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Technical Basis Document No. 11: Saturated Zone Flow and Transport

Revision 2

Prepared for:
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Repository Development
P.O. Box 364629
North Las Vegas, Nevada 89036-8629

Prepared by:
Bechtel SAIC Company, LLC
1180 Town Center Drive
Las Vegas, Nevada 89144

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ACRONYMS AND ABBREVIATIONS

AIN	additional information needed
ATC	Alluvial Testing Complex
CML	carboxylate-modified latex
DOE	U.S. Department of Energy
DVRFS	Death Valley regional flow system
EWDP	Early Warning Drilling Program
GEN	General Agreement
GFM	geologic framework model
HFM	hydrogeologic framework model
KTI	Key Technical Issue
NRC	U.S. Nuclear Regulatory Commission
RT	Radionuclide Transport
SSFM	site-scale saturated zone flow model
TSPAI	Total System Performance Assessment and Integration
USFIC	Unsaturated and Saturated Flow Under Isothermal Conditions
USGS	U.S. Geological Survey

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1. INTRODUCTION

This technical basis document provides a summary of the conceptual understanding of the flow of groundwater and the transport of radionuclides that may be potentially released to the saturated zone beneath and downgradient from Yucca Mountain. This document is one in a series of technical basis documents prepared for each component of the Yucca Mountain repository system important for predicting the likely postclosure performance of the repository. The relationship of saturated zone flow and transport to the other components is illustrated in Figure 1-1.

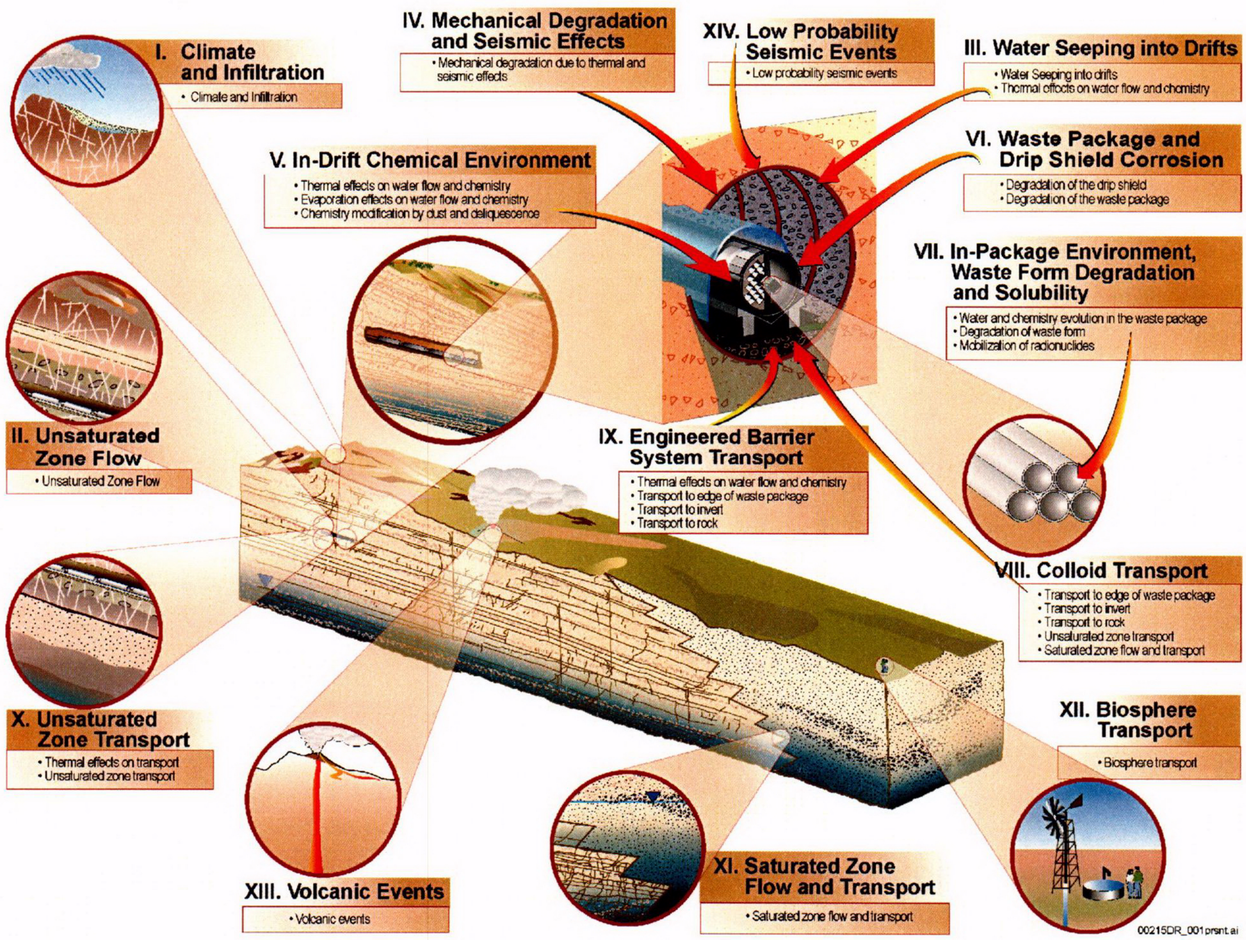


Figure 1-1. Components of the Postclosure Technical Basis for the License Application

This document and the associated references form an outline of the ongoing development of the postclosure safety analysis that will comprise the License Application. This information is also used to respond to open Key Technical Issue (KTI) agreements made between the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE). Placing the DOE responses to individual KTI agreements and NRC additional information needed (AIN) requests within the context of the overall saturated zone flow and transport process, as they relate to postclosure safety analyses, allows for a more direct discussion of the relevance of the agreement.

Appendices to this document are designed to allow for a transparent and direct response to each KTI agreement and AIN requests. Each appendix addresses one or more of the agreements. If agreements apply to similar aspects of the saturated zone subsystem, they were grouped in a single appendix. In some cases, appendices provide detailed discussions of data, analyses, or information related to the further conceptual understanding presented in this technical basis document. In these cases, the appendices are referenced from the appropriate section of the technical basis document. In other cases, the appendices provide information that is related to the technical basis document information but at a level of detail that relates more to the uncertainty in a particular data set or feature, event, or process that is less relevant to the overall technical basis. In these cases, the appendices reference the relevant section of the technical basis document to put the particular KTI agreement into context.

This technical basis document and appendices are responsive to agreements made between the DOE and the NRC during Technical Exchange and Management Meetings on Radionuclide Transport (RT) (Reamer and Williams 2000a), Total System Performance Assessment and Integration (TSPAI) (Reamer 2001), and Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) (Reamer and Williams 2000b), and to AIN requests from the NRC to the DOE dated August 16, 2002 (Schlueter 2002a), August 30, 2002 (Schlueter 2002b), December 19, 2002 (Schlueter 2002c), and February 5, 2003 (Schlueter 2003).

Most of the agreements were based on questions that NRC staff developed from their review of the site recommendation support documents and DOE presentations at the technical exchanges. In general, the agreements required the DOE to present additional information, conduct further testing, perform sensitivity or validation exercises for models, or provide justification for assumptions used in the *Yucca Mountain Site Suitability Evaluation* (DOE 2002). After those technical exchanges, the DOE has conducted the additional analysis and testing necessary to meet the agreements. The appendices present the additional information that forms the technical basis for addressing the intent of the KTI agreements.

This technical basis document provides a summary-level synthesis of many relevant aspects of the saturated zone flow and transport modeling that is being completed to support development of the Yucca Mountain License Application. This includes a summary and synthesis of the detailed technical information presented in the analysis model reports and other technical products that are used as the basis for the description of the saturated zone barrier and the incorporation of this barrier into the postclosure performance assessment. Several analyses, model reports, and other technical products support this summary:

- *A Three-Dimensional Numerical Model of Predevelopment Conditions in the Death Valley Regional Ground-Water Flow System, Nevada and California* (D'Agnese et al. 2002)
- *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (USGS 2001a)
- *Site-Scale Saturated Zone Transport* (BSC 2003a)
- *Saturated Zone Colloid Transport* (BSC 2003b)

- *Site-Scale Saturated Zone Flow Model* (BSC 2003c)
- *SZ Flow and Transport Abstraction* (BSC 2003d)
- *Saturated Zone In-Situ Testing* (BSC 2003e).
- *Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain* (BSC 2003f)
- *Features, Events, and Processes in SZ Flow and Transport* (BSC 2003g).

The basic approach of this document is to provide a comprehensive summary of the saturated zone flow and transport understanding, the details of which are presented in the supporting analyses, reports, and related products.

1.1 OBJECTIVE AND SCOPE

The objectives of this technical basis document are to:

- Describe the processes relevant to the performance of the saturated zone flow and transport component of the postclosure performance assessment
- Present data, analyses, and models used to project the behavior of the saturated zone flow and transport processes
- Summarize the development of the site-scale saturated zone flow and transport models and key subprocess models that are used to analyze data from the saturated zone
- Summarize the results of the flow and transport models used in the assessment of postclosure performance at Yucca Mountain.

