) 5. Barnard (1993)	Yes Yes Yes Yes Yes	n/a n/a n/a n/a n/a	CNWRA NRC CNWRA ?SNL ?SNL
5. Hydraulic properties of the Engineered Barrier System	Not available yet			

During the period of performance confirmation, thermal and hydrologic conditions in the repository may be significantly altered. This would affect groundwater flow velocities in and around the repository. An understanding of these potential effects is necessary for reviewing the performance confirmation program. The listed references are not intended to be complete, but should provide sufficient background.

Table 3-5. LARP Section 8.1.2 — Performance Confirmation: Hydrologic System (FY95) (Cont'd)

Broad Data Need — Human Activity	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Human intrusion scenarios	1. Barnard et al. (1992) 2. Eslinger et al. (1993) 3. Wilson et al. (1994)	Yes Yes Yes	n/a n/a n/a	?SNL ?PNL ?SNL
Human activity is very likely to have an effect on repository performance during the operations period. Because human activity is extremely difficult to predict, scenario development and analyses similar to those performed for the DOE Total System Performance Assessment (TSPA) efforts is likely to provide the best means of addressing these effects.				

Table 3-6. LARP Section 8.1.4 — Performance Confirmation: Climatologic System (FY95)

Broad Data Need — Annual and Seasonal Precipitation	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Precipitation Records	1. Hevesi et al. (1992)	Yes	No	?USGS
	2. Hevesi and Flint (1993)	Yes	No	?USGS
	3. Hevesi et al. (1994)	Yes	No	?USGS
	4. Bowen and Egami (1983)	Yes	No	DOE
	5. Chu (1986)	Yes	No	?NOAA
	6. Eglinton and Dreicer (1984)	Yes	No	?SNL
	7. Hershfield (1961)	Yes	No	?DOC
	8. Nichols (1986)	Yes	No	?USGS
	9. Quiring (1983)	Yes	No	?DOC
	10. Karl (1990)	Yes	No	?ORNL
	11. Quinlan et al. (1987)	Yes	No	?ORNL
	12. French (1986)	Yes	No	?DRI
	13. NOAA (1993)	Yes	No	?NOAA
	14. Ambos and Flint (1994)	Yes	No	?USGS
	15. Klein and Bloom (1987)	Yes	No	?
	16. Czarnecki (1990a,b)	Yes	No	?USGS
	17. McKinley and Oliver (1994)	Yes	No	?USGS
	18. DOE (1991b,g)	Yes	No	DOE
	19. DOE (1993f)	Yes	No	DOE
2. Precipitation Data Collection and Reporting	1. DOE (1991b)	Yes	No	DOE
	2. DOE (1993f)	Yes	No	DOE
3. Precipitation Estimation	1. Hevesi et al. (1992)	Yes	No	?USGS

Climatologic information contributes to repository performance confirmation through setting limits on rates of infiltration and providing necessary boundary and initial conditions for performance confirmation models. Historical data, particularly in the western United States are typically limited extent and in duration.

Broad Data Need — Temperature	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Air Temperature Data	1. Karl (1990)	Yes	No	?ORNL
	2. Quinlan et al. (1987)	Yes	No	?ORNL
	3. NOAA (1993)	Yes	No	?NOAA
	4. Bowen and Egami (1983)	Yes	No	?NOAA
	5. Eglinton and Dreicer (1984)	Yes	No	?SNL
	6. Nichols (1986)	Yes	No	?USGS
	7. Church et al. (1985)	Yes	No	?SNL
	8. Church et al. (1986)	Yes	No	?SNL
	9. Czarnecki (1990a,b)	Yes	No	?USGS
	10. McKinley and Oliver (1994)	Yes	No	?USGS

Air temperature has an effect on infiltration through evaporation. In addition, baseline temperature information is necessary to establish boundary and initial conditions on performance confirmation models.

Table 3-6. LARP Section 8.1.4 — Performance Confirmation: Climatologic System (FY95) (Cont'd)

Broad Data Need — Evapotranspiration/Plants	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Unsaturated Zone Water Balance	1. Leary (1990)	No	No	No
2. Measurement	1. USDA (1974)	No	n/a	No
Evapotranspiration is also important as part establishing boundary and initial conditions on infiltration that are to be used in performance confirmation models.				

Table 3-7. LARP Section 3.1.5 — Integrated Natural System Response to Maximum Design Thermal Load (FY96)

Broad Data Need — Hydrogeologic Framework and Physical Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Delineation of baseline values for the hydrogeologic framework and physical boundaries is required in order to conduct a rational investigation of the effects of maximum thermal loading from proposed repository.				

Broad Data Need — Matrix Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b) 2. Anderson (1992) 3. Craig and Reed (1991) 4. Flint and Flint (1990) 5. Lahoud et al. (1984) 6. Rush et al. (1983) 7. Whitfield et al. (1985)	Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
2. Porosity	1. Anderson (1981a,b) 2. Anderson (1992) 3. Flint and Flint (1990) 4. Lahoud et al. (1984) 5. Rush et al. (1983) 6. Thordarson (1983)	Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes No	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* water Content	1. Anderson (1981a,b) 2. Anderson (1984) 3. Kume and Hammermeister (1991) 4. Lahoud et al. (1984) 5. Loscot and Hammermeister (1992) 6. Rush et al. (1983) 7. Whitfield et al. (1990) 8. Whitfield et al. (1993)	Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE
These data are required to estimate groundwater travel times, in the rock matrix, in the saturated and unsaturated zones. This information is necessary for both site characterization and performance assessments.				

Table 3-7. LARP Section 3.1.5 — Integrated Natural System Response to Maximum Design Thermal Load (FY96) (Cont'd)

Broad Data Need — Fracture Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			
These data are required to estimate groundwater travel times, in fractures, in the saturated and unsaturated zones. Fracture properties are poorly characterized at YM, leading to a lack of information on such properties as *In-Situ* water content and van Genuchten parameters. This information will be required for both site characterization and performance assessments.				

Broad Data Need — Rock Thermal Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Thermal Conductivity	1. DOE (1990a)	Yes	No	DOE
2. Density	1. DOE (1990a) 2. Schwartz (1990)	Yes Yes	No No	DOE ?SNL
3. Specific Heat	1. DOE (1990a)	Yes	No	DOE
To predict the performance of the geologic setting in response to the thermal load imposed on the system by the radioactive waste, particularly during repository operation. Rock thermal properties are necessary to predict thermal perturbations and temperature gradients as a function of time.				

Table 3-7. LARP Section 3.1.5 — Integrated Natural System Response to Maximum Design Thermal Load (FY96) (Cont'd)

Broad Data Need — Hydraulic Head Gradient	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Regional Hydrology Models	1. Rush (1971) 2. Burbey and Prudic (1991) 3. Winograd and Thordarson (1975) 4. Montazer and Wilson (1984)	Yes Yes Yes Yes	No No Yes No	?USGS ?USGS ?USGS ?USGS
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Hydraulic gradients are necessary to determine directions of fluid flow and flow paths from the repository to the accessible environment. Regional hydrology models can be used to provide boundary conditions for the controlled area surrounding the repository.				

Broad Data Need — Infiltration, Recharge/Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Long-Term Net Infiltration	1. Flint et al. (1993) 2. Gauthier (1993) 3. Gauthier and Wilson (1994) 4. Hevesi and Flint (1993)	Yes Yes Yes Yes	No No No No	?DOE ?DOE ?DOE ?DOE
This information is required to predict the rate of flow and amount of water that will pass through the proposed repository. The occurrence of groundwater at locations or depths other than that currently present, in addition to the hydraulic properties of the subsurface media, will depend upon the rates of precipitation, infiltration, percolation and recharge.				

Broad Data Need — Groundwater Geochemistry	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Zone Waters	1. McKinley et al. (1991) 2. Kerrisk (1987) 3. White et al. (1980) 4. Claassen (1985)	Yes Yes Yes Yes	Yes No No No	?USGS ?LANL ?USGS ?USGS
2. Unsaturated Zone Waters	1. Yang et al. (1988) 2. White et al. (1980) 3. Yang et al. (1993) 5. Kerrisk (1983)	Yes Yes Yes Yes	No No No No	?USGS ?USGS ?USGS ?LANL
Groundwater chemistry is an important means for tracing groundwater flow and establishing the hydrogeologic framework.				

Table 3-7. LARP Section 3.1.5 — Integrated Natural System Response to Maximum Design Thermal Load (FY96) (Cont'd)

Broad Data Need — Geologic Structure	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Fault Maps and Data	1. Frizzell and Shulters (1990)	Yes	Yes	?USGS
	2. Scott and Bonk (1984)	Yes	Yes	?USGS
	3. DOE (1988)	Yes	No	DOE
	4. DOE (1990b)	Yes	No	DOE
	5. DOE (1991a)	Yes	No	DOE
	6. DOE (1993a-e)	Yes	No	DOE
	7. Dohrenwend (1982)	Yes	Yes	?USGS
	8. Dohrenwend and Moring (1991a-c)	Yes	Yes	?USGS
	9. Dohrenwend and Moring (1993)	Yes	Yes	?USGS
	10. Dohrenwend et al. (1991a-f)	Yes	Yes	?USGS
	11. Dohrenwend et al. (1992a,b)	Yes	Yes	?USGS
	12. Jennings (1992)	Yes	Yes	?CDMG
2. Fault Slip History Data	1. Young et al. (1992)	Yes	No	CNWRA
	2. Ferrill et al. (1994)	Yes	Yes	CNWRA
	3. Rogers et al. (1987)	Yes	No	DOE

Geologic structure and stratigraphy provides significant control on hydrologic processes, through providing conduits and barriers to hydrologic flow. Changes in these structures may alter the subsurface hydrology. Much information on geologic structure is subject to interpretation, and conceptual models may change as additional data become available

Broad Data Need — Repository Design	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Rock/Soil conditions (along shafts/ramps)	1. DOE (1990a)	Yes	No	DOE
	2. DOE (1992a)	Yes	No	DOE
2. Repository Heating	1. O'Neal et al. (1984)	Yes	No	?LLNL
	2. Buscheck and Nitao (1993a-c)	Yes	No	?LLNL
	3. Pruess and Tsang (1993)	Yes	No	?LBL
	4. Wilson et al. (1994)	Yes	No	?SNL
3. Water Infiltration	1. Wilson et al. (1994)	Yes	No	?SNL
	2. Dodge and Green (1994)	Yes	No	CNWRA
4. Source Term Models	1. Manaktala (1993)	Yes	n/a	CNWRA
	2. Codell and Weller (1994)	Yes	n/a	NRC
	3. Ahola et al. (1994)	Yes	n/a	CNWRA
	4. Wilson et al. (1994)	Yes	n/a	?SNL

Table 3-7. LARP Section 3.1.5 — Integrated Natural System Response to Maximum Design Thermal Load (FY96) (Cont'd)

Broad Data Need — Repository Design	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
5. Hydraulic properties of the Engineered Barrier System	Not available yet			
During the period of performance confirmation, thermal and hydrologic conditions in the repository may be significantly altered. This would affect groundwater flow velocities in and around the repository. Predicting the maximum design thermal load is clearly dependent on repository design issues including waste package design, internal temperature maximum, design surface temperature, age of the waste, and waste package configuration. Much of the repository design is still in development; Modifications will be required as the overall repository design is established. The listed references are not intended to be complete, but should provide sufficient background.				

Table 3-8. LARP Section 3.2.2.1 — (FAC) Nature and Rates of Hydrologic Processes (FY96)

Broad Data Need — Hydrogeologic Framework and Physical Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Delineation of the hydrologic framework and physical boundaries is required in order to conduct a rational investigation and analysis of the proposed repository. Water levels are required to determine groundwater flow directions and travel times.				
Broad Data Need — Matrix Properties	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b) 2. Anderson (1992) 3. Craig and Reed (1991) 4. Flint and Flint (1990) 5. Lahoud et al. (1984) 6. Rush et al. (1983) 7. Whitfield et al. (1985)	Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
2. Porosity	1. Anderson (1981a,b) 2. Anderson (1992) 3. Flint and Flint (1990) 4. Lahoud et al. (1984) 5. Rush et al. (1983) 6. Thordarson (1983)	Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes No	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* water Content	1. Anderson (1981a,b) 2. Anderson (1984) 3. Kume and Hammermeister (1991) 4. Lahoud et al. (1984) 5. Loscot and Hammermeister (1992) 6. Rush et al. (1983) 7. Whitfield et al. (1990) 8. Whitfield et al. (1993)	Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE
These data are required to estimate groundwater travel times, in the rock matrix, in the saturated and unsaturated zones. This information will be required for both site characterization and performance assessments. Hydraulic characterization information can and should be consistent when used interchangeably for these analyses.				

