U.S NUCLEAR REGULATORY COMMISSION
DIVISION OF WASTE MANAGEMENT

NNWSI CONCEPTUAL MODEL UPDATE

NNWSI Repository Project
Subtask 1.4

Prepared by

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Water, Waste, & Land, Inc.

for

Nuclear Waste Consultants Inc.

TECHNICAL ASSISTANCE IN HYDROGEOLOGY
PROJECT B - ANALYSIS
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1.0 INTRODUCTION

Nuclear Waste Consultants, Inc., (NWC) was awarded NRC project RS-MNS-85-009 entitled "Technical Assistance in Hydrogeology - Project B- Analysis" on September 28, 1985. Water, Waste and Land, Inc., (WWL) is subcontracted to NWC as the group responsible for review of hydrogeologic investigations of the Nevada Nuclear Waste Storage Investigation (NNWSI) Project. As part of the contract, Subtask 1.4 requires a conceptual model update every six months. This report represents the last such update and fulfills this Subtask 1.4 requirement.

This report has been divided into three separate chapters. Chapter 2, Regional Hydrogeologic System, gives an overview of the regional geology and hydrology, including site location and regional physiographic description. Chapter 3, Site Unsaturated Hydrogeologic Subsystem, describes the site geology, the geohydrologic units of the unsaturated zone, and the conceptual model of flow through this zone. Chapter 4, Site Saturated Hydrogeologic Subsystem, describes the geohydrologic units of the site saturated zone, the conceptual flow model through this zone, and paleohydrology studies as they relate to performance objectives.

For the purposes of this report, the three groundwater flow systems have been systematically divided into components, elements, and sub-elements. The components are shown in the table of contents as the major sections of each of the chapters. As an example, the components of the Site Unsaturated Hydrogeologic System (Chapter 3) are; (1) Site Location and Physiographic Setting, (2) Hydrogeologic Setting, (3) Flow Mechanisms in the Unsaturated Zone, (4) Boundary and Initial Conditions, and (5) Flow and Transport. Elements are shown in the table of contents as the subsections of each of the components. As an example, for the Site Unsaturated Hydrogeologic System, the component Boundary and Initial Conditions (Section 3.4) has two elements; (1) Boundary Conditions, and (2) Initial Conditions. In some cases these elements are further divided into sub-elements as indicated in the Table of Contents. As a matter of convenience, references cited in each chapter are listed in the final section of that chapter. Mr. Jeff Pohle, the NRC Project Officer, has requested that the following points be incorporated in this final conceptual model update:

1. A description of what is known or thought to be the case about each element of the groundwater flow system;
2. For each such element, a discussion of the uncertainties including identification (and influence) of any assumptions made in the description;
3. For each such uncertainty, include alternative hypotheses, interpretations, or assumptions that are consistent with the uncertainty; and
4. For each such hypothesis, include information needs to discriminate between the alternatives.

The conceptual model presented in this report is based on the conceptual model presented in the Department of Energy's (DOE) Consultation Draft Site Characterization Plan (CDSCP) which was released in January, 1988. Statements, conclusions, and uncertainties presented in this report, unless otherwise noted, are those of the DOE. Comments about the conceptual model uncertainties other than those of the DOE have been included as footnotes throughout the report. These comments have originated from three sources:

1. NRC staff Point Papers on geohydrology which were presented to the DOE;
2. U.S. Geological Survey's (USGS) review comments on the CDSCP; and
3. Comments by WWL.

The comments by the NRC and the USGS have been formatted in a manner which refers back to the original document containing those comments. The reference number for the NRC comments refers to the sequential number which was assigned by the NRC staff to that particular comment. The USGS comments include the page number from the USGS review report on the CDSCP.

2.0 REGIONAL HYDROLOGIC SYSTEM

The hydrogeologic study area is located in the southeastern Great Basin of the Basin and Range Province. This region is characterized by arid climates, with precipitation primarily being a function of elevation. Annual average precipitation at Yucca Mountain is estimated to be on the order of 150 mm/yr. The regional study area is approximately 18,000 km^2 and is divided into three subbasins, the Oasis Valley, The Alkali Flat-Furnace Creek, and the Ash Meadow subbasin. Regionally, flow paths in the hydrogeologic study area vary in direction from southerly in the north half of the study area to southwesterly in the southern half (Winograd and Thordarson, 1975; Waddell, 1982).