The purpose of the site-scale saturated zone flow and transport model is to describe the spatial and temporal distribution of groundwater as it moves from the water table below the repository, through the saturated zone, and to the point of uptake by a potential downgradient receptor. The saturated zone processes that control the movement of groundwater and the movement of dissolved radionuclides and colloidal particles that might be present, and the processes that reduce radionuclide concentrations in the saturated zone, are described in this document.

The evaluation of the saturated zone in the Yucca Mountain area considers the possibility of radionuclide transport from their introduction at the water table beneath the repository to a hypothetical well located at the compliance boundary downgradient from the site. The likely pathway for radionuclides potentially released from the repository to reach the accessible environment is through groundwater aquifers below the repository. These aquifers, collectively referred to as the saturated zone, delay the transport of radionuclides released to the saturated zone and reduce the concentration of radionuclides before they reach the accessible environment.

A simplified conceptualization of the saturated zone flow and transport for Yucca Mountain and its relationship to transport in the unsaturated zone and biosphere is provided in Figure 1-2. Radionuclides released into seepage water contacting breached waste packages in the repository would migrate downward through the unsaturated zone for approximately 210 to 390 m to the water table. At that point, radionuclides would enter the saturated zone and migrate downgradient within the tuff and alluvial aquifers to the accessible environment. At a distance of 15 to 22 km along the flow path from the repository, groundwater flow enters the alluvial aquifer and remains in the alluvium for an additional 1 to 10 km until it is subject to uptake into the accessible environment.

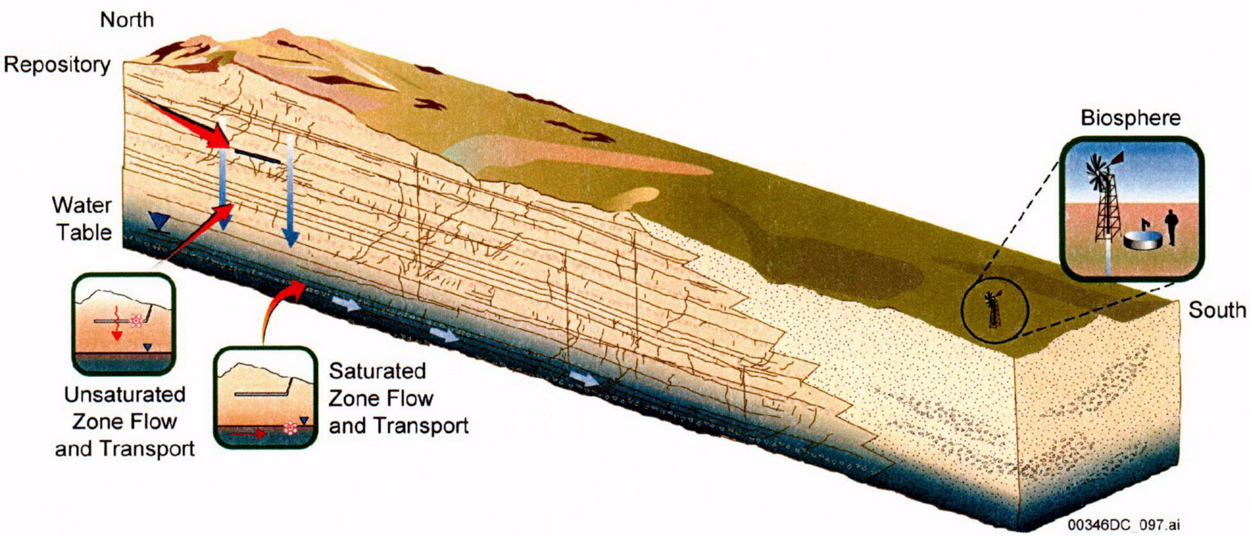


Figure 1-2. Conceptual Representation of Radionuclide Transport Pathways from the Repository to the Biosphere

1.2 DESCRIPTION OF PROCESSES AFFECTING THE PERFORMANCE OF THE SATURATED ZONE

The saturated zone is a barrier to the migration of dissolved and colloidal radionuclides that may be released from the repository. This barrier delays the transport of radionuclides and increases the time until they are potentially withdrawn from a well used by a hypothetical person (the reasonably maximally exposed individual).

Radionuclides that enter the saturated zone are expected to do so over a spatial and temporal scale that depends on the degradation modes and degradation rates of the engineered barriers and the transport processes from the degraded engineered barriers, through the unsaturated zone, to the saturated zone. For example, it is possible that the engineered barriers will fail over a broad temporal scale (ranging from thousands to hundreds of thousands of years) due to natural degradation processes, or they may fail over a relatively short time due to a low probability disruptive event (e.g., a large seismic or volcanic event). The spatial scale over which radionuclides enter the saturated zone may be confined to an area on the order of 100 m^2 for each degraded waste package (for cases where the flow is predominantly vertical through the unsaturated zone), concentrated at locations where most of the unsaturated groundwater flow intersects the water table, or dispersed over a large fraction of the repository footprint (i.e., several square kilometers). The timing and spatial extent of radionuclides that enter the saturated zone and reach the accessible environment are considered in the performance assessment using a range of spatial locations, a range of transport times within the saturated zone, and a range of times when radionuclides are predicted to reach the saturated zone, as described in the *SZ Flow and Transport Abstraction* (BSC 2003d).

The processes that affect the performance of the saturated zone barrier include both groundwater flow and radionuclide transport processes. The groundwater flow processes determine the rate of water movement within the saturated zone and the flow paths through which the water is likely to travel. These flow paths extend from where the radionuclides may possibly enter the saturated zone to where they exit at the point of compliance. These flow paths define the different geologic materials through which potentially released radionuclides are likely to be transported.

Radionuclide transport processes include those that determine the advective velocity of dissolved radionuclides within the saturated fractures or pores of the geologic media and processes that relate to interactions between the dissolved or colloidal radionuclides and the rock or alluvium materials with which they come in contact. Advective transport is determined by the rate of groundwater flow and the effective porosity of the media through which the flow occurs. Lower effective porosities yield higher groundwater velocities and shorter transport times. Dispersive processes are affected by small scale velocity heterogeneity that allows some dissolved constituents to travel faster or slower than the average advective transport time. Dispersive processes also spread the radionuclide mass concentration, although the reduced concentration is not important for postclosure performance because of the mixing that occurs when the radionuclide mass flux is mixed with the annual water demand of 3.7 million m^3 (3,000 acre-feet).

Dissolved radionuclides diffuse from fractures in the volcanic tuff (in which they are advectively transported) into the matrix, which has little advective flux and tends to slow the transport time of these species. The effectiveness of this process depends on the diffusive properties of the matrix and the degree of spacing between the flowing fracture zones. Larger diffusion coefficients or smaller spacings between flowing fracture zones result in slower transport times within the fractured rock.

Many radionuclides potentially important to repository performance are sorbed within the matrix of the rock mass. Although these radionuclides may be sorbed on fracture surfaces, this retardation mechanism has not been considered in the performance assessment. The degree of sorption depends on the individual radionuclide. Some radionuclides (e.g., technetium, iodine and carbon) are not sorbed, and are transported considering only advection, dispersion, and matrix diffusion processes. Other radionuclides (e.g., neptunium, uranium, and plutonium) are sorbed in the matrix or pores of the fractured tuffs and alluvium. The stronger the sorption, the longer the radionuclide transport time compared with advective-dispersive transport times.

These saturated zone flow and transport processes are represented by conceptual and numerical models to predict the expected behavior of the saturated zone barrier as it relates to performance of the Yucca Mountain repository. These include regional and site-scale models of groundwater flow and models of radionuclide transport. The bases of these models are derived from site-specific in situ observations, field tests, and laboratory tests to determine relevant parameter values. This technical basis document presents a summary of the bases for the models and parameters, plus a discussion of the uncertainty associated with the models, the parameters, and the predicted results (i.e., radionuclide transport times) relevant to postclosure performance.

1.3 SUMMARY OF CURRENT UNDERSTANDING

An understanding of saturated zone flow and transport in the vicinity of Yucca Mountain has been gained through the collection of regional and site data and through the incorporation of these data into models that describe processes affecting the behavior of the saturated zone barrier. Hydrogeologic data have been collected from boreholes that penetrate the saturated zone and from nonintrusive field investigations (i.e., geophysical surveys). These data were used to develop a scientific understanding of the subsurface hydrogeology and to assemble the database necessary to evaluate the expected performance characteristics of the saturated zone.

In general, the rate and direction of groundwater flow within the saturated zone is controlled by the spatial configuration of the potentiometric surface, plus the hydrologic properties and characteristics of the materials that constitute the saturated zone. Based on the potentiometric surface in the Yucca Mountain area, groundwater within the saturated zone beneath the repository is inferred to move from upland areas of recharge (located north of Yucca Mountain) towards areas of natural discharge (springs and playas south of Yucca Mountain). This flow direction is supported by hydrochemistry and isotopic data.

Groundwater flow in the saturated zone below and directly downgradient from the repository occurs in fractured, porous volcanic tuffs relatively close to the water table and in fractured carbonate rocks of Paleozoic age (limestones and dolomites) at much greater depths. At distances of about 15 to 18 km downgradient from the repository, where the volcanic rocks thin out beneath valley fill materials, the water table transitions from volcanic rocks to valley-fill (alluvial) material.