Table 3-8. LARP Section 3.2.2.1 — (FAC) Nature and Rates of Hydrologic Processes (FY96) (Cont'd)

Broad Data Need — Fracture Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			
These data are required to estimate groundwater travel times, in fractures, in the saturated and unsaturated zones. Fracture properties are poorly characterized at YM, leading to a lack of information on such properties as *In-Situ* water content and van Genuchten parameters. This information will be required for both site characterization and performance assessments. Hydraulic characterization information can and should be consistent when used interchangeably for these analyses.				

Broad Data Need — Hydraulic Head Gradient	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Regional Hydrology Models	1. Rush (1971) 2. Burbey and Prudic (1991) 3. Winograd and Thordarson (1975) 4. Montazer and Wilson (1984)	Yes Yes Yes Yes	No No Yes No	?USGS ?USGS ?USGS ?USGS
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Hydraulic gradients are necessary to determine directions of fluid flow and flow paths from the repository to the accessible environment. Regional hydrology models can be used to provide boundary conditions for the controlled area surrounding the repository.				

Table 3-8. LARP Section 3.2.2.1 — (FAC) Nature and Rates of Hydrologic Processes (FY96) (Cont'd)

Broad Data Need — Infiltration, Recharge/Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Long-Term Net Infiltration	1. Flint et al. (1993) 2. Gauthier (1993) 3. Gauthier and Wilson (1994) 4. Hevesi and Flint (1993)	Yes Yes Yes Yes	No No No No	?DOE ?DOE ?DOE ?DOE
This information is required to predict flow rates and flux through the proposed repository. The occurrence of groundwater at locations or depths other than that currently present, in addition to the hydraulic properties of the subsurface media, will depend upon the rates of precipitation, infiltration, percolation and recharge.				
Broad Data Need — Groundwater Geochemistry	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Zone Waters	1. McKinley et al. (1991) 2. Kerrisk (1987) 3. White et al. (1980) 4. Claassen (1985)	Yes Yes Yes Yes	Yes No No No	?USGS ?LANL ?USGS ?USGS
2. Unsaturated Zone Waters	1. Yang et al. (1988) 2. White et al. (1980) 3. Yang et al. (1993) 5. Kerrisk (1983)	Yes Yes Yes Yes	No No No No	?USGS ?USGS ?USGS ?LANL
Groundwater chemistry is an important means for tracing groundwater flow and establishing the hydrogeologic framework.				
Broad Data Need — Geologic Structure	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Fault Maps and Data	1. Frizzell and Shulters (1990) 2. Scott and Bonk (1984) 3. DOE (1988) 4. DOE (1990b) 5. DOE (1991a) 6. DOE (1993a-e) 7. Dohrenwend (1982) 8. Dohrenwend and Moring (1991a-c) 9. Dohrenwend and Moring (1993) 10. Dohrenwend et al. (1991a-f) 11. Dohrenwend et al. (1992a,b) 12. Jennings (1992)	Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes No No No No Yes Yes Yes Yes Yes Yes	?USGS ?USGS DOE DOE DOE DOE ?USGS ?USGS ?USGS ?USGS ?USGS ?CDMG
2. Fault Slip History Data	1. Young et al. (1992) 2. Ferrill et al. (1994) 3. Rogers et al. (1987)	Yes Yes Yes	No Yes No	CNWRA CNWRA DOE

Table 3-8. LARP Section 3.2.2.1 — (FAC) Nature and Rates of Hydrologic Processes (FY96) (Cont'd)

Broad Data Need — Geologic Structure	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
3. Volcanic Features	1. DOE (1990c) 2. Connor and Hill (1994a,b) 3. Crowe et al. (1993) 4. Hill et al. (1994)	Yes Yes Yes Yes	No Yes Yes Yes	?LANL CNWRA CNWRA CNWRA
4. Subsidence Data	1. DOE (1991c)	No	No	?USGS
Geologic structure and stratigraphy provide significant control on hydrologic processes, through providing conduits and barriers to flow. Changes in these structures may alter subsurface hydrology. Information on geologic structure is subject to interpretation, and conceptual models may change as data become available				

Table 3-9. LARP Section 3.2.2.7 — (PAC) Natural Phenomena and Groundwater (FY97)

Broad Data Need — Hydrogeologic Framework	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Stream Flow	1. Robison (1984) 2. Robison et al. (1988) 3. DOE (1991d,e) 4. DOE (1992b) 5. Glancy (1994) 6. Squires and Young (1984)	Yes Yes Yes Yes Yes Yes	No No Yes No No No	?USGS ?USGS DOE DOE ?USGS ?USGS
3. Groundwater Flux/Flow Rate	1. Andrews et al. (1993) 2. DOE (1990d) 3. DOE (1991f,g) 4. DOE (1992b) 5. DOE (1993g-l) 6. Dudley et al. (1985) 7. Eslinger et al. (1993) 8. Wilson et al. (1994) 9. Wittmeyer et al. (1994)	Yes Yes Yes Yes Yes Yes Yes Yes Yes	No No No No No No No No No	?USGS DOE DOE DOE DOE ?SNL ?PNL ?SNL CNWRA
Hydrologic flow data are needed to determine if there is a potential for impoundment given the surface geometry, water availability and infiltration rates to the water table.				
Broad Data Need — Physical Boundaries	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Topographic Maps	1. USGS topographic maps (1 to 24,000 - 9 quadrangles covering the site area)	Yes	Yes	?USGS
2. Topographic Data	1. USGS digital elevation data (DEM format - 30 pixel resolution)	Yes	Yes	?USGS
Because this PAC requires that a large surface water impoundment result from natural phenomena and that the impoundment be of sufficient size to alter groundwater hydrology, no KTU was identified for this PAC. This PAC is related to 3.2.2.5 Flooding, 3.2.4.2 Changes to Hydrologic System from Climate, 3.2.1.10 Extreme Erosion, and 3.2.2.9 Changes in Hydrologic Conditions. Topographic data are needed to determine the geometry of potential impoundments.				

Table 3-9. LARP Section 3.2.2.7 — (PAC) Natural Phenomena and Groundwater (FY97) (Cont'd)

Broad Data Need — Recharge/Infiltration-Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Models of Quaternary Climate	1. Winograd et al. (1988)	Yes	No	?USGS
	2. Winograd et al. (1992)	Yes	No	?USGS
	3. Spaulding (1983)	Yes	No	?USGS
	4. Spaulding (1985)	Yes	No	?USGS
	5. Whelan et al. (1994)	Yes	No	?USGS
	6. Long and Childs (1993)	Yes	No	?
	7. Benson and Klieforth (1989)	Yes	No	?USGS
2. Present/Historic Climate Data	1. Quiring (1983)	Yes	No	?DOC
	2. Long and Childs (1993)	Yes	No	?
	3. DOE (1991b)	Yes	No	DOE
	4. DOE (1993f,m)	Yes	No	DOE
3. Precipitation Records	1. Hevesi et al. (1992)	Yes	No	?USGS
	2. Hevesi and Flint (1993)	Yes	No	?USGS
	3. Hevesi et al. (1994)	Yes	No	?USGS
	4. Bowen and Egami (1983)	Yes	No	DOE
	5. Chu (1986)	Yes	No	?NOAA
	6. Eglinton and Dreicer (1984)	Yes	No	?SNL
	7. Hershfield (1961)	Yes	No	?DOC
	8. Nichols (1986)	Yes	No	?USGS
	9. Quiring (1983)	Yes	No	?DOC
	10. Karl (1990)	Yes	No	?ORNL
	11. Quinlan et al. (1987)	Yes	No	?ORNL
	12. French (1986)	Yes	No	?DRI
	13. NOAA (1993)	Yes	No	?NOAA
	14. Ambos and Flint (1994)	Yes	No	?USGS
	15. Klein and Bloom (1987)	Yes	No	?
	16. Czarnecki (1990a,b)	Yes	No	?USGS
	17. McKinley and Oliver (1994)	Yes	No	?USGS
	18. DOE (1991b,g)	Yes	No	DOE
	19. DOE (1993f)	Yes	No	DOE
4. Potential Evapotranspiration	1. Flint and Childs (1991)	Yes	No	?USGS
	2. Czarnecki (1990b)	Yes	No	?USGS
	3. DOE (1993f,q)	Yes	No	DOE
5. Future Climate Estimates	1. DeWispelare et al. (1993)	Yes	n/a	CNWRA
Paleoclimate and current or historic climate data are needed to extrapolate potential water source amounts over the repository during its performance period. Future climate estimates were obtained by means of expert opinion elicitation.				

Table 3-9. LARP Section 3.2.2.7 — (PAC) Natural Phenomena and Groundwater (FY97) (Cont'd)

Broad Data Need — Geologic Structure	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Landslide Data	Not available yet			
2. Potential-Landslide-Material Properties	1. DOE (1992c)	Yes	No	DOE
3. Fault Maps and Data	1. Frizzell and Shulters (1990)	Yes	Yes	?USGS
	2. Scott and Bonk (1984)	Yes	Yes	?USGS
	3. DOE (1988)	Yes	No	DOE
	4. DOE (1990b)	Yes	No	DOE
	5. DOE (1991a)	Yes	No	DOE
	6. DOE (1993a-e)	Yes	No	DOE
	7. Dohrenwend (1982)	Yes	Yes	?USGS
	8. Dohrenwend and Moring (1991a-c)	Yes	Yes	?USGS
	9. Dohrenwend and Moring (1993)	Yes	Yes	?USGS
	10. Dohrenwend et al. (1991a-f)	Yes	Yes	?USGS
	11. Dohrenwend et al. (1992a,b)	Yes	Yes	?USGS
	12. Jennings (1992)	Yes	Yes	?CDMG
4. Fault Slip History Data	1. Young et al. (1992)	Yes	No	CNWRA
	2. Ferrill et al. (1994)	Yes	Yes	CNWRA
	3. Rogers et al. (1987)	Yes	No	DOE
5. Volcanic Features	1. DOE (1990c)	Yes	No	LANL?
	2. Connor and Hill (1994a,b)	Yes	Yes	CNWRA
	3. Crowe et al. (1993)	Yes	Yes	CNWRA
6. Subsidence Data	1. DOE (1991f)	No	No	?USGS
7. Epicenters	1. NEIC PDE database	Yes	Yes	?USGS
	2. Harmsen (1994)	Yes	No	?USGS
	3. Rogers et al. (1987)	Yes	No	?USGS
	4. DOE (1991h)	Yes	No	DOE
	5. DOE (1992c)	Yes	No	DOE
	6. DOE (1993n)	Yes	No	DOE
8. Ground Motion Effects	1. DOE (1993o,p)	No	No	DOE
Maps and analyses of landslides in the YM region, along with slope stability studies are needed to estimate the likelihood of landslide occurrence and the potential for surface water impoundment by this means. Fault location and earthquake data are needed to estimate the potential for impoundment by fault offset and to estimate the potential size and location of future earthquakes and fault slip events which may cause impoundment by landslides or fault scarps. Volcanic effects data are needed to estimate the likelihood of debris flow or other future impoundments. Subsidence data is needed to estimate the potential for future impoundment by this means.				

Table 3-10. LARP Section 3.2.2.11 — (PAC) Potential for Unsaturated Zone Saturation (FY97)

Broad Data Need — Hydrogeologic Framework and Physical Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
3. Water Levels in the Recent Geological Past	1. Levy (1991) 2. Marshall et al. (1993) 3. NaRC (1992)	Yes Yes Yes	No No No	?LANL ?USGS ?NaRC

Estimates of past water levels in the vicinity of YM may serve to bound the range of plausible future water levels resulting from natural processes. In order to be representative of past conditions, water level elevations during glacial and interglacial times should be estimated.

Broad Data Need — Matrix Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b) 2. Anderson (1992) 3. Craig and Reed (1991) 4. Flint and Flint (1990) 5. Lahoud et al. (1984) 6. Rush et al. (1983) 7. Whitfield et al. (1985)	Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
2. Porosity	1. Anderson (1981a,b) 2. Anderson (1992) 3. Flint and Flint (1990) 4. Lahoud et al. (1984) 5. Rush et al. (1983) 6. Thordarson (1983)	Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes No	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* water Content	1. Anderson (1981a,b) 2. Anderson (1984) 3. Kume and Hammermeister (1991) 4. Lahoud et al. (1984) 5. Loscot and Hammermeister (1992) 6. Rush et al. (1983) 7. Whitfield et al. (1990) 8. Whitfield et al. (1993)	Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE

These data are required to estimate groundwater travel times in the unsaturated rock matrix.

Table 3-10. LARP Section 3.2.2.11 — (PAC) Potential for Unsaturated Zone Saturation (FY97) (Cont'd)

Broad Data Need — Site Data: Fracture Proprties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			
These data are required to estimate groundwater travel times in unsaturated fractures.				
Broad Data Need — Hydraulic Head Gradient	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Regional Hydrology Models	1. Rush (1971) 2. Burbey and Prudic (1991) 3. Winograd and Thordarson (1975) 4. Montazer and Wilson (1984)	Yes Yes Yes Yes	No No Yes No	?USGS ?USGS ?USGS ?USGS
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Hydraulic gradients and regional hydrology models are necessary to determine the current potentiometric surface. This serves as a baseline from which to predict past and future fluctuations in the water table elevation.				