The study area has three major aquifers, the Valley Fill (alluvium), the Tuff, and the Lower Carbonate. These aquifers are separated in some areas by intervening aquitards. Large ranges of hydrologic properties exist in the various units. Fracture flow in the Tuff units yields large transmissivities. Recharge occurs primarily in the highland areas where precipitation is the highest and by underflow from surrounding basins. The groundwater discharges in the topographic lows in the form of springs, playas, and underflow out of the study area.

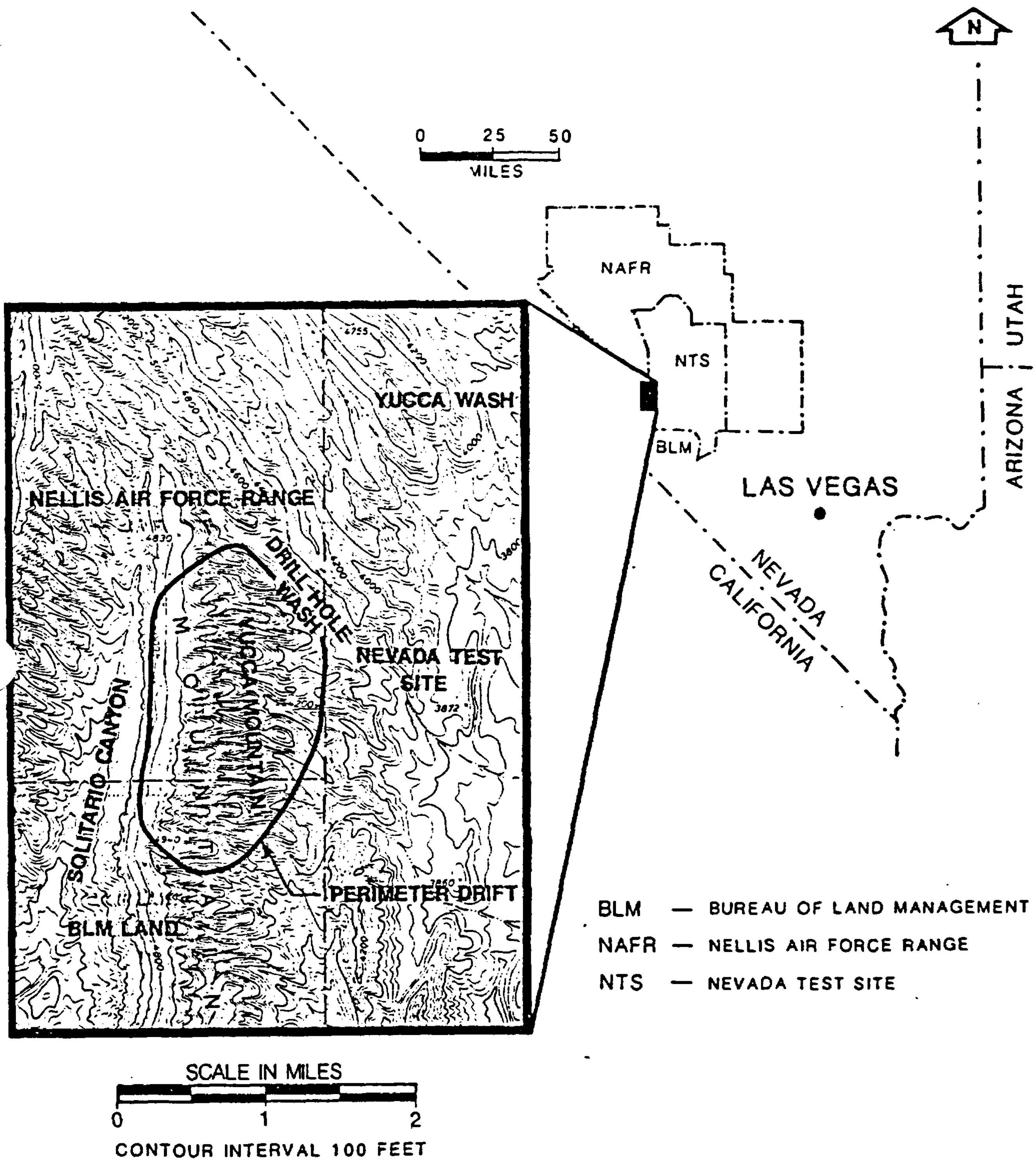
The Regional Hydrologic System has been divided into nine major components:

1. Location and Regional Physiography
2. Regional Meteorology
3. Study Area Subbasins
4. Hydrogeologic Units
5. Boundary Conditions
6. Potentiometric Levels
7. Flow and Transport
8. Isotopic and Regional Hydrochemistry
9. Regional Paleohydrology

Each of these components, along with their elements and sub-elements, are described in the following sections.

2.1 LOCATION AND REGIONAL PHYSIOGRAPHY

As shown on Figure 2-1, the Yucca Mountain site is located on and immediately adjacent to the southwestern portion of the Nevada Test Site, which



PROPOSED REPOSITORY LOCATION AND SURFACE FACILITIES ARE LOCATED WITHIN THE OUTLINE SHOWN ABOVE.

SOURCE: DOE, 1984

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FIGURE 2-1

YUCCA MOUNTAIN LOCATION MAP

Date: SEPT 1988

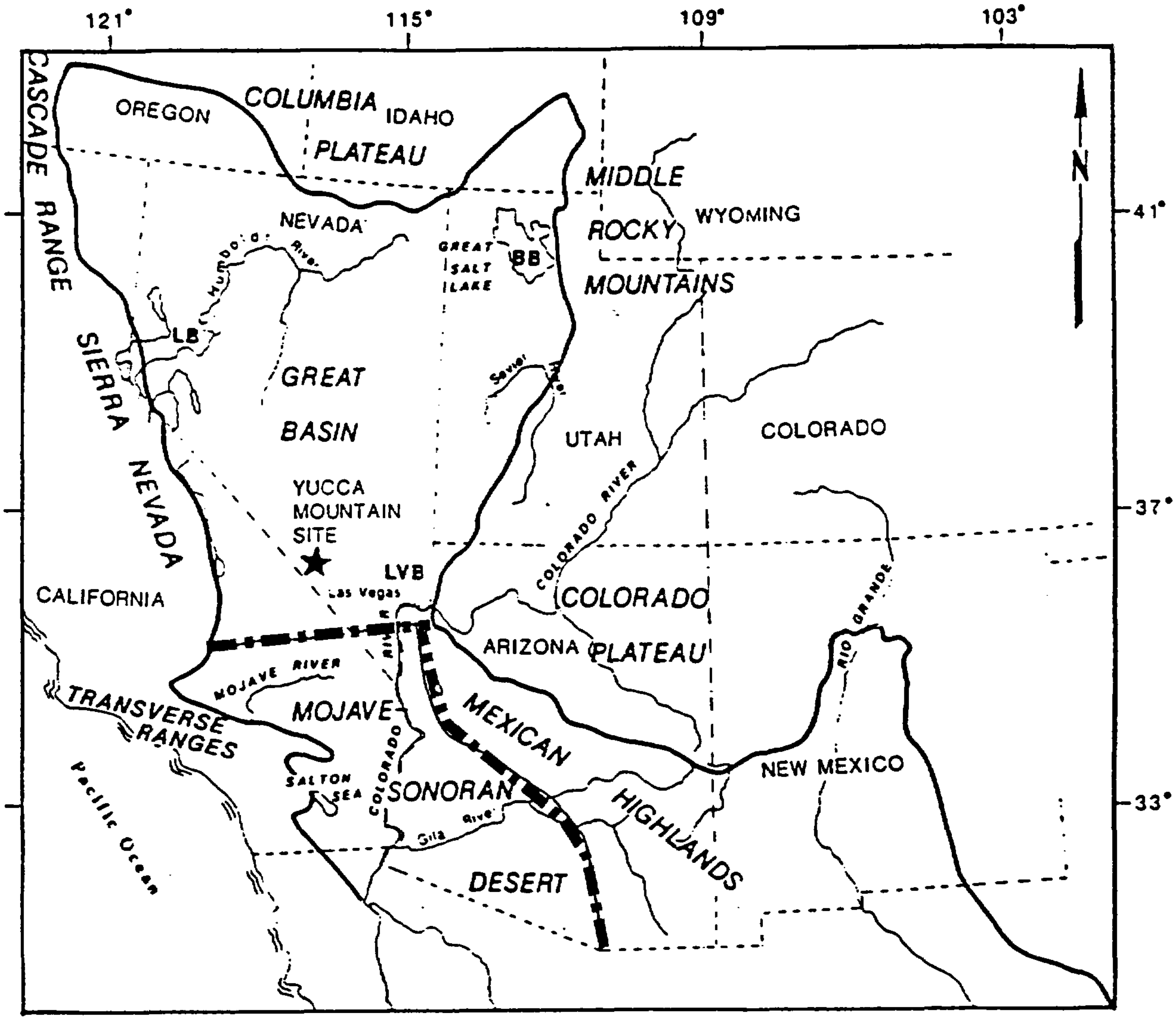
Project: 4001

is in Nye County, Nevada, about 105 km (65 miles) northwest of Las Vegas. The Yucca Mountain site is located exclusively within lands controlled by the Federal Government. The land parcel under consideration, which includes the underground facilities, the surface facilities, and the controlled area for the repository, is divided as follows: (1) the DOE controls the eastern portion through the withdrawn land of the Nevada Test Site; (2) the Department of Air Force controls the northwestern portion through the land-use permit for the Nellis Air Force Range (NAFR); and (3) the BLM holds the southwestern portion in public trust. The Candidate Area is an region that has been recommended for site characterization. By definition, the controlled area is a specific location that encompasses no more than 100 km^2 and extends no more than 5 km in any direction from the outer boundary of the original locations of the radioactive waste in a disposal system, plus the subsurface underlying such a surface location.

The Yucca Mountain site lies within the southwestern Great Basin, the northernmost subprovince of the Basin and Range Province. Generally defined, the Basin and Range province is that area of southwestern North America that is characterized by more or less regularly spaced sub-parallel mountain ranges and intervening alluviated basins formed by extensional faulting. As shown on Figure 2-2 the western boundary of the Basin and Range Province is defined by the Transverse Ranges, the Sierra Nevada, and the southern Cascade Range; the northern boundary by the Columbia Plateau; and the northeast boundary by the Wasatch Range of the middle Rocky Mountains (Hunt, 1974). The distinctive physiography of the province is largely the product of the most recent extensional phase of deformation. The physiographic features surrounding Yucca Mountain are illustrated on Figure 2-3.

2.2 REGIONAL METEOROLOGY

Defining the existing climatic conditions establishes the basis for comparing the future and past climates with the present climate. Establishing the existing climatic conditions and the infiltration rates associated with these conditions is important in evaluating whether climatic variations will affect infiltration rates and subsequent rises or declines in the water table in the Yucca Mountain area. The sections that follow will provide a brief overview of the climate of the Yucca Mountain area, including temperature and