The most likely pathway for radionuclides to reach the accessible environment is through the uppermost groundwater aquifers below the repository. These aquifers (i.e., the saturated zone) delay the transport of radionuclides and reduce the radionuclide concentration before they reach the accessible environment. Delay in the release of radionuclides to the accessible environment allows radioactive decay to further diminish the mass of radionuclides that are ultimately released. Dilution of radionuclide concentrations in the groundwater used by the potential receptor occurs during transport and in the process of extracting more groundwater from wells than water containing radionuclides released from the repository. The key processes that affect the performance of the saturated zone barrier are summarized in the following text.

To determine the characteristics of the saturated zone, flow and transport processes need to be considered. Pertinent data for characterizing groundwater flow in the saturated zone includes measurements of water levels in boreholes and wells (which define the configuration of the water table and potentiometric surface) and hydraulic testing to determine hydraulic properties (e.g., hydraulic conductivity, permeability, and storage coefficient) of the rock and alluvial materials.

Data on hydraulic properties have been obtained from more than 150 hydraulic tests conducted in boreholes and wells in the Yucca Mountain area. These hydraulic tests include constant-discharge pumping tests, slug injection (falling head) tests, pressure injection tests, and fluid logging techniques (e.g., temperature measurement and tracer injection surveys). Multiple-well pumping and tracer tests have been conducted in the three C-Wells, a complex of boreholes located about 3 km east of the repository. Multiple-well hydraulic tests and single-well hydraulic and tracer tests have been conducted in cooperation with Nye County at the Alluvial Testing Complex, a complex of wells located near U.S. Highway 95.

Hydrochemical data (e.g., chloride and sulfate concentrations) and isotopic data (e.g., $^{234}U/^{238}U$ ratios, and strontium, oxygen, deuterium, and carbon isotope ratios) also have been collected from a number of boreholes and wells. These data were used to independently define likely groundwater flow paths from the repository area.

Processes important to the transport of radionuclides in the saturated zone include advection, sorption, diffusion (especially matrix diffusion), hydrodynamic dispersion, decay and ingrowth, and colloid transport. These characteristics have been evaluated through a range of in situ tests (such as at the C-Wells and Alluvial Testing complexes) and laboratory tests. In situ tests generally are used to evaluate properties such as effective porosity and longitudinal dispersivity, while laboratory tests are used to evaluate sorption characteristics. Sorption coefficients (K_ds) have been measured in the laboratory for a number of important radionuclides based on crushed-rock and alluvium samples using batch and column tests that used borehole core samples from selected saturated zone rock units at Yucca Mountain. Estimates of K_ds have been developed for various radionuclides (e.g., americium, thorium, uranium, protactinium, neptunium, and plutonium).

Estimates of colloid filtration in saturated, fractured volcanic rocks have been obtained from tracer tests conducted at the C-Wells complex using polystyrene microspheres as surrogate colloids. Physical data applicable to the attachment, detachment, and transport of radionuclides on natural colloidal substrates (e.g., silica and clay minerals) have been obtained for selected radionuclides (e.g., ^{239}Pu and ^{243}Am) through laboratory experiments and testing.

Analyses conducted using the saturated zone transport model indicate that the saturated zone is a barrier to the transport of radionuclides released from the repository to the accessible environment within the 10,000-year period of regulatory concern. The saturated zone is expected to delay the transport of sorbing radionuclides and radionuclides associated with colloids for many thousands of years, even under wetter climatic conditions in the future. Nonsorbing radionuclides are expected to be delayed for hundreds of years during transport in the saturated zone.

1.4 ORGANIZATION OF THIS REPORT

The report is organized as:

Section 1. Introduction–Objectives and scope of this document and a discussion of the saturated zone as a barrier.

Section 2. Saturated Zone Flow–Descriptions of regional and site-scale field and laboratory testing, data collection activities, and modeling of groundwater flow processes.

Section 3. Saturated Zone Radionuclide Transport–Site-scale field and laboratory testing, data collection activities, and modeling of radionuclide transport processes.

Section 4. Summary–Results of the saturated zone flow and transport processes as they relate to postclosure performance projections of the repository.

Section 5. References–Sources of information used in this document.

Appendices–Thirteen appendices (Table 1-1) address specific KTI agreement items and AIN requests.

Table 1-1. List of Appendices and the KTI Agreements that are Addressed

Appendix	Appendix Title	Key Technical Issues Addressed
A	The Hydrogeologic Framework Model/Geologic Framework Model Interface	USFIC 5.10
B	Hydrostratigraphic Cross Sections	RT 2.09 AIN-1 AND USFIC 5.05 AIN-1
C	Potentiometric Surface and Vertical Gradients	USFIC 5.08 AIN-1
D	Regional Model and Confidence Building	USFIC 5.02, USFIC 5.12, AND USFIC 5.11 AIN-1
E	Horizontal Anisotropy	USFIC 5.01
F	^{14}C Residence Time	USFIC 5.06
G	Uncertainty in Flow Path Lengths in Tuff and Alluvium	RT 2.08, RT 3.08, and USFIC 5.04
H	Transport Properties	RT 1.05, RT 2.01, RT 2.10, GEN 1.01 (#28 and #34), AND RT 2.03 AIN-1
I	Transport—Spatial Variability of Parameters	RT 2.02, TSPAI 3.32 and TSPAI 4.02.
J	Determination of Whether Kinetic Effects Should be Included in the Transport Model	RT 1.04.
K	Transport—K_ds in Alluvium	RT 2.06, RT 2.07, and GEN 1.01 (#41 and #102)
L	Transport—Temporal Changes in Hydrochemistry	TSPAI 3.31
M	Microspheres as Analogs	RT 3.08 AIN-1 and GEN 1.01 (#43 and #45)

1.5 NOTE REGARDING THE STATUS OF SUPPORTING TECHNICAL INFORMATION

This document was prepared using the most current information available. This technical basis document and the appendices provide KTI agreement responses (Table 1-1) that were prepared using preliminary or draft information reflecting the status of the Yucca Mountain Project scientific and design bases at the time of submittal. In some cases, this involved using draft analysis, model reports, and other references, the contents of which may change with time. Information that changes through revisions of the reports and references will be reflected in the License Application as the approved analyses of record at the time of License Application submittal. Consequently, this technical basis document and the KTI agreement appendices will not routinely be updated to reflect changes in the supporting references prior to submittal of the License Application.

2. SATURATED ZONE GROUNDWATER FLOW

2.1 INTRODUCTION

The following sections summarize the understanding of saturated zone flow processes, models, and parameters. This understanding is important to describing the likely groundwater flow paths and flow rates, as well as the geologic units through which groundwater is likely to flow in the vicinity of Yucca Mountain. This summary includes discussions of the regional and site-scale geologic setting, hydrogeologic setting, hydrogeochemistry, and groundwater flow modeling.

The hydrogeologic setting in the Death Valley region in general, and in the vicinity of Yucca Mountain in particular, has been the focus of data collection, interpretation, and analysis over the last several decades. This focus has, in part, been due to Federal government interest in understanding the groundwater flow system at the Nevada Test Site and in the region around Death Valley National Park, as well as State of Nevada and Nye County interest in understanding the available groundwater resources in the area. Early work by Maxey and Eakin (1950) provided a quantitative basis for estimating groundwater recharge as a function of precipitation in the arid southwest, and Winograd and Thordarson (1975) established the likely groundwater flow paths controlling the discharge of groundwater to springs in and around Death Valley. Since these early investigations, studies of groundwater flow in the Death Valley region have benefited from additional geologic and hydrologic characterization conducted via drilling and testing at numerous boreholes and wells in the area.

A general understanding of regional-scale groundwater flow is important for understanding the Yucca Mountain groundwater flow system because the regional-scale system sets the context for the site-scale system. An important aspect of the regional hydrogeologic system is that it occurs in an enclosed basin without any surface or subsurface discharge to the ocean (i.e., all water that naturally leaves the region does so exclusively through evaporation or evapotranspiration). This regional basin, which includes natural discharge at springs in the Death Valley area, is referred to as the Death Valley regional flow system.

The site-scale conceptual model is a synthesis of what is known about flow and transport processes at the scale required for postclosure performance assessment analyses, that is, at a scale relevant to assessing potential radionuclide transport from beneath Yucca Mountain to a point about 18 km south of Yucca Mountain where the reasonably maximally exposed individual may extract groundwater from the aquifer. This knowledge builds on, and is consistent with, knowledge that has accumulated at the regional scale, but it is more detailed because a higher density of data is available at the site-scale level.

2.2 REGIONAL GROUNDWATER FLOW SYSTEM

The Death Valley regional flow system encompasses an area of about 70,000 km^2 in southern California and southern Nevada, between latitudes 35° and 38° 15' north and longitudes 115° and 118° 45' west. The region varies topographically and geologically, and these features tend to control the groundwater flow system. The highest elevations are in the Spring Mountains (greater than 3,600 m) and in the Sheep Range (greater than 2,900 m). The lowest elevations occur in Death Valley (-86 m) and along the major tributaries to the Amargosa River. The major physiographic features within the regional flow system are illustrated in Figure 2-1.