Table 3-10. LARP Section 3.2.2.11 — (PAC) Potential for Unsaturated Zone Saturation (FY97) (Cont'd)

Broad Data Need — Recharge/Infiltration, Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Mechanisms That Could Cause Water Level Rises: Climate Change	1. Ahola and Sagar (1992)	Yes	No	CNWRA
	2. DeWispelare et al. (1993)	Yes	No	CNWRA
	4. Crowley and North (1990)	No	No	?
	5. Czarnecki (1985)	No	No	?USGS
	7. Flint et al. (1993)	Yes	No	?USGS
	8. Giorgi et al. (1992)	No	No	?
	9. Imbrie et al. (1984)	No	No	?
	10. Long and Childs (1993)	Yes	No	?
	11. McMahon (1985)	No	No	?
	12. NaRC (1992)	Yes	No	?NaRC
	13. Spaulding (1985)	No	No	?USGS
	14. Winograd et al. (1988)	No	No	?USGS
	15. Winograd et al. (1992)	No	No	?USGS

There are a variety of processes which could cause the water table to rise in the vicinity of YM. To the extent possible, these mechanisms should be identified and evaluated with site-specific data. One of these mechanisms consists of climatic change that could result in increased precipitation and infiltration.

Broad Data Need — Groundwater Geochemistry	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Zone Waters	1. McKinley et al. (1991)	Yes	Yes	?USGS
	2. Kerrisk (1987)	Yes	No	?LANL
	3. White et al. (1980)	Yes	No	?USGS
	4. Claassen (1985)	Yes	No	?USGS
2. Unsaturated Zone Waters	1. Yang et al. (1988)	Yes	No	?USGS
	2. White et al. (1980)	Yes	No	?USGS
	3. Yang et al. (1993)	Yes	No	?USGS
	5. Kerrisk (1983)	Yes	No	?LANL

Groundwater chemistry is an important means for tracing groundwater flow and establishing the hydrogeologic framework. This is particularly true when trying to establish bounding limits on water table rises based on chemical evidence such as radiogenic and stable isotopes.

Broad Data Need — Geologic Structure	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Mechanisms That Could Cause Water Level Rises: Movement or Disruption of the Steep Hydraulic Gradient North of the Proposed Repository	1. Ahola and Sagar (1992)	Yes	No	CNWRA
	2. Czarnecki (1990c)	No	No	?USGS
	3. Czarnecki and Waddell (1984)	No	No	?USGS
	4. NaRC (1992)	Yes	No	?NaRC

Table 3-10. LARP Section 3.2.2.11 — (PAC) Potential for Unsaturated Zone Saturation (FY97) (Cont'd)

Broad Data Need — Geologic Structure	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
2. Mechanisms That Could Cause Water Level Rises: Igneous Intrusions	1. Ahola and Sagar (1992)	Yes	No	CNWRA
	2. Carrigan et al (1990)	No	No	?LLNL
	3. Crowe et al. (1983a)	No	No	?LANL
	4. Crowe et al. (1983b)	No	No	?LANL
	5. Crowe (1986)	No	No	?LANL
	6. Crowe et al. (1986)	No	No	?LANL
	8. Evans and Smith (1992)	No	No	?USGS
	9. Kuiper (1991)	No	No	?
	10. NaRC (1992)	Yes	No	?NaRC
	11. Smith et al. (1990)	Yes	No	?
	12. Trapp (1989)	No	No	NRC
3. Mechanisms That Could Cause Water Level Rises: Earthquakes	1. Carrigan and King (1991)	No	No	?LLNL
	2. Carrigan et al. (1991)	No	No	?LLNL
	3. Cook and Kemeny (1991)	No	No	?
	4. NaRC (1992)	Yes	No	?NaRC
Each of the mechanisms listed above could cause water levels at YM to approach the proposed repository. (1) A steep hydraulic gradient exists approximately 2 km north of the proposed repository. Water levels on the north side of this gradient are approximately 300 m higher than on the south. Southward movement of this steep gradient, or a sudden release of water behind the gradient, could inundate the proposed repository. (2) A future igneous intrusion south of the site could act as a dam, causing groundwater to rise to the level of the repository. High temperatures and increased pore pressures associated with an intrusion could also cause a rise in water levels. (3) Earthquakes may increase pore pressures in the vicinity of the repository, causing water levels to rise.				

Table 3-11. LARP Section 3.2.2.4 — (FAC) Unsaturated Zone Hydrogeologic Conditions (FY98)

Broad Data Need — Site Data: Hydrologic Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
The existence of unsaturated conditions will reduce the volume of groundwater flowing through the repository and increase groundwater travel times from the repository to potential receptors. Water levels are required to determine where unsaturated conditions exist.				
Broad Data Need — Site Data: Matrix Properties	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b) 2. Anderson (1992) 3. Craig and Reed (1991) 4. Flint and Flint (1990) 5. Lahoud et al. (1984) 6. Rush et al. (1983) 7. Whitfield et al. (1985)	Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
2. Porosity	1. Anderson (1981a,b) 2. Anderson (1992) 3. Flint and Flint (1990) 4. Lahoud et al. (1984) 5. Rush et al. (1983) 6. Thordarson (1983)	Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes No	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* water Content	1. Anderson (1981a,b) 2. Anderson (1984) 3. Kume and Hammermeister (1991) 4. Lahoud et al. (1984) 5. Loscot and Hammermeister (1992) 6. Rush et al. (1983) 7. Whitfield et al. (1990) 8. Whitfield et al. (1993)	Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE
These data are required to estimate groundwater travel times in the unsaturated rock matrix.				
Broad Data Need — Site Data: Fracture Properties	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS

Table 3-11. LARP Section 3.2.2.4 — (FAC) Unsaturated Zone Hydrogeologic Conditions (FY98) (Cont'd)

Broad Data Need — Site Data: Fracture Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			
These data are required to estimate groundwater travel times in unsaturated fractures.				
Broad Data Need — Infiltration, Recharge/Discharge	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Long-Term Net Infiltration	1. Flint et al. (1993) 2. Gauthier (1993) 3. Gauthier and Wilson (1994) 4. Hevesi and Flint (1993)	Yes Yes Yes Yes	No No No No	?DOE ?DOE ?DOE ?DOE
This information is required to predict the rate of flow and amount of water that will pass through the proposed repository. The occurrence of groundwater at locations or depths other than that currently present, in addition to the hydraulic properties of the subsurface media, will depend upon the rates of precipitation, infiltration, percolation and recharge.				
Broad Data Need — Groundwater Geochemistry	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Unsaturated Zone Waters	1. Yang et al. (1988) 2. White et al. (1980) 3. Yang et al. (1993) 5. Kerrisk (1983)	Yes Yes Yes Yes	No No No No	?USGS ?USGS ?USGS ?LANL
Groundwater chemistry is an important means for tracing groundwater flow and establishing the hydrogeologic framework.				

Table 3-12. LARP Section 3.2.2.10 — (PAC) Complex Engineering Measures (FY98)

Broad Data Need — Hydrogeologic Framework.	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
3. Perched water/flooding	1. Kume and Hammermeister (1991) 2. DOE (1991d,f)	No No	No No	USGS? DOE
At this time, the construction of the north ramp for the underground studies facility (ESF) has just begun. Thus, the assessment of groundwater conditions at YM that might require complex engineering measures in the design and construction of the underground facility can only be made from existing geohydrologic borehole data, to show possible locations of perched water, flooding potential, etc.				
Broad Data Need — Physical Boundaries.	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Rock/Soil conditions (along shafts/ramps)	1. DOE (1990a) 2. DOE (1992a)	Yes Yes	No No	DOE DOE
Geologic information on the soil/rock conditions at the surface locations of the shafts/ramps as well as along the length/alignment is critical in assessing the geologic conditions in the design and construction of the underground facility including the shafts and ramps. To date, this data exist for the surface portal and startup tunnel for the Exploratory Study Facility North Ramp. The boreholes completed in alignment the North Ramp (e.g., North Ramp Geologic designated boreholes) have been drilled, however, the information has not yet been published.				
Broad Data Need — Site Data: Matrix Properties	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b) 2. Anderson (1992) 3. Craig and Reed (1991) 4. Flint and Flint (1990) 5. Lahoud et al. (1984) 6. Rush et al. (1983) 7. Whitfield et al. (1985)	Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
2. Porosity	1. Anderson (1981a,b) 2. Anderson (1992) 3. Flint and Flint (1990) 4. Lahoud et al. (1984) 5. Rush et al. (1983) 6. Thordarson (1983)	Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes No	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS

Table 3-12. LARP Section 3.2.2.10 — (PAC) Complex Engineering Measures (FY98) (Cont'd)

Broad Data Need — Site Data: Matrix Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
3. *In-Situ* water Content	1. Anderson (1981a,b) 2. Anderson (1984) 3. Kume and Hammermeister (1991) 4. Lahoud et al. (1984) 5. Loscot and Hammermeister (1992) 6. Rush et al. (1983) 7. Whitfield et al. (1990) 8. Whitfield et al. (1993)	Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE
These data are required to estimate groundwater travel times in the unsaturated rock matrix.				
Broad Data Need — Site Data: Fracture Properties	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			
These data are required to estimate groundwater travel times in-unsaturated fractures.				
Broad Data Need — Hydraulic Head Gradient	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Regional Hydrology Models	1. Rush (1971) 2. Burbey and Prudic (1991) 3. Winograd and Thordarson (1975) 4. Montazer and Wilson (1984)	Yes Yes Yes Yes	No No Yes No	?USGS ?USGS ?USGS ?USGS

Table 3-12. LARP Section 3.2.2.10 — (PAC) Complex Engineering Measures (FY98) (Cont'd)

Broad Data Need - Hydraulic Head Gradient	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Hydraulic gradients are necessary to determine directions of fluid flow and flow paths from the repository to the accessible environment. Regional hydrology models can be used to provide boundary conditions for the controlled area surrounding the repository.				
Broad Data Need — Infiltration, Recharge/Discharge	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Long-Term Net Infiltration	1. Flint et al. (1993) 2. Gauthier (1993) 3. Gauthier and Wilson (1994) 4. Hevesi and Flint (1993)	Yes Yes Yes Yes	No No No No	?DOE ?DOE ?DOE ?DOE
This information is required to predict the rate of flow and amount of water that will pass through the proposed repository. Changes in groundwater locations or depths, in addition to hydraulic properties of the subsurface media, will depend upon the rates of precipitation, infiltration, percolation and recharge.				
Broad Data Need — Site Data: Geologic Structure	**Data Source(s)**	**Data Obtained**	**Entered in GIS?**	**QA Status**
1. Fault Maps and Data	1. Frizzell and Shulters (1990) 2. Scott and Bonk (1984) 3. DOE (1988) 4. DOE (1990b) 5. DOE (1991a) 6. DOE (1993a-e) 7. Dohrenwend (1982) 8. Dohrenwend and Moring (1991a-c) 9. Dohrenwend and Moring (1993) 10. Dohrenwend et al. (1991a-f) 11. Dohrenwend et al. (1992a,b) 12. Jennings (1992)	Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes No No No No Yes Yes Yes Yes Yes Yes	?USGS ?USGS DOE DOE DOE DOE ?USGS ?USGS ?USGS ?USGS ?USGS ?CDMG
2. Fault Slip History Data	1. Young et al. (1992) 2. Ferrill et al. (1994) 3. Rogers et al. (1987)	Yes Yes Yes	No Yes No	CNWRA CNWRA DOE
Rock conditions regarding faulting (i.e., orientation, dip, width of fault zone, breccia material) is necessary in assessing the complexity of the design and construction of shafts and ramps which penetrate through them.				

Table 3-12. LARP Section 3.2.2.10 — (PAC) Complex Engineering Measures (FY98) (Cont'd)

Broad Data Need — Geologic Structure/Repository (borehole) Design.	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Drilling Logs (borehole depth, fracture zones, competent zones)	1. Fernandez et al. (1994) 2. Jarrell (1991)	Yes Yes	No No	?SNL ?
2. Borehole Construction Information (e.g., borehole diameter, casing depth, grout volumes, deviations, etc.)	1. Fernandez et al. (1994)	Yes	No	?SNL
Accurate geologic and drilling information for each borehole is critical in assessing whether they have been properly sealed.				