BB = BONNEVILLE BASIN

LB = LAHONTAN BASIN

LVB = LAS VEGAS BASIN

0 100 200 MILES

0 100 200 KILOMETERS

BASIN AND RANGE PROVINCE BOUNDARY IS INDICATED BY HEAVY SOLID LINE.
DASHED LINE INDICATES SUBPROVINCE BOUNDARIES

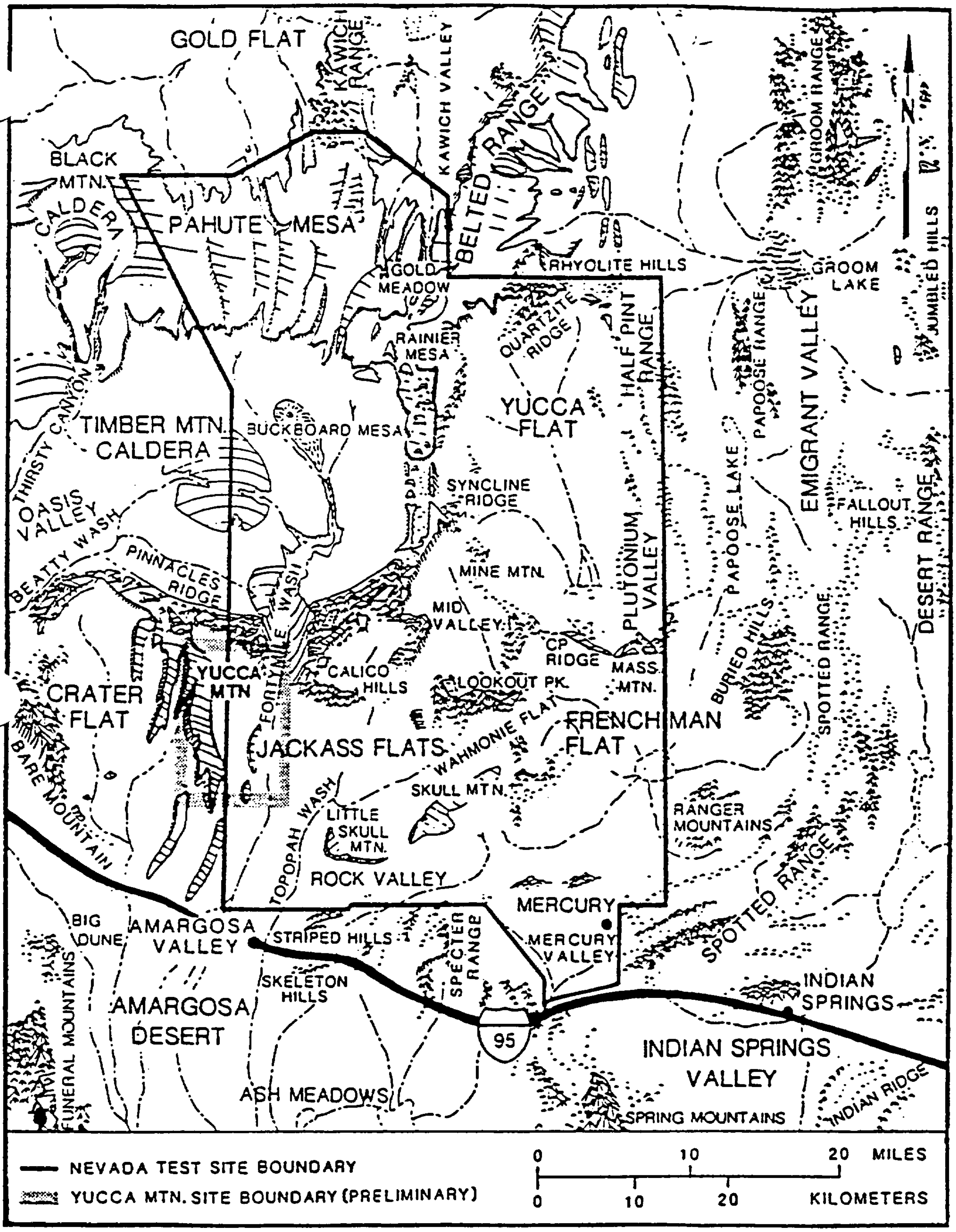
SOURCE: HUNT, 1974

Water, Waste & Land, Inc.

FIGURE 2-2
BOUNDARIES AND SUBPROVINCES OF THE
BASIN AND RANGE PHYSIOGRAPHIC PROVINCE

Date: SEPT 1988

Project: 4001



SOURCE: DOE, 1986

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FIGURE 2-3
PHYSIOGRAPHIC FEATURES OF YUCCA MOUNTAIN
AND SURROUNDING REGION

Date: SEPT 1988

Project: 4001

precipitation ranges. A more in-depth evaluation of the regional meteorology is provided in Chapter 5 of the CDSCP (DOE, 1988) for Yucca Mountain.