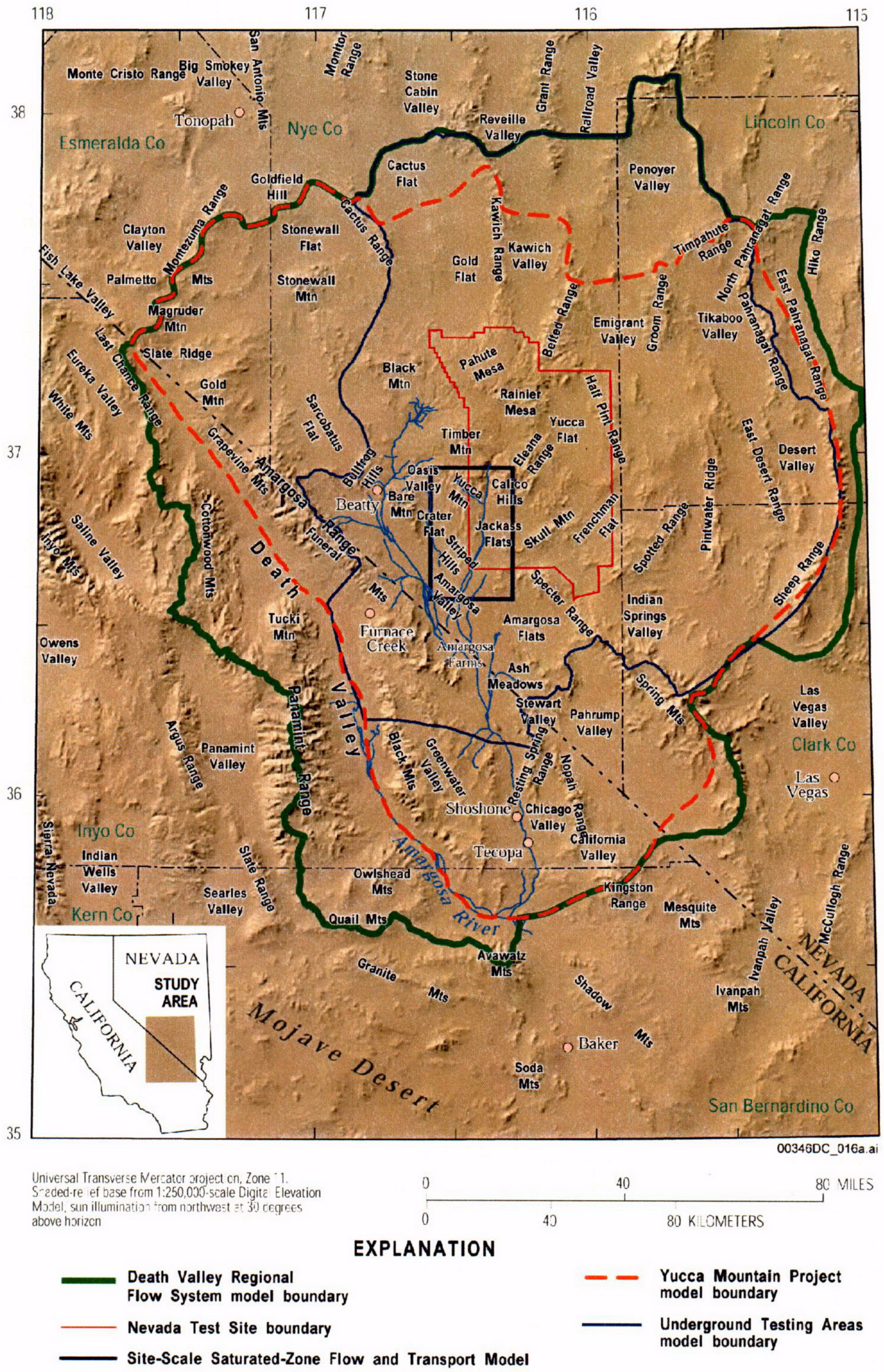
Groundwater in the Death Valley region flows through a variety of rock types ranging from Paleozoic carbonate to Tertiary volcanic rocks (such as those in the Yucca Mountain area) to alluvial aquifers (such as those from which water is extracted for irrigation and other domestic purposes in the Amargosa Farms area). Within the Death Valley region, the presence of hydrostratigraphic discontinuities due to tectonic features, such as faults, has caused many of the aquifers to be heterogeneous. Faults, which disrupt the hydrostratigraphic continuity, divert water in regional circulation to subregional and local discharge.

The following discussion summarizes regional recharge and discharge areas and amounts, hydraulic potentials, hydrogeologic characteristics, and hydrochemistry observations and inferences that are used to constrain the groundwater flow system in the vicinity of Yucca Mountain.

2.2.1 Regional Groundwater Recharge and Discharge

One of the first steps in developing a consistent representation of the groundwater flow regime in a groundwater basin is to identify the major recharge and discharge locations, types, and amounts. By comparing these distributions, an overall understanding of the water budget within the basin can be developed. Differences between the annual average recharge and discharge amounts are indicative of conditions when water is added to (or taken from) the total water in storage within the aquifers of the basin.

Groundwater recharge in the Death Valley region principally is from water that directly infiltrates the soil horizon due to precipitation (rainfall and snowmelt) and that is not lost from the soil horizon due to evaporation or transpiration. Although some recharge occurs along intermittent rivers and streams in the area, most notably the Amargosa River and tributaries, the areal and temporal extent of this recharge is negligible from the perspective of the overall water budget (although local geochemistry and isotopic variations have, in part, been attributed to local intermittent recharge; Hevesi et al. 2002, p. 12). Although this intermittent recharge was not explicitly incorporated in the regional flow model, its effect on the site-scale flow model has been included (see Section 2.3.2). Net infiltration in the region is controlled by variability in precipitation and other factors, including the timing of precipitation, elevation, slope, soil or rock type, and vegetation. Net infiltration usually is episodic and generally occurs after periods of winter precipitation when evapotranspiration is low (Hevesi et al. 2002, p. 10).



Source: Belcher et al. 2002, Figure 1.

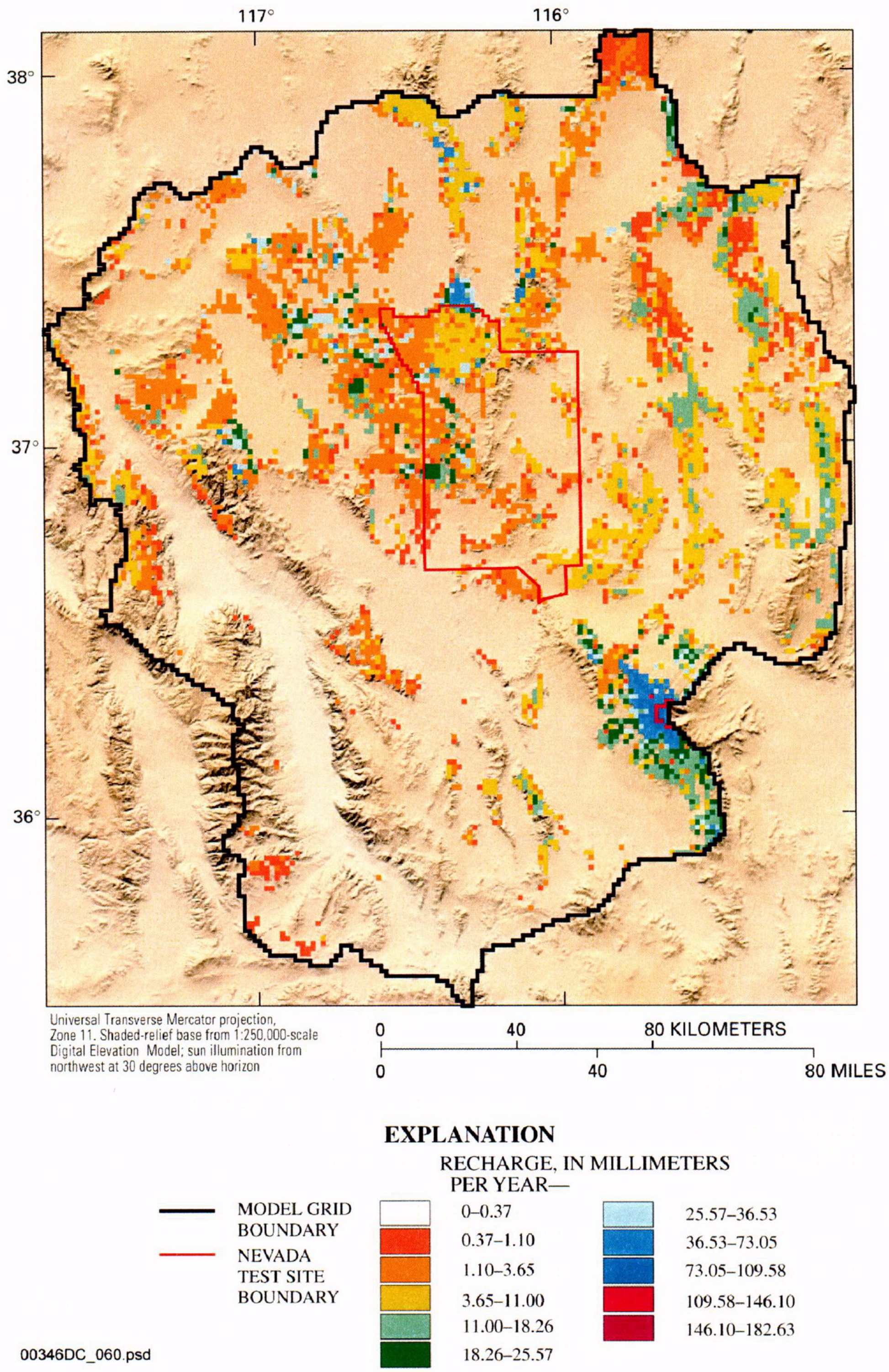
NOTE: The different model boundaries reflect different regional model studies that are discussed and referenced in the source.