Table 3-13. LARP Section 3.2.2.9 — (PAC) Changes in Hydrologic Conditions (FY99)

Broad Data Need — Hydrogeologic Framework and Physical Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
3. Water Levels in the Recent Geological Past	1. Levy (1991) 2. Marshall et al. (1993) 3. NaRC (1992)	Yes Yes Yes	No No No	?LANL ?USGS ?NaRC
Estimates of past water levels in the vicinity of YM may serve to bound the range of plausible future water levels resulting from natural processes. In order to be representative of past conditions, water level elevations during glacial and interglacial times should be estimated.				
Broad Data Need — Matrix Properties	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b) 2. Anderson (1992) 3. Craig and Reed (1991) 4. Flint and Flint (1990) 5. Lahoud et al. (1984) 6. Rush et al. (1983) 7. Whitfield et al. (1985)	Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
2. Porosity	1. Anderson (1981a,b) 2. Anderson (1992) 3. Flint and Flint (1990) 4. Lahoud et al. (1984) 5. Rush et al. (1983) 6. Thordarson (1983)	Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes No	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* water Content	1. Anderson (1981a,b) 2. Anderson (1984) 3. Kume and Hammermeister (1991) 4. Lahoud et al. (1984) 5. Loscot and Hammermeister (1992) 6. Rush et al. (1983) 7. Whitfield et al. (1990) 8. Whitfield et al. (1993)	Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE
These data are required to estimate groundwater travel times in the unsaturated rock matrix.				

Table 3-13. LARP Section 3.2.2.9 — (PAC) Changes in Hydrologic Conditions (FY99) (Cont'd)

Broad Data Need — Site Data: Fracture Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			
These data are required to estimate groundwater travel times in unsaturated fractures.				
Broad Data Need — Hydraulic Head Gradient	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Regional Hydrology Models	1. Rush (1971) 2. Burbey and Prudic (1991) 3. Winograd and Thordarson (1975) 4. Montazer and Wilson (1984)	Yes Yes Yes Yes	No No Yes No	?USGS ?USGS ?USGS ?USGS
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Hydraulic gradients and regional hydrology models are necessary to determine the current potentiometric surface. This serves as a baseline from which to predict past and future fluctuations in the water table elevation.				

Table 3-13. LARP Section 3.2.2.9 — (PAC) Changes in Hydrologic Conditions (FY99) (Cont'd)

Broad Data Need — Recharge/Infiltration, Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Mechanisms That Could Cause Water Level Rises: Climate Change	1. Ahola and Sagar (1992)	Yes	No	CNWRA
	2. DeWispelare et al. (1993)	Yes	No	CNWRA
	4. Crowley and North (1990)	No	No	?
	5. Czarnecki (1985)	No	No	?USGS
	7. Flint et al. (1993)	Yes	No	?USGS
	8. Giorgi et al. (1992)	No	No	?
	9. Imbrie et al. (1984)	No	No	?
	10. Long and Childs (1993)	Yes	No	?
	11. McMahon (1985)	No	No	?
	12. NaRC (1992)	Yes	No	?NaRC
	13. Spaulding (1985)	No	No	?USGS
	14. Winograd et al. (1988)	No	No	?USGS
	15. Winograd et al. (1992)	No	No	?USGS
There are a variety of processes which could cause the water table to rise in the vicinity of YM. To the extent possible, these mechanisms should be identified and evaluated with site-specific data. One of these mechanisms consists of climatic change that could result in increased precipitation and infiltration.				
Broad Data Need — Groundwater Geochemistry	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Saturated Zone Waters	1. McKinley et al. (1991)	Yes	Yes	?USGS
	2. Kerrisk (1987)	Yes	No	?LANL
	3. White et al. (1980)	Yes	No	?USGS
	4. Claassen (1985)	Yes	No	?USGS
Broad Data Need — Groundwater Geochemistry	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
2. Unsaturated Zone Waters	1. Yang et al. (1988)	Yes	No	?USGS
	2. White et al. (1980)	Yes	No	?USGS
	3. Yang et al. (1993)	Yes	No	?USGS
	5. Kerrisk (1983)	Yes	No	?LANL
Groundwater chemistry is an important means for tracing groundwater flow and establishing the hydrogeologic framework. This is particularly true when trying to establish bounding limits on water table rises based on chemical evidence such as radiogenic and stable isotopes.				
Broad Data Need — Geologic Structure	**Data Source(s)**	**Data Obtained?**	**Entered in GIS?**	**QA Status**
1. Mechanisms That Could Cause Water Level Rises: Movement or Disruption of the Steep Hydraulic Gradient North of the Proposed Repository	1. Ahola and Sagar (1992)	Yes	No	CNWRA
	2. Czarnecki (1990c)	No	No	?USGS
	3. Czarnecki and Waddell (1984)	No	No	?USGS
	4. NaRC (1992)	Yes	No	?NaRC

Table 3-13. LARP Section 3.2.2.9 — (PAC) Changes in Hydrologic Conditions (FY99) (Cont'd)

Broad Data Need — Geologic Structure	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
2. Mechanisms That Could Cause Water Level Rises: Igneous Intrusions	1. Ahola and Sagar (1992)	Yes	No	CNWRA
	2. Carrigan et al (1990)	No	No	?LLNL
	3. Crowe et al. (1983a)	No	No	?LANL
	4. Crowe et al. (1983b)	No	No	?LANL
	5. Crowe (1986)	No	No	?LANL
	6. Crowe et al. (1986)	No	No	?LANL
	8. Evans and Smith (1992)	No	No	?USGS
	9. Kuiper (1991)	No	No	?
	10. NaRC (1992)	Yes	No	?NaRC
	11. Smith et al. (1990)	Yes	No	?
	12. Trapp (1989)	No	No	NRC
3. Mechanisms That Could Cause Water Level Rises: Earthquakes	1. Carrigan and King (1991)	No	No	?LLNL
	2. Carrigan et al. (1991)	No	No	?LLNL
	3. Cook and Kemeny (1991)	No	No	?
	4. NaRC (1992)	Yes	No	?NaRC

Each of the mechanisms listed above could cause water levels at YM to approach the proposed repository. (1) A steep hydraulic gradient exists approximately 2 km north of the proposed repository. Water levels on the north side of this gradient are approximately 300 m higher than on the south. Southward movement of this steep gradient, or a sudden release of water behind the gradient, could inundate the proposed repository. (2) A future igneous intrusion south of the site could act as a dam, causing groundwater to rise to the level of the repository. High temperatures and increased pore pressures associated with an intrusion could also cause a rise in water levels. (3) Earthquakes may increase pore pressures in the vicinity of the repository, causing water levels to rise.

Broad Data Need — Repository Design	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Changes in Groundwater Flow Due to Heat Generated by Wastes	1. O'Neal et al. (1984)	Yes	No	?LLNL
	2. Buscheck and Nitao (1993a-c)	Yes	No	?LLNL
	3. Pruess and Tsang (1993)	Yes	No	?LBL
	4. Wilson et al. (1994)	Yes	No	?SNL
2. Water Infiltration	1. Wilson et al. (1994)	Yes	No	?SNL
	2. Dodge and Green (1994)	Yes	No	CNWRA
3. Source Term Models	1. Manaktala (1993)	Yes	n/a	CNWRA
	2. Codell and Weller (1994)	Yes	n/a	NRC
	3. Ahola et al. (1994)	Yes	n/a	CNWRA
	4. Wilson et al. (1994)	Yes	n/a	?SNL
4. Hydraulic properties of the Engineered Barrier System	Not available yet			

Heat generated by the wastes will affect the groundwater flow field in the vicinity of the repository. The relative distribution of water between the matrix and fractures may be altered. This could result in increased flow through the fractures.

Table 3-13. LARP Section 3.2.2.9 — (PAC) Changes in Hydrologic Conditions (FY99) (Cont'd)

Broad Data Need — Human Activity	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Potential for Increased Groundwater Withdrawals	1. ABC (1989a,b)	Yes	No	CNWRA
2. Human intrusion scenarios	1. Barnard et al. (1992) 2. Eslinger et al. (1993) 3. Wilson et al. (1994)	Yes Yes Yes	n/a n/a n/a	?SNL ?PNL ?SNL
Increased withdrawals to supply municipalities such as Las Vegas could result in increased hydraulic gradients and groundwater flow rates. This would increase the flow rate of any contaminants that enter the saturated zone. Because human activity is extremely difficult to predict, scenario development and analyses similar to those performed for the DOE TSPA efforts are likely to provide the best means of addressing these effects.				

Table 3-14. LARP Section 3.3 — Assessment of Compliance with the Groundwater Travel Time Performance Objective (FY00).

Broad Data Need — Hydrogeologic Framework and Physical Boundaries	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Hydrogeologic Framework/Physical Boundaries	1. Stirewalt et al. (1994) 2. Schenker et al. (1994)	Yes Yes	Yes No	CNWRA ?SNL
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
3. Water Levels in the Recent Geological Past	1. Levy (1991) 2. Marshall et al. (1993) 3. NaRC (1992)	Yes Yes Yes	No No No	?LANL ?USGS ?NaRC
Estimates of past water levels in the vicinity of YM may serve to bound the range of plausible future water levels resulting from natural processes. In order to be representative of past conditions, water level elevations during glacial and interglacial times should be estimated.				

Broad Data Need — Matrix Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Anderson (1981a,b) 2. Anderson (1992) 3. Craig and Reed (1991) 4. Flint and Flint (1990) 5. Lahoud et al. (1984) 6. Rush et al. (1983) 7. Whitfield et al. (1985)	Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
2. Porosity	1. Anderson (1981a,b) 2. Anderson (1992) 3. Flint and Flint (1990) 4. Lahoud et al. (1984) 5. Rush et al. (1983) 6. Thordarson (1983)	Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes No	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* water Content	1. Anderson (1981a,b) 2. Anderson (1984) 3. Kume and Hammermeister (1991) 4. Lahoud et al. (1984) 5. Loscot and Hammermeister (1992) 6. Rush et al. (1983) 7. Whitfield et al. (1990) 8. Whitfield et al. (1993)	Yes Yes Yes Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes Yes Yes Yes	?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS ?USGS
4. Van Genuchten Parameters (alpha, beta, residual saturation)	1. Flint and Flint (1990) 2. Peters et al. (1984) 3. Rutherford et al. (1992)	Yes Yes Yes	No No No	?USGS ?DOE ?DOE
These data are required to estimate groundwater travel times in the unsaturated rock matrix.				

Table 3-14. LARP Section 3.3 — Assessment of Compliance with the Groundwater Travel Time Performance Objective (FY00) (Cont'd).

Broad Data Need — Site Data: Fracture Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Hydraulic Conductivities	1. Craig and Reed (1991) 2. Lahoud et al. (1984) 3. Whitfield et al. (1985)	Yes Yes Yes	Yes Yes Yes	?USGS ?USGS ?USGS
2. Fracture Densities	1. Craig and Reed (1991) 2. Erickson and Waddell (1985) 3. Lahoud et al. (1984) 4. Whitfield et al. (1985) 5. Whitfield et al. (1990)	Yes Yes Yes Yes Yes	No No No No No	?USGS ?USGS ?USGS ?USGS ?USGS
3. *In-Situ* Water Content	Not available yet			
4. Fracture Dimensions (e.g., aperture, length, orientation)	1. Erickson and Waddell (1985) 2. Whitfield et al. (1990)	Yes Yes	No No	?USGS ?USGS
5. Van Genuchten Parameters (alpha, beta, residual saturation)	Not available yet			
These data are required to estimate groundwater travel times in unsaturated fractures.				

Broad Data Need — Rock Thermal Properties	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Thermal Conductivity	1. DOE (1990a)	Yes	No	DOE
2. Density	1. DOE (1990a) 2. Schwartz (1990)	Yes Yes	No No	DOE ?SNL
3. Specific Heat	1. DOE (1990a)	Yes	No	DOE
Overall performance of the geologic setting may be affected by the thermal load imposed on the system by the radioactive waste, particularly during repository operation. Rock thermal properties are necessary to predict thermal perturbations and temperature gradients as a function of time.				

Broad Data Need — Hydraulic Head Gradient	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Regional Hydrology Models	1. Rush (1971) 2. Burbey and Prudic (1991) 3. Winograd and Thordarson (1975) 4. Montazer and Wilson (1984)	Yes Yes Yes Yes	No No Yes No	?USGS ?USGS ?USGS ?USGS
2. Current Water Levels	1. Robison (1984) 2. Robison et al. (1988)	Yes Yes	No No	?USGS ?USGS
Hydraulic gradients and regional hydrology models are necessary to determine the current potentiometric surface. This serves as a baseline from which to predict past and future fluctuations in the water table elevation.				

Table 3-14. LARP Section 3.3 — Assessment of Compliance with the Groundwater Travel Time Performance Objective (FY00) (Cont'd).