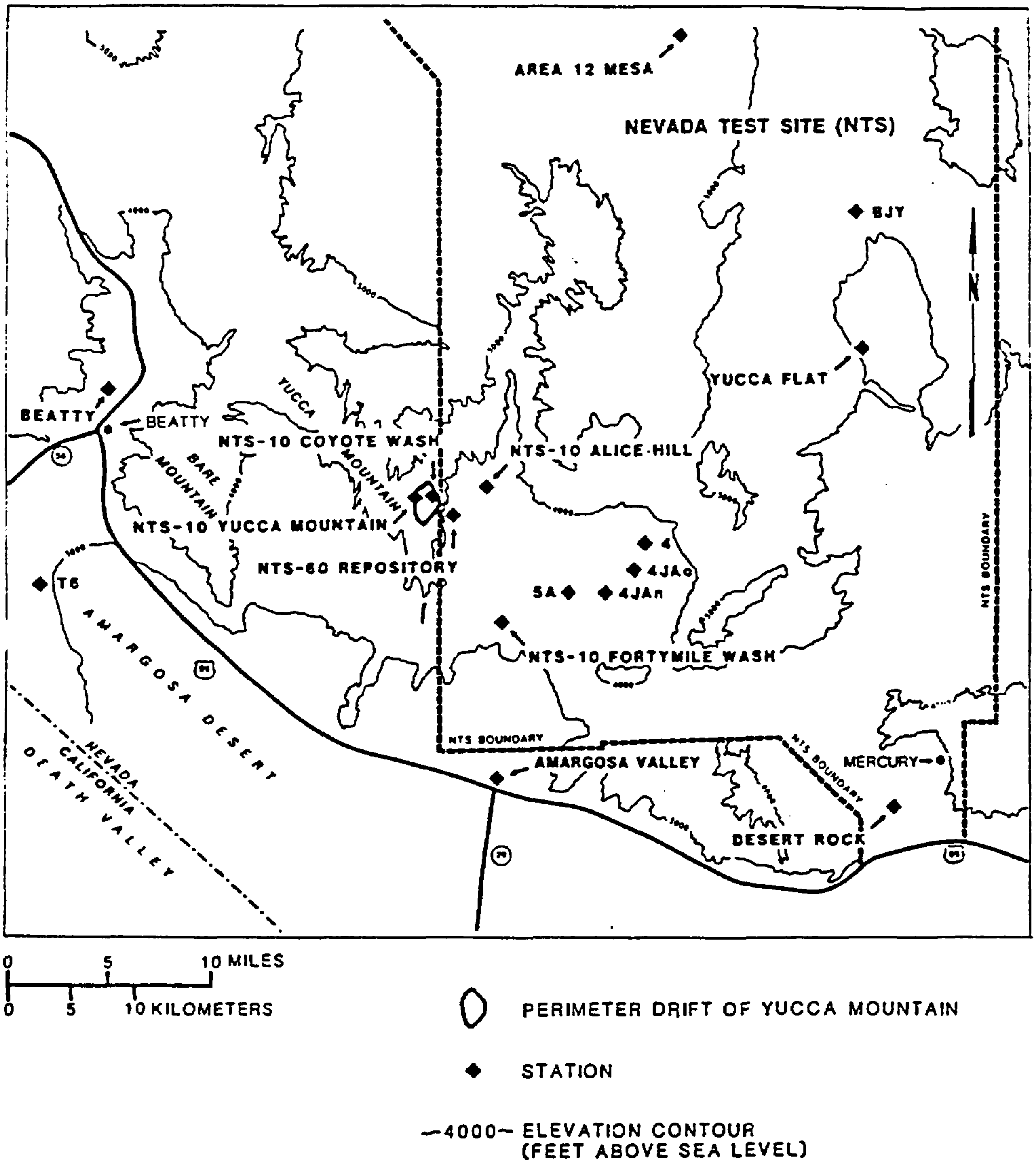
2.2.1 Climate

Although monitoring stations have been established in the study area, long-term site-specific climatological data for Yucca Mountain are not presently available, as the period of record from these stations is less than two years. Therefore, data from two weather stations near Yucca Mountain, operated by the National Weather Service (NWS), have been used to provide a general description of the climate in the area. One of these stations is located approximately 32 km northeast of the Yucca Mountain site in Yucca Flat, a broad alluvial basin. The other station is near Beatty, Nevada, approximately 24 km west of the Yucca Mountain site. The locations of available weather stations in the vicinity of Yucca Mountain are shown on Figure 2-4.