Figure 2-1. Major Physiographic Features in the Death Valley Regional Flow System

C03

Estimates of net infiltration are based on a number of approaches. A traditional approach has been to empirically correlate net infiltration to average annual precipitation. This approach was originally postulated by Maxey and Eakin (1950). A more process-based approach was recently developed by the U.S. Geological Survey (USGS), in which the estimated recharge is a function of precipitation, soil depth, evapotranspiration, soil and rock permeability, and other factors. The application of this approach resulted in an estimate of net infiltration in the Yucca Mountain region (Figure 2-2 and Table 2-1). Although there is uncertainty (about a factor of three) in the range of estimates of average annual net infiltration over the Death Valley region, the results generally confirm that most of the recharge occurs at higher elevations in the Spring Mountains and in the Sheep Range, and at other locations above about 1,500 m elevation.

Naturally occurring discharge from aquifers in the Death Valley region generally occurs due to evapotranspiration from the shallow water table beneath playas or at springs. Locations of surface features where regional discharge is expected are described by D'Agnese et al. (2002). The current understanding of discharge locations and rates are summarized in Figure 2-3 and Table 2-2. These estimates have been compiled from estimates of evapotranspiration rates and observations of spring discharge in the area.



Source: D'Agnese et al. 2002, Figure 21.

Figure 2-2. Location of Principal Recharge Areas and Amounts in the Death Valley Regional Flow System

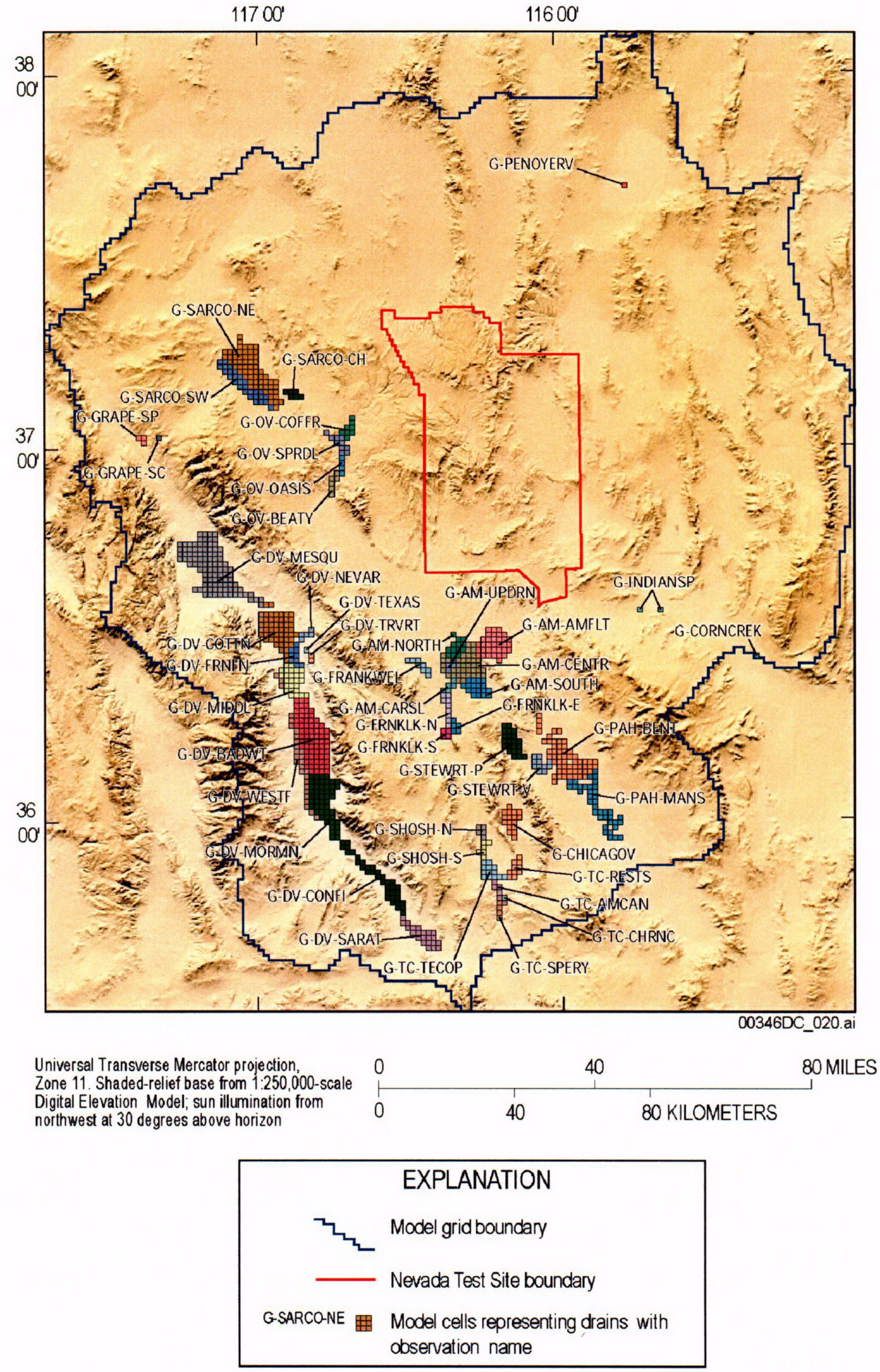
C04

Table 2-1. Summary of Precipitation, Modeled Net Infiltration, and Estimated Recharge Using Maxey-Eakin Methods for the Area of the Death Valley Regional Groundwater Flow Model.

Precipitation Model	Model Type	Average Value for Area of Death Valley Groundwater Flow Model (mm/year)	Total Area Volume (million m^3/year)	Net Infiltration or Recharge as a Percentage of Precipitation
1980 to 1995 Modeled Precipitation		202	7,980	—
	Model net infiltration	7.8	310	3.9
	Model net infiltration of areas with >200 mm/year precipitation	4.8	190	6.2
	Modified Maxey-Eakin estimated recharge	6.3	250	3.1
	Modified Maxey-Eakin of areas with >200 mm/year precipitation	2.6	110	5.1
	Original Maxey-Eakin estimated recharge	4.8	190	2.4
1920 to 1993 Cokriged Precipitation		188	7,430	—
	Modified Maxey-Eakin estimated recharge	5.1	200	2.7
	Original Maxey-Eakin estimated recharge	3.7	150	2.0

Source: Based on Hevesi et al. 2002, Table 2.

NOTE: Volumetric flows rounded to the nearest 10 million m^3/year.



Source: Based on D'Agnese et al. 2002, Figure 18.

NOTE: Location codes are defined in Table 2-2.

Figure 2-3. Location of Principal Naturally Occurring Discharge Areas in the Death Valley Regional Flow System

C05

Table 2-2. Inferred Naturally Occurring Discharge Amounts in the Death Valley Regional Flow System

Location	Location Code	Observed Discharge (m^3/day)
Ash Meadows, Amargosa Flat	G-AM-AMFLT	6,019
Ash Meadows, Carson Slough	G-AM-CARSL	498
Ash Meadows, central area	G-AM-CENTR	21,444
Ash Meadows, upper drainage	G-AM-UPDRN	3,219
Ash Meadows, northern area	G-AM-NORTH	19,499
Ash Meadows, southern area	G-AM-SOUTH	10,085
Chicago Valley	G-CHICAGOV	1,452
Corn Creek Springs	G-CORNCREK	676
Death Valley, Badwater basin area	G-DV-BADWT	5,019
Death Valley, Confidence Hills area	G-DV-CONFI	6,651
Death Valley, Cottonball basin area	G-DV-COTTN	3,547
Death Valley, Furnace Creek alluvial fan	G-DV-FRNFN	10,185
Death Valley, Mesquite Flat area	G-DV-MESQU	29,075
Death Valley, Middle basin	G-DV-MIDDL	2,587
Death Valley, Mormon Point area	G-DV-MORMN	7,225
Death Valley, Nevares Springs	G-DV-NEVAR	1,884
Death Valley, Saratoga Springs area	G-DV-SARAT	6,535
Death Valley, Texas Spring	G-DV-TEXAS	1,220
Death Valley, Travertine Springs	G-DV-TRVRT	4,633
Death Valley, western alluvial fans	G-DV-WESTF	13,637
Franklin Well area	G-FRANKWEL	1,182
Franklin Lake, eastern area	G-FRNKLK-E	411
Franklin Lake, northern area	G-FRNKLK-N	2,254
Franklin Lake, southern area	G-FRNKLK-S	711
Grapevine Springs, Scotty's Castle area	G-GRAPE-SC	1,035
Grapevine Springs, spring area	G-GRAPE-SP	2,450
Indian Springs and Cactus Springs	G-INDIANSP	2,240
Oasis Valley, Beatty area	G-OV-BEATY	2,774
Oasis Valley, Coffer's Ranch area	G-OV-COFFR	5,343
Oasis Valley, middle Oasis Valley area	G-OV-OASIS	3,157
Oasis Valley, Springdale area	G-OV-SPRDL	8,113
Pahrump Valley, Bennett Spring area	G-PAH-BENT	16,753
Pahrump Valley, Manse Spring area	G-PAH-MANS	5,375
Penoyer Valley area	G-PENOYERV	12,833
Sarcobatus Flat, Coyote Hills area	G-SARCO-CH	1,503
Sarcobatus Flat, northeastern area	G-SARCO-NE	30,421
Sarcobatus Flat, southwestern area	G-SARCO-SW	11,960
Shoshone basin, northern area	G-SHOSH-N	2,259
Shoshone basin, southern area	G-SHOSH-S	4,831
Stewart Valley, predominantly playa area	G-STEWRT-P	995
Stewart Valley, predominantly vegetation area	G-STEWRT-V	2,381
Tecopa basin, Amargosa Canyon area	G-TC-AMCAN	3,394
Tecopa basin, China Ranch area	G-TC-CHRNC	1,784
Tecopa basin, Resting Spring area	G-TC-RESTS	2,537
Tecopa basin, Sperry Hills area	G-TC-SPERY	1,341
Tecopa basin, central area	G-TC-TECOP	12,221
	TOTAL	**105,776,270 m^3 per year**