Broad Data Need — Recharge/Infiltration, Discharge	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Mechanisms That Could Cause Water Level Rises: Climate Change	1. Ahola and Sagar (1992)	Yes	No	CNWRA
	2. DeWispelare et al. (1993)	Yes	No	CNWRA
	4. Crowley and North (1990)	No	No	?
	5. Czarnecki (1985)	No	No	?USGS
	7. Flint et al. (1993)	Yes	No	?USGS
	8. Giorgi et al. (1992)	No	No	?
	9. Imbrie et al. (1984)	No	No	?
	10. Long and Childs (1993)	Yes	No	?
	11. McMahon (1985)	No	No	?
	12. NaRC (1992)	Yes	No	?NaRC
	13. Spaulding (1985)	No	No	?USGS
	14. Winograd et al. (1988)	No	No	?USGS
	15. Winograd et al. (1992)	No	No	?USGS

There are a variety of processes which could cause the water table to rise in the vicinity of YM. To the extent possible, these mechanisms should be identified and evaluated with site-specific data. One of these mechanisms consists of climatic change that could result in increased precipitation and infiltration.

Broad Data Need — Groundwater Geochemistry	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Saturated Zone Waters	1. McKinley et al. (1991)	Yes	Yes	?USGS
	2. Kerrisk (1987)	Yes	No	?LANL
	3. White et al. (1980)	Yes	No	?USGS
	4. Claassen (1985)	Yes	No	?USGS
2. Unsaturated Zone Waters	1. Yang et al. (1988)	Yes	No	?USGS
	2. White et al. (1980)	Yes	No	?USGS
	3. Yang et al. (1993)	Yes	No	?USGS
	5. Kerrisk (1983)	Yes	No	?LANL

Groundwater chemistry is an important means for tracing groundwater flow and establishing the hydrogeologic framework. This is particularly true when trying to establish bounding limits on water table rises based on chemical evidence such as radiogenic and stable isotopes.

Table 3-14. LARP Section 3.3 — Assessment of Compliance with the Groundwater Travel Time Performance Objective (FY00) (Cont'd).

Broad Data Need — Geologic Structure	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Mechanisms That Could Cause Water Level Rises: Movement or Disruption of the Steep Hydraulic Gradient North of the Proposed Repository	1. Ahola and Sagar (1992) 2. Czarnecki (1990c) 3. Czarnecki and Waddell (1984) 4. NaRC (1992)	Yes No No Yes	No No No No	CNWRA ?USGS ?USGS ?NaRC
2. Mechanisms That Could Cause Water Level Rises: Igneous Intrusions	1. Ahola and Sagar (1992) 2. Carrigan et al (1990) 3. Crowe et al. (1983a) 4. Crowe et al. (1983b) 5. Crowe (1986) 6. Crowe et al. (1986) 8. Evans and Smith (1992) 9. Kuiper (1991) 10. NaRC (1992) 11. Smith et al. (1990) 12. Trapp (1989)	Yes No No No No No No No Yes Yes No	No No No No No No No No No No No	CNWRA ?LLNL ?LANL ?LANL ?LANL ?LANL ?USGS ? ?NaRC ? NRC
3. Mechanisms That Could Cause Water Level Rises: Earthquakes	1. Carrigan and King (1991) 2. Carrigan et al. (1991) 3. Cook and Kemeny (1991) 4. NaRC (1992)	No No No Yes	No No No No	?LLNL ?LLNL ? ?NaRC
Each of the mechanisms listed above could cause water levels at YM to approach the proposed repository. (1) A steep hydraulic gradient exists approximately 2 km north of the proposed repository. Water levels on the north side of this gradient are approximately 300 m higher than on the south. Southward movement of this steep gradient, or a sudden release of water behind the gradient, could inundate the proposed repository. (2) A future igneous intrusion south of the site could act as a dam, causing groundwater to rise to the level of the repository. High temperatures and increased pore pressures associated with an intrusion could also cause a rise in water levels. (3) Earthquakes may increase pore pressures in the vicinity of the repository, causing water levels to rise.				

Broad Data Need — Repository Design	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
1. Changes in Groundwater Flow Due to Heat Generated by Wastes	1. O'Neal et al. (1984) 2. Buscheck and Nitao (1993a-c) 3. Pruess and Tsang (1993) 4. Wilson et al. (1994)	Yes Yes Yes Yes	No No No No	?LLNL ?LLNL ?LBL ?SNL
2. Water Infiltration	1. Wilson et al. (1994) 2. Dodge and Green (1994)	Yes Yes	No No	?SNL CNWRA
3. Source Term Models	1. Manaktala (1993) 2. Codell and Weller (1994) 3. Ahola et al. (1994) 4. Wilson et al. (1994)	Yes Yes Yes Yes	n/a n/a n/a n/a	CNWRA NRC CNWRA ?SNL

Table 3-14. LARP Section 3.3 — Assessment of Compliance with the Groundwater Travel Time Performance Objective (FY00) (Cont'd).

Broad Data Need — Repository Design	Data Source(s)	Data Obtained?	Entered in GIS?	QA Status
4. Hydraulic properties of the Engineered Barrier System	Not available yet			
Heat generated by the wastes will affect the groundwater flow field in the vicinity of the repository. The relative distribution of water between the matrix and fractures may be altered. This could result in increased flow through the fractures.				

4 SUMMARY AND CONCLUSIONS

4.1 CURRENT STATUS

Technical issues related to hydrology and climatology/meteorology represent a significant portion of the sections currently in development for the LARP and many of the KTUs identified during the development of Compliance Determination Strategies. To assure timely review of the hydrological and climatological aspects of the LA, it seems reasonable to identify the data needs and computer codes that will be used during the review process as early as possible. This will enable NRC/CNWRA staff to become familiar at an early stage with data and methods that are likely to be presented by DOE. This approach will also have the advantage of identifying areas of overlap between the different LARP sections, as well as providing background information that is critical to the development of the hydrology and climatology CDMs that make up the LARP. The disadvantage in this approach is the premature selection of data and/or computer codes in the absence of any indications by DOE.

In this letter report, an initial effort has been made to identify both broad data needs and specific data sources for those CDMs/LARP sections related to hydrology and climatology. Based on this effort, there are three types of data at this relatively high level that are important to CDM development. These include:

- Basic data that are applicable to systems outside of YM, but are necessary for calculations such as thermodynamic data, kinetic rate data. These data are informational in nature and do not carry site-specific spatial information.

- Site specific data that are necessary to define the boundary and initial conditions at YM. These data are currently being generated as part of YM Site Characterization, and will presumably become available in on-line DOE databases such as the ATDTS and the TDB being developed by the YMPO (Harloe, 1993). These are the data that carry information in a geographic context and are effectively stored and displayed in a GIS database.

- Design data that are necessary to define the effects of the repository itself such as repository design criteria and man-made materials to be used. Many of these design issues are in development and final design decisions have not yet been made. In addition, most of these data do not have a geographic context, and are not well-suited to a GIS format.

Once the broad data needs are identified, the next step is to identify specific data needs and the existing sources for these data. At this time, this effort has been conducted by CNWRA staff using their familiarity with the current literature. Where they are known, the appropriate DOE study plans have been identified as a future data source. As the capability to access on-line electronic databases improves, the effort can focus more tightly on data generated under these study plans.

In identifying specific data needs, several points can be noted:

- Data have tended to come out in a number of short reports and papers rather than as large compilations. This is particularly true with regard to site-specific data, which tend to be reported in the proceedings of conferences (e.g., The Annual International High Level Radioactive Waste Management Conference or the Materials Research Symposia on the

Scientific Basis for Nuclear Waste Management), or as national laboratory (e.g. Sandia, Los Alamos) or agency reports (e.g., USGS Open-File Reports).

- Some of the specific data such as porosity and saturated hydraulic conductivity are measured quantities. However, some of the data such as post-emplacement temperature distribution are derived from models. Extrapolation of limited data may also be required to provide the desired spatial coverage. Such extrapolation may be as simple as contouring the existing data, or may require more detailed modeling such as kriging or stochastic analysis.

- Many of the different review plans can use the same data. Identifying these sources at this stage will help to reduce the amount of duplication in developing any database. It may be appropriate to identify these cross-linkages explicitly.

- The QA status of many of these data is uncertain. Many of the data were gathered prior to the development of DOE QA procedures, but in most cases, they are the only data currently available. As site characterization proceeds, it may be appropriate for DOE to bring these existing data into compliance with QA procedures, or for results from current site characterization activities to supersede these data. It is important for NRC/CNWRA staff to keep current with regard to these issues so that QA status can be monitored and data can be updated accordingly in the databases being developed.

Because of the spatial nature of a geologic HLW repository, much of the site-specific data is best displayed in a GIS database. At present, only geochemical data (Broxton et al., 1986; McKinley et al., 1991) have been converted to electronic format and entered into the CNWRA GIS database as part of this task.

4.2 FUTURE EFFORTS

Future efforts will focus on the following:

- Continue to identify specific data sources. As on-line databases become available, these will be used to identify the most current data sources, and obtain electronic copies where possible.

- Specific data sources identified will be obtained. For those data that are best displayed in a geographic context, data entered into the CNWRA GIS database. For those data that are not already available in electronic format (from DOE or other agencies), some effort will be needed to convert these data for GIS entry. For those data such as the results of expert elicitation or design information, hard copies and electronic copies, where appropriate, can be maintained at CNWRA.

- It may be appropriate to develop a small bibliographic database to monitor the status of the database and to indicate cross-references between different LARP sections.

- Methods and computer codes tentatively identified in Table 2-3 and 2-4 will be investigated in more detail. Where DOE has indicated a "code of choice," it may be appropriate to obtain versions of these codes for installation and adaptation to NRC/CNWRA computer facilities.

- Results from these efforts will be used to help in CDM development. Data justification, uncertainty, and limitations will all be used to help develop the rationale sections for the different CDMs. In the future, computer codes and the existing databases will be used to test the suitability of proposed CDM approaches.

It is important to remember that effort will focus on those CDMs that are scheduled for completion in the relatively short term. Less effort will be spent on those scheduled for completion in out years. Any changes to the CDM completion schedule that may result from the DOE PPA will require additional changes in scheduling for work performed under this task.

5 REFERENCES

Adrian Brown Consultants. 1989a. *Water Resources in Southern Nevada*, Draft Report to the Center for Nuclear Waste Regulatory Analyses. 8912220BB.NW2: Denver, CO.

Adrian Brown Consultants. 1989b. *A Methodology for Assessing Ground Water Resources as a Potential Source of Human Intrusion- Application to the Yucca Mountain Site*, Draft Report to the Center for Nuclear Waste Regulatory Analyses. 891110ML.GW1: Denver, CO.

Ahola, M.P., and B. Sagar. 1992. *Regional Groundwater Modeling of the Saturated Zone in the Vicinity of Yucca Mountain, Nevada*, CNWRA92-001, San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Ahola, M.P., A.H. Chowdury, S.M. Hsiung, and J. Philip. 1994. Comparison of coupled thermal-mechanical-hydrological analyses of a fractured rock mass. *Proceedings of the Fifth International Conference on High Level Radioactive Waste Management*: La Grange Park, IL: American Nuclear Society: 2,492–2,499.

Ambos, D.S. and A.L. Flint. 1994. *Precipitation Measurements from a Network of Non-Recording Gages at Yucca Mountain, Nevada, October 1991 - April 1993*. USGS Open-File Report. Denver, CO: U.S. Geological Survey. In Review.

Anderson, L.A. 1981a. *Rock Property Analysis of Core Samples from the Calico Hills UE25a-3 Borehole, Nevada Test Site, Nevada*. USGS Open-File Report 81-1337. Denver, CO: U.S. Geological Survey.

Anderson, L.A. 1981b. *Rock Property Analysis of Core Samples from the Yucca Mountain UE25a-1 Borehole, Nevada Test Site, Nevada*. USGS Open-File Report 81-1338. Denver, CO: U.S. Geological Survey.

Anderson, L.A. 1984. *Rock Property Measurements on Large-Volume Core Samples from Yucca Mountain USW GU-3/G-3 and USW G-4 Boreholes, Nevada Test Site, Nevada*. USGS Open-File Report 84-552. Denver, CO: U.S. Geological Survey.

Anderson, L.A. 1992. *Water Permeability and Related Rock Properties Measured on Core Samples from the Yucca Mountain USW GU-3/G-3 and G-4 Boreholes, Nevada Test Site, Nevada*. U.S. Geological Survey Open-File Report 92-201. Denver, CO: U.S. Geological Survey.

Andrews, R.W., T.C. Dale, and J.A. McNeish. 1994. *Total System Performance Assessment - 1993: An Evaluation of the Potential Yucca Mountain Repository*. INTERA Report WBS:1.2.5.4.1. Las Vegas, NV: INTERA Inc.

Barnard, R.W. 1993. *Review of Radionuclide Source Terms Used for Performance Assessment Analyses*. SAND92-2431. Albuquerque, NM: Sandia National Laboratories.

Barnard, R.W., M.L. Wilson, H.A. Dockery, J.H. Gauthier, P.G. Kaplan, R.R. Eaton, F.W. Bingham, and T.H. Robey. 1992. *TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain*. SAND91-2795. Albuquerque, NM: Sandia National Laboratories.