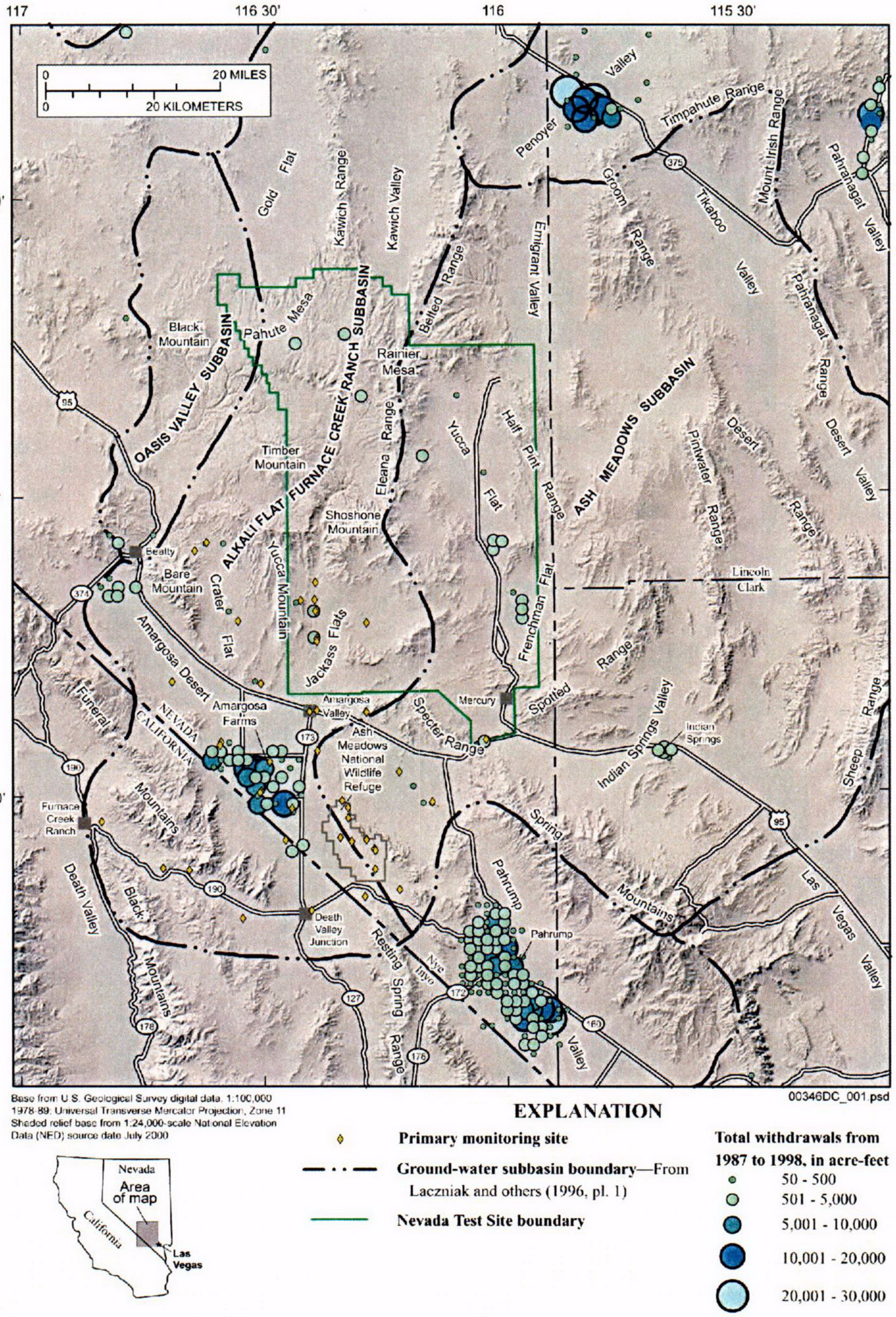
Source: Based on D'Agnese et al. 2002.

In addition to natural discharge, groundwater has been withdrawn from the aquifers in the Death Valley regional groundwater basin for various domestic, agricultural, industrial, and government purposes over the last several decades. Locations and estimates of groundwater extraction are summarized in Figure 2-4. Although these discharges from the regional aquifers are small in comparison to natural discharge, they potentially affect the flow paths and flow rates in the vicinity of the pumping centers.

In comparing areas of recharge and discharge, it is apparent that most of the recharge occurs at higher elevations, while most discharge occurs at lower elevations. The total volumetric annual recharge and discharge rates in the basin should be similar assuming there is no net water gain or loss from the aquifers within the basin. The differences between Tables 2-1, 2-2, and Figure 2-4 might result from several factors. For example, they may reflect the degree of temporal averaging in different techniques or in the estimation method used to determine the net infiltration (Hevesi et al. 2002). Alternatively, the differences may indicate that there is a nonsteady component of the regional flow system and that recharge and discharge are not in equilibrium. However, it is more likely that the estimates of recharge and discharge are essentially equivalent, and the differences simply represent the precision of the estimation method. Therefore, given the vastness of the groundwater basin, it is not surprising that the regional estimates of recharge and discharge only agree to within a factor of about three, as the regional recharge estimates range from about 110 to 310 million m^3/year, and the regional discharge estimate is about 106 million m^3/year. Uncertainty in the estimate of the overall water budget was considered in the estimate of the aquifer characteristics that affect the local flow system around Yucca Mountain.

2.2.2 Regional Potentiometric Surface

D'Agnese et al. (1997) constructed a regional-scale potentiometric map for the Death Valley regional flow system (Figure 2-5). This regional-scale map was constructed using data describing water levels from monitoring wells, boundaries of perennial marshes and ponds, spring locations, general inferences based on the distribution of recharge and discharge areas, and a general understanding of the regional hydrogeology. The regional potentiometric surface corresponds to the major recharge and discharge areas identified above. The major recharge areas are represented by potential highs in the Spring Mountains, the Sheep Range, and other areas with elevations greater than 1,500 m. Discharge is represented by areas with a very low potential gradient or in areas with elevations less than 500 m.



Source: Fenelon and Moreo 2002, Figure 11.

NOTE: To convert total withdrawals over the reported period to annual water withdrawals, divide by 12 to convert to acre-feet/year, or multiply by about 100 to convert to m^3/year (there are 1,233 m^3 in 1 acre-foot). Therefore, the largest pumping center in the Amargosa Valley during this period was discharging 1 to 2 million m^3/year, on average.

Figure 2-4. Location of Principal Anthropogenic Groundwater Discharge Areas in the Death Valley Regional Flow System

C06

Universal Transverse Mercator projection, Zone 11.
Shaded-relief base from 1:250,000-scale Digital Elevation Model;
sun illumination from northeast at 30 degrees above horizon

00034DC-SZ-PMR-11.ai

25 0 25 50 KILOMETERS

25 0 25 50 MILES

N

EXPLANATION

Death Valley Regional Flow System Boundary

—1,000— Potentiometric contour- Shows altitude of potentiometric surface. Contour interval 100 meters. Datum is sea level.

Source: Based on D'Agnese et al. 1997, Figure 27.

NOTE: The regional flow system model boundary indicated on this figure reflects the boundaries used by D'Agnese et al. (1997), which have been revised in the more recent interpretations described by D'Agnese et al. (2002) and presented in Figures 2-1 to 2-3.

Figure 2-5. Regional-Scale Potentiometric Surface Map

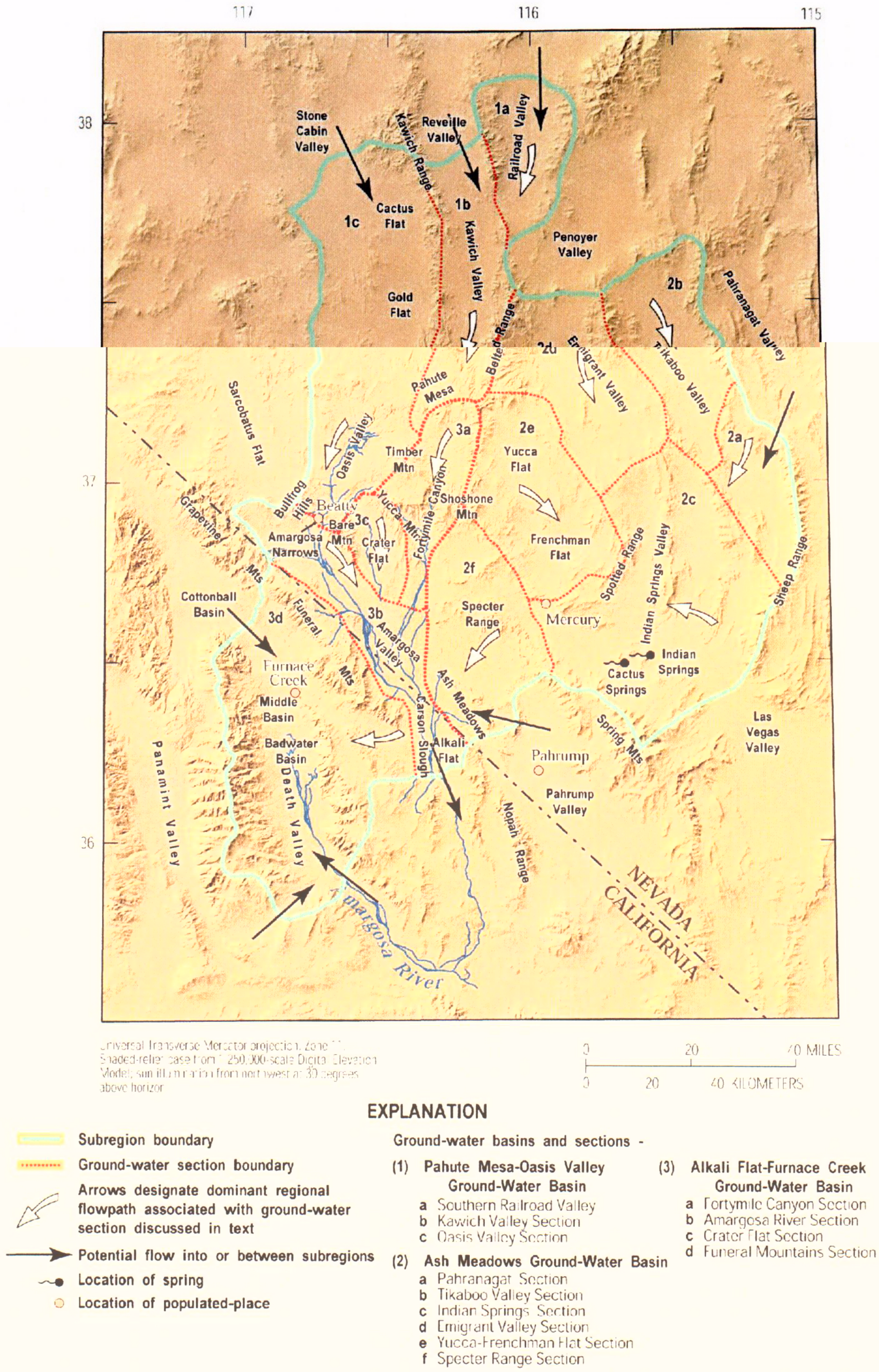
C07

Using only the potentiometric information and knowledge of major recharge and discharge areas, D'Agnese et al. (2002) inferred the general regional groundwater flow directions in the central Death Valley subregion of the Death Valley regional flow system (Figure 2-6), which generally is southerly in the vicinity of Yucca Mountain. Although these interpreted flow directions are useful indicators of general trends, they do not directly quantify uncertainty in the flow paths, and they primarily are used to confirm the flow directions developed at the scale of the site model.

2.2.3 Death Valley Regional Hydrogeology

Hydrogeology in the Death Valley region is characterized by rocks of differing lithology and hydraulic characteristics depending in part on the location and proximity to major tectonic features. Faults can also affect the flow system, ranging from acting as barriers to groundwater flow when flow is perpendicular to the fault strike to providing preferential flow paths (horizontally and vertically) when flow is parallel to the fault strike.

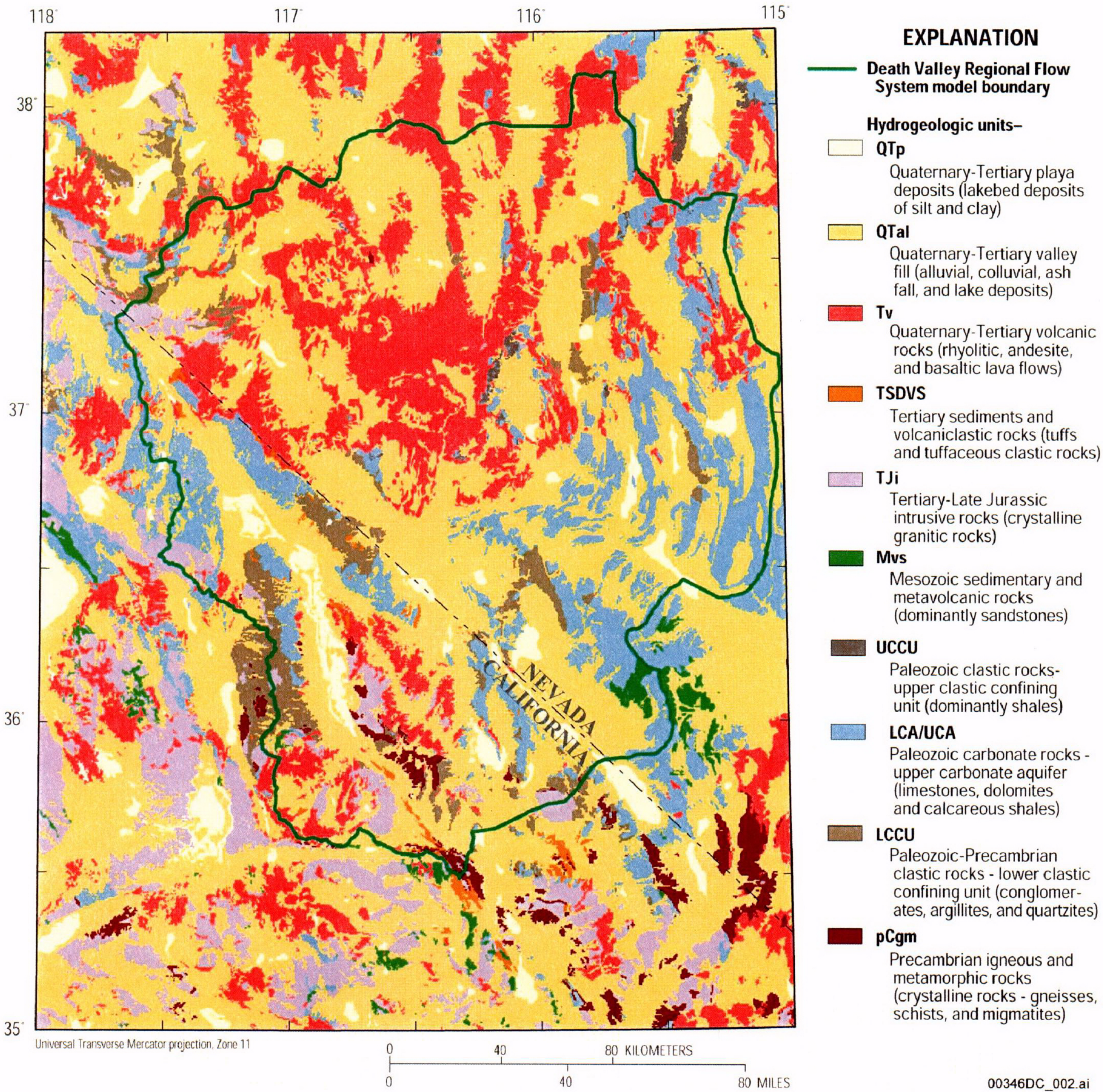
The major hydrogeologic units from oldest to youngest are: the Lower Clastic Confining Unit, the Lower Carbonate Aquifer, the Upper Clastic (Eleana) Confining Unit, the Upper Carbonate Aquifer, the Volcanic Aquifers, the Volcanic Confining Units, and the Alluvial Aquifer. The Lower Clastic Confining Unit forms the basement and generally is present beneath the other units except in caldera complexes. The Lower Carbonate Aquifer is the most extensive and transmissive unit in the region, and it is the source of regional discharge in the springs of Death Valley National Park. The Upper Clastic Confining Unit is present in the north-central part of the Nevada Test Site. It typically impedes flow between the overlying Upper Carbonate Aquifer and the underlying Lower Carbonate Aquifer, and is associated with many of the large hydraulic gradients in and around the Nevada Test Site. The Volcanic Aquifers and Volcanic Confining Units form a stacked series of alternating aquifers and confining units in and around the Nevada Test Site. The Volcanic Aquifers are moderately transmissive and are saturated in western sections of the Nevada Test Site. The Alluvial Aquifer forms a discontinuous aquifer in the region. Regional outcrops of these hydrogeologic units are depicted in Figure 2-7, and representative cross sections through the region, depicting the correlation of these different units, are presented in Figure 2-8.