Benson, L.V., and H. Klieforth. 1989. Stable isotopes in precipitation and ground water in the Yucca Mountain region, Nevada - Paleoclimatic interpretation. *Aspects of Climate Variability in the Pacific and W. Americas, Monograph 55*. Washington, DC: American Geophysical Union.

Bowen, J.L., and R.T. Egami. 1983. *Atmospheric Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada*. NVO-258. Washington, DC: U.S. Department of Energy.

Britch, M.S. 1990. *Watershed Modeling at Yucca Mountain, Nevada*. M.S. Thesis. Corvallis, OR: Oregon State University.

Broxton, D.E., R.G. Warren, R.C. Hagan, and G. Luedemann. 1986. *Chemistry of Diagenetically Altered Tuffs at a Potential Nuclear Waste Repository, Yucca Mountain, Nye County, Nevada*. LA-10802-MS. Los Alamos, NM: Los Alamos National Laboratory.

Burbey, T.J., and D.E. Prudic. 1991. *Conceptual Evaluation of Regional Ground-Water Flow in the Carbonate-Rock Province of the Great Basin, Nevada, Utah, and Adjacent States*. U.S. Geological Survey Professional Paper 1409-D. Washington, DC: U.S. Geological Survey.

Buscheck, T.A., and J.J. Nitao. 1993a. The analysis of repository-heat-driven hydrothermal flow at Yucca Mountain. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 847–867.

Buscheck, T.A., and J.J. Nitao. 1993b. Repository-heat-driven hydrothermal flow at Yucca Mountain, Part 1: Modeling and analysis. *Nuclear Technology* 104: 418–448.

Buscheck, T.A., and J.J. Nitao. 1993c. The impact of repository-heat on thermo-hydrological performance at Yucca Mountain. *Proceedings of the Topical Meeting on Site Characterization and Model Validation, Focus '93*. La Grange Park, IL: American Nuclear Society: 127–144.

Carrigan, C.R., and G.P. King. 1991. Models of water table excursions induced by seismic events at Yucca Mountain, Nevada. (Abstract). *EOS* 72: 116.

Carrigan, C.R., G.P. King, and G.E. Barr. 1990. *A Scoping Study of Water Table Excursions Induced by Seismic and Volcanic Events*. UCRL-ID-105340. Livermore, CA: Lawrence Livermore National Laboratory.

Carrigan, C.R., G.P. King, G.E. Barr, and N.E. Bixler. 1991. Potential for water table excursions induced by seismic events at Yucca Mountain, Nevada. *Geology* 19: 1,157–1,160.

Chu, J.H. 1986. *Atmospheric Phenomena at Yucca Mountain, Nevada Test Site*. Unpublished tabular data. Washington, DC: National Oceanic and Atmospheric Administration.

Church, H.W., D.L. Freeman, K. Boro, and R.T. Egami. 1985. *Meteorological Tower Data Yucca Ridge (YR) Site*. SAND85-1053. Albuquerque, NM: Sandia National Laboratories.

Church. H.W., D.L. Freeman, K. Boro, and R.T. Egami. 1986. *Meteorological Tower Data for the Yucca Alluvial (YA) Site*. SAND86-2533. Albuquerque, NM: Sandia National Laboratories.

Claassen, H.C. 1985. *Sources and Mechanisms of Recharge for Groundwater in the West Central Amargosa Desert, Nevada: A Geochemical Interpretation*. U.S. Geological Survey Professional Paper 712F. Reston, VA: U.S. Geological Survey.

Codell, R., and R. Weller. 1994. Further development of a source term model for a repository in unsaturated tuff. *Proceedings of the Fifth International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 477–484.

Connor, C.B., and B.E. Hill. 1994a. *The CNWRA Volcanism Geographic Information System Data Base*. CNWRA 94-004. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Connor, C.B. and B.E. Hill. 1994b. Field volcanism research. *NRC High-Level Radioactive Waste Research at CNWRA January-June 1994*. CNWRA 94-01S. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Cook, W., and J.M. Kemeny. 1991. A mechanical estimate for water level change due to a normal faulting earthquake. Abstract. *EOS* 71: 116

Craig, R.W., and R.L. Reed. 1991. *Geohydrology of Rocks Penetrated by Test Well USW H-6, Yucca Mountain, Nye County, Nevada*. USGS Water-Resources Investigations Report 89-4025. Denver, CO: U.S. Geological Survey.

Crowe, B.M., D.T. Vaniman, and W.J. Carr. 1983a. *Status of Volcanic Hazards Studies for the Nevada Nuclear Waste Storage Investigations*. LA-9325-MS. Los Alamos, NM: Los Alamos National Laboratory.

Crowe, B.M., S. Self, D.T. Vaniman, R. Amos, and F. Perry. 1983b. Aspects of potential magmatic disruption of a high-level radioactive waste repository in southern Nevada. *Journal of Geology* 91: 259–276.

Crowe, B.M. 1986. Volcanic hazard assessment for disposal of high-level radioactive waste, In: *Active Tectonics*. Washington, DC: National Academy Press.

Crowe, B.M., K.H. Wohlrtz, D.T. Vaniman, E. Gladney, and B. Bower. 1986. *Status of Volcanic Hazards Studies for the Nevada Nuclear Waste Storage Investigations*. LA-9325-MS-2. Los Alamos, NM: Los Alamos National Laboratory.

Crowe, B.M., F.V. Perry, and G.A. Valentine. 1993. *Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project*. LA-9325. Los Alamos, NM: Los Alamos National Laboratory.

Crowley, T.J., and G.R. North. 1990. Modeling future climate for nuclear waste disposal. *Proceedings of the First International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 1,259–1,266.

Czarnecki, J.B. 1985. *Simulated Effects of Increased Recharge on the Ground-Water Flow System of Yucca Mountain and Vicinity, Nevada-California*. USGS Water-Resources Investigations Report 84-4344. Denver, CO: U.S. Geological Survey.

Czarnecki, J.B. 1990a. *Geohydrology and Evapotranspiration at Franklin Lake Playa, Inyo Country, California*. USGS Open-File Report 90-356. Denver, CO: U.S. Geological Survey.

Czarnecki, J.B. 1990b. *Geohydrologic and Evapotranspiration Data from Franklin Lake Playa, Inyo County, California*. USGS Open-File Report 89-595. Denver, CO: U.S. Geological Survey.

Czarnecki, J.B. 1990c. Preliminary simulations related to a large horizontal hydraulic gradient at the north end of Yucca Mountain, Nevada. *Proceedings, American Institute of Hydrology Spring Meeting*. Las Vegas, NV: Americna Institute of Hydrology.

Czarnecki, J.B., and R.K. Waddell. 1984. *Finite-Element Simulation of Ground-Water Flow in the Vicinity of Yucca Mountain, Nevada-California*. USGS Water-Resources Investigations Report 84-4349. Denver, CO: U.S. Geological Survey.

DeWispelare, A., L.R. Herren, M. Miklas, and R. Clemen. 1993. *Expert Elicitation of Future Climate in the Yucca Mountain Vicinity - Iterative Performance Assessment Phase 2.5*. CNWRA 93-016. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Dodge, F.T., and R.T. Green. 1994. Thermohydrology. *NRC High-Level Radioactive Waste Research at CNWRA, July-December 1993*. B. Sagar, ed. CNWRA 93-02S. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Dohrenwend, J.C. 1982. *Surficial Geologic Map of the Walker Lake 1° by 2° Quadrangle, Nevada-California. Scale 1:250,000*. USGS Miscellaneous Field Studies Map MF-2174, Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C. and B.C. Moring. 1991a. *Reconnaissance Photogeologic Map of Young Faults in the Vya 1° by 2° Quadrangle, Nevada, Oregon, and California. Scale 1:250,000*. U.S. Geological Survey Miscellaneous Field Studies Map MF2174. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C. and B.C. Moring. 1991b. *Reconnaissance Photogeologic Map of Young Faults in the Winnemucca 1° by 2° Quadrangle, Nevada, Oregon, and California. Scale 1:250,000*. USGS Miscellaneous Field Studies Map MF2175. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C. and B.C. Moring. 1991c. *Reconnaissance Photogeologic Map of Young Faults in the McDermitt 1° by 2° Quadrangle, Nevada, Oregon, and California. Scale 1:250,000*. USGS Miscellaneous Field Studies Map MF2177. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C., M.A. McKittrick, and B.C. Moring. 1991a. *Reconnaissance Photogeologic Map of Young Faults in the Lovelock 1° by 2° Quadrangle, Nevada and California. Scale 1:250,000.* USGS Miscellaneous Field Studies Map MF2178 Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C., M.A. McKittrick, and B.C. Moring. 1991b. *Reconnaissance Photogeologic Map of Young Faults in the Wells 1° by 2° Quadrangle, Nevada, Utah, and Idaho. Scale 1:250,000.* USGS Miscellaneous Field Studies Map MF2184. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C., C.M. Menges, B.A. Schell, and B.C. Moring. 1991c. *Reconnaissance Photogeologic Map of Young Faults in the Las Vegas 1° by 2° Quadrangle, Nevada, California and Arizona. Scale 1:250,000.* USGS Miscellaneous Field Studies Map MF2184. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C., M.A. McKittrick, and B.C. Moring. 1991d. *Reconnaissance Photogeologic Map of Young Faults in the Elko 1° by 2° Quadrangle, Nevada, and Utah. Scale 1:250,000.* USGS Miscellaneous Field Studies Map MF2179. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C., B.A. Schell and B.C. Moring. 1991e. *Reconnaissance Photogeologic Map of Young Faults in the Lund 1° by 2° Quadrangle, Nevada, and Utah. Scale 1:250,000.* USGS Miscellaneous Field Studies Map MF2180. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C., B.A. Schell, and B.C. Moring. 1991f. *Reconnaissance Photogeologic Map of Young Faults in the Ely 1° by 2° Quadrangle, Nevada, and Utah. Scale 1:250,000.* USGS Miscellaneous Field Studies Map MF2181. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C., B.A. Schell, and B.C. Moring. 1992a. *Reconnaissance Photogeologic Map of Young Faults in the Goldfield 1° by 2° Quadrangle, Nevada, California. Scale 1:250,000.* USGS Miscellaneous Field Studies Map MF2183. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C. and B.C. Moring. 1992b. *Reconnaissance Photogeologic Map of Young Faults in the Millett 1° by 2° Quadrangle, Nevada, Oregon, and California. Scale 1:250,000.* USGS Miscellaneous Field Studies Map MF2176. Reston, VA: U.S. Geological Survey.

Dohrenwend, J.C. and B.C. Moring. 1993. Reconnaissance photogeologic map of late tertiary and quaternary faults in Nevada. *Cordilleran and Rocky Mountain Section Meeting, Geological Society of America, May 19-21. Abstracts with Programs.* Reno, NV: Geological Society of America.

Dudley, A.L., R.R. Peters, J.H. Gauthier, M.L. Wilson, M.S. Tierney and E.A. Klavetter. 1985. *Total System Performance Code (TOSPAC).* SAND85-2675. Albuquerque, NM: Sandia National Laboratories.

Eglinton, T.W., and R.J. Dreicer. 1984. *Meteorological Design Parameters for the Candidate Site of a Radioactive-Waste Repository at Yucca Mountain, Nevada.* SAND84-0440/2. Albuquerque, NM: Sandia National Laboratories.

Erickson, J.R., and R.K. Waddell. 1985. *Identification and Characterization of Hydrologic Properties of Fractured Tuff Using Hydraulic and Tracer Tests--Test Well USW H-4, Yucca Mountain, Nye County, Nevada*. USGS Water-Resources Investigations Report 85-4066. Denver, CO: U.S. Geological Survey.

Eslinger, P.W., L.A. Doremus, D.W. Engel, T.B. Miley, M.T. Murphy, W.E. Nichols, M.D. White, D.W. Langford, and S.J. Ouderkirk. 1993. *Preliminary Total-System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain*. PNL-8444. Richland, WA: Pacific Northwest Laboratory.

Evans, J.R., and M. Smith. 1992. Teleseismic tomography of the Yucca Mountain Region: volcanism and tectonism. *Proceedings of the Third International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 2,372–2,380.

Fernandez, J.A., J.B. Case, C.A. Givens, and B.C. Carney. 1994. *A Strategy to Seal Exploratory Boreholes in Unsaturated Tuff*. SAND93-1184. Albuquerque, NM: Sandia National Laboratories.

Ferrill, D.A., S.R. Young, G.L. Stirewalt, A.D. Morris, and D.B. Henderson. 1994. Tectonic Processes in the central Basin and Range region. *NRC High-Level Radioactive Waste Research at CNWRA January-June 1994*. CNWRA 94-01S. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Flint, A.L., and S.W. Childs. 1987. Calculation of solar radiation in mountainous terrain. *Agricultural and Forest Meteorology* 40: 233–249.