Source: Based on D'Agnese et al. 2002, Figure 11.

NOTE: The Central Death Valley Subregion is one of three subregions identified in the Death Valley Regional Flow Model.

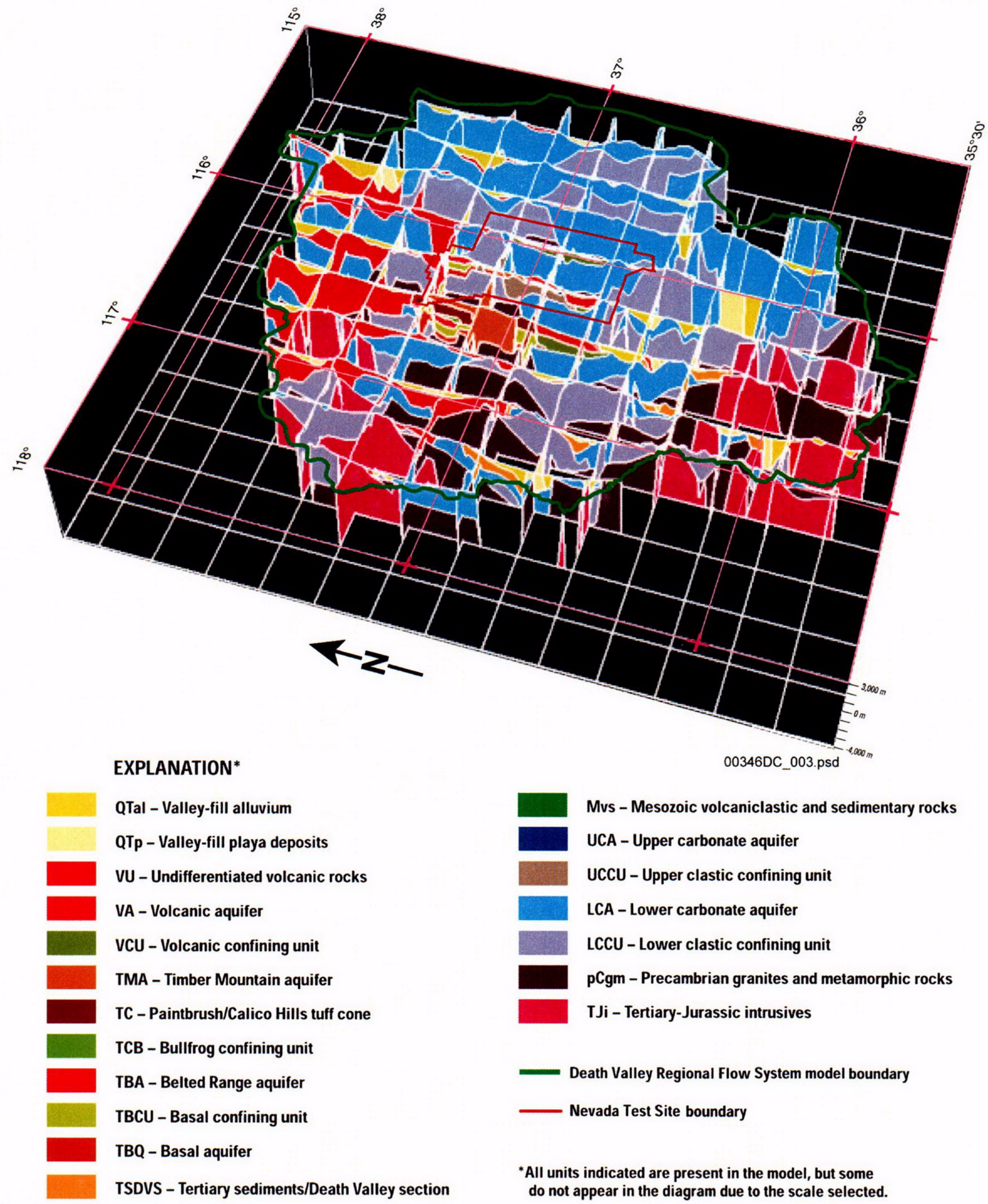
Figure 2-6. Inferred Groundwater Flow Paths in the Central Death Valley Subregion



Source: Belcher et al. 2002, Figure 4.

Figure 2-7. Outcrops of Major Hydrogeologic Units in the Death Valley Region

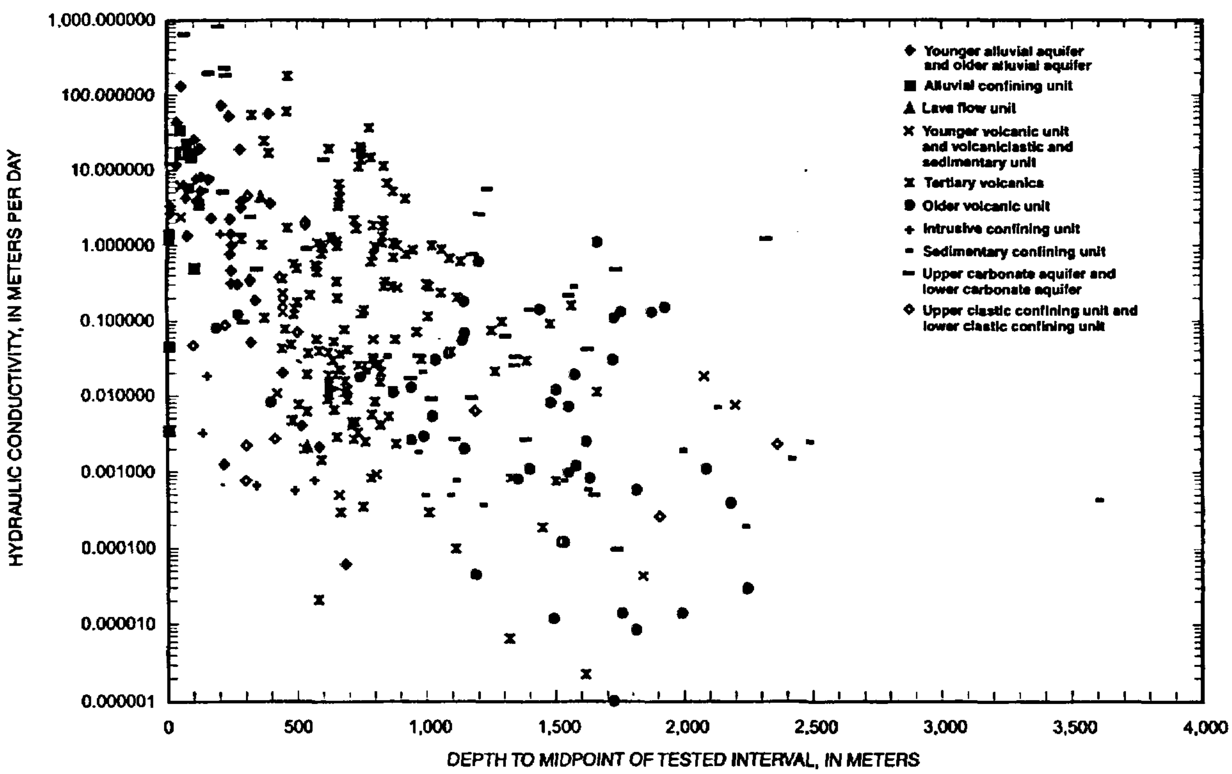
C09



Source: Belcher et al. 2002, Figure 35.

Figure 2-8. Representative Hydrogeologic Cross Sections through the Death Valley Region

Understanding the regional groundwater flow requires evaluating the water-transmitting capability of the major lithologic units. Belcher and Elliot (2001) compiled estimates of transmissivity, hydraulic conductivity, storage coefficients, and anisotropy ratios for major hydrogeologic units within the Death Valley region. Belcher et al. (2002) used a compilation of 930 hydraulic conductivity measurements to derive estimates of the hydraulic characteristics for several of the hydrogeologic units. Regional variability in aquifer characteristics is summarized in Figure 2-9. Although this figure illustrates an apparent depth dependency of hydraulic conductivity, the objective of presenting the information in this format primarily is to depict variability in hydraulic conductivity as a function of rock type. The depth dependency, which presumably is related to confining stress, has not been directly incorporated in the regional hydrogeologic models. Although the information is presented as a function of rock type, it is also probable that the range of variation within a particular rock type is largely affected by the degree of fracturing of the rock in the vicinity of the borehole that was tested (i.e., they reflect local heterogeneity of the rock mass). Uncertainty and variability in hydraulic conductivity were evaluated during construction of the regional and site-scale hydrogeologic models. Uncertainty in hydraulic conductivity does not greatly constrain the flow models.



Source: Belcher and Elliot 2001, Figure 4.

Figure 2-9. Depth Dependency of Regional Hydraulic Conductivity Estimates