Flint, A.L., and S.W. Childs. 1991. Use of the Priestley-Taylor evaporation equation for soil water limited conditions in a small forest clearcut. *Agricultural and Forest Meteorology* 56: 247–260.

Flint, A.L., and L.E. Flint. 1987. Estimation of cloudy sky radiation using air temperature and modeled clear sky radiation. *Agronomy Abstracts*: November 29–December 4.

Flint, A.L., L.E. Flint, and J.A. Hevesi. 1993. The Influence of long term climate change on net infiltration at Yucca Mountain, Nevada. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 152–159.

Flint, L.E., and A.L. Flint. 1990. *Preliminary Permeability and Water-Retention Data for Nonwelded and Bedded Tuff Samples, Yucca Mountain Area, Nye County, Nevada*. U.S. Geological Survey Open-File Report 90-569. Denver, CO: U.S. Geological Survey.

Flint, A.L., and L.E. Flint. 1994. Spatial distribution of potential near surface moisture flux at Yucca Mountain. *Proceedings of the Fifth Annual International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 2,352–2,358.

French, R. H. 1986. *Daily, Seasonal, and Annual Precipitation at the Nevada Test Site*. Las Vegas, NV: Desert Research Institute: Water Resources Center.

Frizzel, V.A., and J. Shulters. 1990. *Geologic Map of the Nevada Test Site, Southern Nevada. 1: 100,000.* USGS Miscellaneous Investigations Series Map I-2046. Washington, DC: U.S. Geological Survey.

Gauthier, J.A., and M.L. Wilson. 1994. Chapter 8: Infiltration and percolation rates. *Total System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993).* M.L. Wilson, ed. SAND93-2675. Albuquerque, NM: Sandia National Laboratories.

Gauthier, J.A. 1993. The most likely groundwater flux through the unsaturated tuff matrix at USW H-1. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management.* La Grange Park, IL: American Nuclear Society: 146–151.

Giorgi, F. G. Bates, and S. Nieman. 1992. Simulation of the arid climate of the southern Great Basin using a regional climate model. *Bulletin of American Meteorology Society* 73: 1,807–1,882.

Glancy, P.A. 1994. *Evidence of Prehistoric Flooding and the Potential for Future Extreme Flooding at Coyote Wash, Yucca Mountain, Nye County, NV.* USGS Open-File Report 92-458. Denver, CO: U.S. Geological Survey.

Harloe, E. 1993. *External Database Access Options Report.* Letter Report to NRC. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Hansen, E.M., F.K. Schwarz, and J.T. Reidel. 1977. *Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages.* Hydrometeorological Report No. 49. Silver Spring, MD: Office of Hydrology: National Weather Service.

Harmsen, S.C. 1994. *Preliminary Seismicity and Focal Mechanisms for the Southern Great Basin of Nevada and California: January 1992 Through September 1992.* USGS Open-File Report 93-369. Denver, CO: U.S. Geological Survey.

Hershfield, B.M. 1961. *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 years.* U.S. Weather Bureau Technical Paper No. 40. Washington DC: U.S. Department of Commerce.

Hevesi, J.A., A.L. Flint, and J.D. Istok. 1992. Precipitation estimation in mountainous terrain using multivariate geostatistics. Part II: isohyetal maps. *Journal of Applied Meteorology* 31: 677–688.

Hevesi, J.A., and A.L. Flint. 1993. The influence of seasonal climatic variability on shallow infiltration at Yucca Mountain. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management.* La Grange Park, IL: American Nuclear Society: 122–131.

Hevesi, Joseph. A, Dale S. Ambos, and Alan L. Flint. 1994. A preliminary characterization of the spatial variability of precipitation at Yucca Mountain, Nevada. *Proceedings of the Fifth International Conference on High-Level Radioactive Waste Management.* La Grange Park, IL: American Nuclear Society: 2,520–2,529.

Hill, B.E., G.L. Stirewalt, and C.B. Connor. 1994. Volcanism research. *NRC High-Level Radioactive Waste Research at CNWRA January-June 1994*. CNWRA 94-01S. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Imbrie, J., J.D. Hays, D.G. Martinson, A. McIntyre, A.C. Mix, J.J. Morley, N.G. Pisias, W.L. Press, and N.J. Shackleton. 1984. The orbital theory of pleistocene climate: Support from a revised chronology of the marine record. A. Berger, J. Imbrie, J. Hay, S. Gulka, B. Saltzman, eds. *Milankovitch and Climate Part 1*. Boston, MA: Reidel. 269–305.

Jarrell, M.D. 1991. *Technology to Seal Exploratory Boreholes*. Presentation to the Nuclear Waste Technical Review Board Panel on Structural Geology and Geoengineering. Albuquerque, NM: IT Corporation: 15.

Jennings, C.W. 1992. *A Preliminary Fault Map of California*. CDMG Open-File Report 92-03. Sacramento, CA: The Resources Agency: California Department of Conservation: Division of Mines and Geology.

Johnson, R.L. 1993. *Overall Review Strategy for the Nuclear Regulatory Commission's High-Level Waste Repository Program*. Washington, DC: Nuclear Regulatory Commission.

Karl, T.R. 1990. *United States Historical Climatology Network (HCN) Serial Temperature and Precipitation Data*. ORNL/CDIAC-30. Oak Ridge, TN: Carbon Dioxide Information Analysis Center: Oak Ridge National Laboratory.

Kerrisk, J.F. 1983. *Reaction-Path Calculations of Groundwater Chemistry and Mineral Formation at Rainier Mesa, Nevada*. LA-9912-MS. Los Alamos, NM: Los Alamos National Laboratory.

Kerrisk, J.F. 1987. *Groundwater Chemistry at Yucca Mountain, Nevada, and Vicinity*. LA-10929-MS. Los Alamos, NM: Los Alamos National Laboratory.

Klein, W. H. and H. J. Bloom. 1987. Specification of monthly precipitation over the United States from the surrounding 700 mb height field. *Monthly Weather Review* 115: 2,118–2,132.

Kuiper L.K. 1991. Water table rise due to magma intrusion beneath Yucca Mountain. Abstract. *EOS* 72:121.

Kume, J., and D.P. Hammermeister. 1991. *Geohydrologic Data from Drill-Bit Cuttings and Rotary Cores from Test Hole USW UZ-13, Yucca Mountain Area, Nye County, Nevada*. USGS Open-File Report 90-362. Denver, CO: U.S. Geological Survey.

Lahoud, R.G., D.H. Lobmeyer, and M.S. Whitfield. 1984. *Geohydrology of Volcanic Tuff Penetrated by Test Well UE-25b#1, Yucca Mountain, Nye County, Nevada*. USGS Water-Resources Investigations Report 84-4253. Denver, CO: U.S. Geological Survey.

Leary, K.D. 1990. *Analysis of Techniques for Estimating Potential Recharge and Shallow Unsaturated Zone Water Balance Near Yucca Mountain, Nevada*. M.S. Thesis. Reno, NV: University of Nevada, Reno.

Levy, S. 1991. Mineralogic alteration history and paleohydrology at Yucca Mountain, Nevada *Proceedings of the Second International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 477–485.

Long, A., and S.W. Childs. 1993. Rainfall and net infiltration probabilities for future climate conditions at Yucca Mountain. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 112–121.

Loscot, C.L., D.P. Hammermeister. 1992. *Geohydrologic Data from Test Holes UE-25 UZ#4 and UE-25 UZ#5, Yucca Mountain Area, Nye County, Nevada*. USGS Open-File Report 90-369. Denver, CO: U.S. Geological Survey.

Manaktala, H.K. 1993. *Characteristics of Spent Nuclear Fuel and Cladding Relevant to High-Level Waste Source Term*. CNWRA 93-006. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Marshall, B.D., Z.E. Peterman, and J.S. Stuckless. 1993. Strontium isotopic evidence for a higher water table at Yucca Mountain. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management:* La Grange Park, IL: American Nuclear Society: 1,948–1,952.

McKinley, P.W., M.P. Long, and L.V. Benson. 1991. *Chemical Analyses of Water for Selected Wells and Springs in the Yucca Mountain Area, Nevada and Southeastern California*. USGS Open-File Report 90-355. Denver, CO: U.S. Geological Survey.

McKinley, P.W., and T.A. Oliver. 1994. *Meteorological, Stream-Discharge, and Water-Quality Data for 1986 Through 1991 from Two Small Basins in Central Nevada*. USGS Open-File Report 93-651. Denver, CO: U.S. Geological Survey.

McMahon, J.A.. 1985. *Deserts*. Audobon Society Nature Series. New York, NY: Alfred Knopt.

Montazer, P., and W.E. Wilson. 1984. *Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada*. USGS Water-Resources Investigations Report 84-4345. Denver, CO: U.S. Geological Survey.

National Oceanic and Atmospheric Administration. 1960. *Generalized Estimates of Probable Maximum Precipitation for the United States West of the 105th Meridian for Areas to 400 Square Miles and Duration to 24 hours*. Technical Paper No. 38. Washington, DC: U.S. Weather Service.

National Oceanic and Atmospheric Administration. 1993. Monthly climatological data reports. Wahington, DC: 1,978-1,992.

National Research Council. 1992. *Ground Water at Yucca Mountain: How High Can It Rise? Final Report of the Panel on Coupled Hydrologic Tectonic/Hydrothermal Systems at Yucca Mountain*. Washington, DC: National Academy Press.

Nichols, W.D. 1986. *Geohydrology of the Unsaturated Zone at the Burial Site for Low-Level Radioactive Waste near Beatty, Nye County, Nevada.* USGS Open-File Report 85-198. Denver, CO: U.S. Geological Survey.

O'Farrell, T.P., and L.A. Emery. 1976. *Ecology of the Nevada Test Site: A Narrative Summary and Annotated Bibliography.* NVO-167. Boulder City, NV: Desert Research Institute: Applied Ecology and Physiology Center.

O'Neal, W.C., D.W. Gregg, J.N. Hockman, E.W. Russell, and W. Stein. 1984. *Preclosure Analysis of Conceptual Waste Package Designs for a Nuclear Waste Repository in Tuff.* UCRL-53595. Livermore, CA: Lawrence Livermore National Laboratory.

Peters, R.R., E.A. Klavetter, I.J. Hall, S.C. Blair, P.R. Heller, and G.W. Gee. 1984. *Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials from Yucca Mountain, Nye County, Nevada.* SAND84-1471. Albuquerque, NM: Sandia National Laboratories.

Pruess, K., and Y. Tsang. 1993. Modeling of strongly heat-driven flow processes at a potential high-level nuclear waste repository at Yucca Mountain, Nevada. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management.* La Grange Park, IL: American Nuclear Society: 568–575.

Quinlan, F.T., T.R. Karl, and C.N. Williams Jr. 1987. *United States Historical Climatology network (HCN) Serial Temperature and Precipitation Data.* NDP-019. Oak Ridge, TN: Carbon Dioxide Information Analysis Center: Oak Ridge National Laboratory.

Quiring, R.F. 1968. *Climatological Data, Nevada Test Site and Nuclear Rocket Development Station.* ESSA Technical Memorandum ARL-7. Las Vegas, NV: Environmental Sciences Service Administration: U.S. Department of Commerce.

Quiring, R.F. 1983. *Precipitation Climatology of the Nevada Test Site.* WSNSO 351-99. Las Vegas, NV: National Weather Service, U.S. Department of Commerce.

Robinson, T.W. 1957. The phreatophyte problem. *Symposium on Phreatophytes.* Pacific Southwest Regional Meeting. Sacramento, CA: American Geophysical Union.

Robison, J.H. 1984. *Ground-Water Level Data and Preliminary Potentiometric-Surface Maps. Yucca Mountain and Vicinity, Nye County, Nevada.* USGS Water-Resources Investigations Report, 84-4197. Denver, CO: U.S. Geological Survey.

Robison, J.H., D.M. Stephens, R.R. Luckey, and D.A. Baldwin. 1988. *Water Levels in Periodically Measured Wells in the Yucca Mountain Area, Nevada, 1981-87.* USGS Open-File Report 88-468. Denver, CO: U.S. Geological Survey.

Rogers, A.M., S.C. Harmsen, and M.E. Meremonte. 1987. *Evaluation of the Seismicity of the Southern Great Basin and its Relationship to the Tectonic Framework of the Region.* USGS Open-File Report 87-408. Denver, Colorado. U.S. Geological Survey.

Rush, F.E., W. Thordarson, and L. Bruckheimer. 1983. *Geohydrologic and Drill-Hole Data for Test Well USW H-1, Adjacent to Nevada Test Site, Nye County, Nevada*. USGS Open-File Report 83-141. Denver, CO: U.S. Geological Survey.

Rush, F.E. 1971. *Regional Ground-Water Systems in the Nevada Test Site Area, Nye, Lincoln, and Clark Counties, Nevada*. USGS Water Resources-Reconnaissance Series Report 54. Denver, CO: U.S. Geological Survey.

Rutherford, B.M., I.J. Hall, R.R. Peters, R.G Easterling, and E.A. Klavetter. 1992. *Statistical Analysis of Hydrologic Data for Yucca Mountain*. SAND87-2380. Albuquerque, NM: Sandia National Laboratories.

Savard, C.S. 1994. Groundwater recharge in Fortymile Wash near Yucca Mountain, Nevada, 1992-93. *Proceedings of the Fifth Annual International Conference on High-Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 2,805–1,813.

Schenker, A.R., D.C. Guerin, and T.H. Robey. 1994. *Stratigraphy and Hydrogeologic Properties Development for the Total-System Performance Assessment 1993*. SAND94-0244. Albuquerque, NM: Sandia National Laboratories.

Schwartz, B.M. 1990. *SNL Yucca Mountain Project Data Report: Density and Porosity Data for Tuffs from the Unsaturated Zone at Yucca Mountain Nevada*. SAND88-0811. Albuquerque, NM: Sandia National Laboratories.

Scott, R.B., and J. Bonk. 1984. *Preliminary Geologic Map (1:12,000 scale) of Yucca Mountain, Nye County, Nevada, with Geologic Cross Sections*. USGS Open-File Report 84-494. Denver, CO: U.S. Geological Survey.

Smith, E.I., D.L. Feuerback, T.R. Naumann, and J.E. Faulds. 1990. The area of most recent volcanism near Yucca Mountain Nevada. Implications for volcanic risk assessment. *Proceedings of the First International Conference on High Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 81–90.

Spaulding, W.G. 1983. *Vegetation and Climates of the Last 45,000 years in the Vicinity of the Nevada Test Site, South-Central Nevada*. USGS Open-File Report 83-535. Denver, CO: U.S. Geological Survey.

Spaulding, W.G. 1985. *Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South-Central Nevada*. USGS Professional Paper 1329. Washington, DC: U.S. Geological Survey.

Squires, R.R., and R.L. Young. 1984. *Flood Potential of Forty Mile Wash and its Principal Southwestern Tributaries, Nevada Test Site, Southern Nevada*. USGS Water-Resources Investigations Report 83-4001. Denver, CO: U.S. Geological Survey.

Stirewalt, G., B. Henderson, and S. Young. 1994. *A Preliminary Three-Dimensional Geological Framework Model for Yucca Mountain, Nevada: Report to Accompany Model Transfer to the*

Nuclear Regulatory Commission. CNWRA 94-023. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Thordarson, W. 1983. *Geohydrologic Data and Test Results from Well J-13, Nevada Test Site, Nye County, Nevada*. USGS Open-File Report 83-4171. Denver, CO: U.S. Geological Survey.

Trapp, J. 1989. *Probability of Volcanism at Yucca Mountain*. Memorandum. Washington, DC: Nuclear Regulatory Commission.

U.S. Department of Agriculture. 1974. Evaporation and transpiration. *National Handbook of Recommended Methods for Water Data Acquisition*. Washington DC: U.S. Department of Agriculture.

U.S. Department of Commerce. 1986. *Monthly and Annual Wind Distribution by Pasquill Stability Classes. Star Program, 6 classes*. Job No. 01775. Asheville, NC: National Climatic Data Center:

U.S. Department of Energy. 1988. *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada*. DOE/RW-0199. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1990a. *Yucca Mountain Project Reference Information Base*. YMP/CC-0002 (Version 04.002). Las Vegas, NV: U.S. Department of Energy.

U.S. Department of Energy. 1990b. *Evaluating the Location and Recency of Faulting Near Prospective Surface Facilities*. DOE Study Plan No. 8.3.1.17.4.2. Los Alamos, NM: Los Alamos National Laboratory.

U.S. Department of Energy. 1990c. *Characterization of Volcanic Features*. DOE Study Plan No. 8.3.1.8.5.1. Los Alamos, NM: Los Alamos National Laboratory.

U.S. Department of Energy. 1990d. *Characterization of Quaternary Regional Hydrology*. DOE Study Plan No. 8.3.1.5.2.1. Denver, CO: U.S. Geological Survey.

U.S. Department of Energy. 1991a. *Quaternary Faulting Within the Site Area*. DOE Study Plan No. 8.3.1.17.4.6. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1991b. *Characterization of the Meteorology for Regional Hydrology and Meteorological Monitoring*. DOE Study Plan No. 8.3.1.2.1.1. Washington DC: U.S. Department of Energy.

U.S. Department of Energy. 1991c. *Geodetic Leveling*. DOE Study Plan No. 8.3.1.17.4.10. Washington DC: U.S. Department of Energy.

U.S. Department of Energy. 1991d. *Characterization of Flood Potential of the Yucca Mountain Site*. DOE Study Plan No. 8.3.1.16.1.1. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1991e. *Characterization of Run-Off and Streamflow*. DOE Study Plan No. 8.3.1.2.1.2. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1991f. *Characterization of Unsaturated Zone Infiltration*. DOE Study Plan No. 8.3.1.2.2.1. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1991g. *Characterization of the Regional Groundwater Flow System*. DOE Study Plan No. 8.3.1.2.1.3. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1991h. *Historical and Current Seismicity*. DOE Study Plan No. 8.3.1.17.4.1. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1992a. *Studies to Provide Soil and Rock Properties of Potential Locations of Surface and Subsurface Facilities*. DOE Study Plan No. 8.3.1.14.2. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1992b. *Regional Hydrologic Synthesis and Modeling*. DOE Study Plan No. 8.3.1.2.1.4. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1992c. *Relevant Earthquake Sources*. DOE Study Plan No. 8.3.1.1.7.3.1. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993a. *Tectonic Models and Synthesis*. DOE Study Plan No. 8.3.1.17.4.12. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993b. *Characterization of Structural Features Within the Site Area*. DOE Study Plan No. 8.3.1.4.2.2 R2 Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993c. *Systematic Acquisition of Site Specific Subsurface Information*. DOE Study Plan No. 8.3.1.4.3.1. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993d. *Quaternary Faulting Within 100 km of the Site Including the Walker Lane*. DOE Study Plan No. 8.3.1.17.4.3. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993e. *Quaternary Faulting Proximal to the Site Within NE Trending Fault Zones*. DOE Study Plan No. 8.3.1.17.4.4. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993f. *Meteorological Data Collection at the Yucca Mountain Site*. DOE Study Plan No. 8.3.1.12.2.1. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993g. *Site Unsaturated Zone Synthesis and Modeling*. DOE Study Plan No. 8.3.1.2.2.9. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993h. *Characterization of the Yucca Mountain Unsaturated Zone in the ESF*. DOE Study Plan No. 8.3.1.2.2.4 R1 Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993i. *Fluid Flow in Unsaturated Fractured Rock*. DOE Study Plan No. 8.3.1.2.2.8. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993j. *Water Movement Test*. DOE Study Plan No. 8.3.1.2.2.2 R1 Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993k. *Characterization of Quaternary Regional Hydrology*. DOE Study Plan No. 8.3.1.5.2.1.1 R2 Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993l. *Characterization of Future Regional Hydrology*. DOE Study Plan No. 8.3.1.5.2.2. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993m. *Characterization of Modern Regional Climate*. DOE Study Plan No. 8.3.1.5.1.1. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993n. *Current and Historic Seismicity*. DOE Study Plan No. 8.3.1.17.4.1. R1 Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993o. *Effects of Local Site Geology on Surface and Subsurface Ground Motion*. DOE Study Plan No. 8.3.1.17.3.4. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993p. *Ground Motion at the Site from Controlling Seismic Events*. DOE Study Plan No. 8.3.1.17.3.5. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1993q. *Characterization of the Unsaturated-Zone Infiltration*. DOE Study Plan No. 8.3.1.2.2.1. Denver, CO: U.S. Geological Survey.

Wallace, A., and E.M. Romney. 1972. *Radioecology and Ecophysiology of Desert Plants at the Nevada Test Site*. Riverside, CA: University of California.

Whelan, J.F., D.T. Vaniman, J.S. Stuckless, and R.J. Moscati. 1994. Paleoclimatic and paleohydrologic records from secondary calcite: Yucca Mountain, Nevada. *Proceedings From the Fifth International Conference on High Level Radioactive Waste Management*. American Nuclear Society: La Grange Park, IL: 2,738–2,745.

White, A.F., H.C. Claassen, and L.V. Benson. 1980. *The Effect of Dissolution of Volcanic Glass on the Water Chemistry in a Tuffaceous Aquifer, Rainier Mesa, Nevada*. USGS-WSP-1535-Q. Denver, CO: U.S. Geological Survey.

Whitfield, M.S., E.P. Eshom, W. Thordarson, and D.H. Schaefer. 1985. *Geohydrology of Rocks Penetrated by Test Well USW H-4, Yucca Mountain, Nye County, Nevada*. USGS Water-Resources Investigations Report 85-4030. Denver, CO: U.S. Geological Survey.

Whitfield, M.S., W. Thordarson, and D.P. Hammermeister. 1990. *Drilling and Geohydrologic Data for Test Hole USW UZ-1, Yucca Mountain, Nye County, Nevada*. USGS Open-File Report 90-354. Denver, CO: U.S. Geological Survey.

Whitfield, M.S., C.M. Cope, and C.L. Loscot. 1993. *Borehole and Geohydrologic Data for Test Hole USW UZ-6, Yucca Mountain Area, Nye County, Nevada.* USGS Open-File Report 92-28. Denver, CO: U.S. Geological Survey.

Wilson, M.L., . 1994. *Total System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993).* SAND93-2675. Albuquerque, NM: Sandia National Laboratories.

Winograd, I.J., and W. Thordarson. 1975. *Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site.* USGS Professional Paper 712-C. Reston, VA: U.S. Geological Survey.

Winograd, I.J., B.J. Szabo, T.B. Coplen, and A.C. Riggs. 1988. A 250,000-year climatic record from Great Basin vein calcite: Implications for Milankovitch theory. *Science* 258: 255–260.

Winograd, I. J., T.B. Coplen, J.M. Landwehr, A.C. Riggs, K.R. Ludwig, B.J. Szabo, P.T. Kolesar, and K.M. Revesz. 1992. Continuous 500,000-year climate record from vein calcite in Devils Hole, Nevada. *Science* 258: 255–260.

Wittmeyer, G.W., W.M. Murphy, and D.A. Ferrill. 1994. Regional hydrogeological processes of the Death Valley region. *NRC High-Level Radioactive waste research at the CNWRA January-June 1994.* B. Sagar, ed. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Yang, I.C., A.K. Turner, T.M. Sayre, and P. Montazer. 1988. *Triaxial-Compression Extraction of Pore Water from Unsaturated Tuff, Yucca Mountain, Nevada.* Water-Resources Investigations Report USGS-WRI-88-4189. Denver, CO: U.S. Geological Survey.

Yang, I.C., C.A. Peters, and D.C. Thorstenson. 1993. Carbon isotopic data from test hole USW UZ-1, Yucca Mountain, Nevada. *Proceedings of the Fourth International Conference on High Level Radioactive Waste Management:* . La Grange Park, IL: American Nuclear Society: 401–406.

Young, S., G. Stirewalt, and A. Morris. 1992. *Geometric Models of Faulting at Yucca Mountain.* CNWRA 92-008. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

APPENDIX A

ABBREVIATIONS

LIST OF ABBREVIATIONS

ABC	Adrian Brown Consultants
ACRI	Analytic and Computational Research Incorporated
ATDTS	Automated Technical Data Tracking System
CDM	Compliance Determination Method
CDMG	California Department of Conservation, Division of Mines and Geology
CDS	Compliance Determination Strategy
CNWRA	Center for Nuclear Waste Regulatory Analyses
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DRI	Desert Research Institute
EPA	U.S. Environmental Protection Agency
EMSO	El Niño Southern Oscillation
FAC	Favorable Condition
FCRG	Form and Content Regulatory Guide
GIS	Geographic Information System
HLW	High-Level Radioactive Waste
KTU	Key Technical Uncertainty
LA	License Application
LANL	Los Alamos National Laboratory
LARP	License Application Review Plan
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory
NaRC	National Research Council

LIST OF ABBREVIATIONS (CONT'D)

NAS	National Academy of Sciences
NCAR	National Center for Atmospheric Research
NEIC POE	National Earthquake Information Center, Preliminary Determination of Epicenters
NOAA	National Oceanographic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NWPA	National Waste Policy Act
NWS	National Weather Service
ORNL	Oak Ridge National Laboratory
PAC	Potentially Adverse Condition
PNL	Pacific Northwest Laboratory
PPA	Proposed Program Approach
QA	Quality Assurance
SAR	Safety Analysis Report
SER	Safety Evaluation Report
SNL	Sandia National Laboratories
TDB	Technical Data Base
TOP	Technical Operating Procedure
TSPA	Total System Performance Assessment
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
YM	Yucca Mountain
YMPO	Yucca Mountain Project Office