In general, summers at Yucca Mountain are dominated by continental tropical air masses and winters are dominated by continental polar air masses. Table 2-1 provides a general outline of the climatic conditions experienced at Yucca Flat during the 10-yr period from 1962 to 1971 (Bowen and Egami, 1983a). The DOE considers that parameters at the Yucca Mountain site which will probably differ from the Yucca Flat summary are temperature minimums, wind speeds, and direction. Also, precipitation amounts are expected to be greater at Yucca Mountain because of its higher elevation (1,463 m at the NTS-10 Yucca Mountain station versus 1,196 m at the Yucca Flat station).

2.2.2 Temperature

Temperature data from the 10-yr climatological summary for Yucca Flat and the 39-yr (1922 to 1960) period of record at Beatty are presented in Table 2-2. The DOE considers that although the exact relationship between the recording stations in Table 2-2 and Yucca Mountain is not known, the temperature at the Yucca Mountain site is expected to closely resemble the Yucca Flat data. There will probably be substantial temperature ranges, with cool summer nights and mild winter daily maximums during most years.



SOURCE: DOE, 1988

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FIGURE 2-4
METEROLOGICAL MONITORING STATIONS IN THE VICINITY OF YUCCA MOUNTAIN

Date:	SEPT 1988
Project:	4001

E 2-1

CLIMATOLOGICAL SUMMARY FOR .UCCA FLAT, NEVADA, 1962 TO 1971[a]

(PAGE 1 OF 2)

MONTH	TEMPERATURE[b] (°F)							DEGREE DAYS (Base 65°)		PRECIPITATION[b,c] (INCHES)											
	AVERAGES			EXTREMES													SNOW				
	DAILY MAXIMUM	DAILY MINIMUM	MONTHLY	HIGHEST	YEAR	LOWEST	YEAR	HEATING	COOLING	AVERAGE	GREATEST MONTHLY	YEAR	LEAST MONTHLY	YEAR	GREATEST DAILY	YEAR	AVERAGE	GREATEST MONTHLY	YEAR	GREATEST DAILY	YEAR
JAN	52.1	20.8	36.5	73	1971	-2	1970	877	0	.53	4.02	1969	T	1971#	1.25	1969	0.9	4.3	1962	4.3	1962
FEB	56.7	25.8	41.3	77	1963	5	1971#	662	0	.84	3.55	1969	T	1967#	1.16	1969	1.9	17.4	1969	6.2	1969
MAR	60.9	27.7	44.3	87	1966	9	1969	634	0	.29	.60	1969	.02	1966	.38	1969	2.0	7.5	1969	4.5	1969
APR	67.8	34.4	51.1	89	1962	13	1966	411	1	.45	2.57	1965	T	1962	1.08	1965	0.7	3.0	1964	3.0	1964
MAY	78.9	43.5	61.2	97	1967	25	1967	147	38	.24	1.62	1971	T	1970#	.86	1971	0	T	1964	T	1964
JUN	87.6	49.9	68.8	107	1970	29	1971#	35	154	.21	1.13	1969	T	1971	.45	1969	0	0		0	
JUL	96.1	57.0	76.6	107	1967	40	1964#	0	366	.52	1.34	1966	0	1963	.77	1969	0	0		0	
AUG	95.0	58.1	76.6	107	1970	39	1968	1	368	.34	1.04	1965	0	1962	.35	1971#	0	0		0	
SEP	86.4	46.7	66.5	105	1971	25	1971	51	103	.68	2.38	1969	0	1968#	2.13	1969	0	0		0	
OCT	76.1	36.9	56.5	94	1964+	12	1971	266	9	.13	.45	1969	0	1967#	.42	1969	0	T	1971	T	1971
NOV	61.8	27.6	44.7	82	1962	13	1966	602	0	.71	3.02	1965	0	1962	1.10	1970	0.5	4.8	1964	2.3	1964
DEC	50.7	19.9	35.3	70	1964	-14	1967	914	0	.79	2.66	1965	T	1969#	1.31	1965	2.3	9.9	1971	7.4	1971
ANN	72.5	37.4	54.0	107	AUG 1970#	-14	DEC 1967	4600	1039	5.73	4.02	JAN 1969	0	SEP 1968#	2.13	SEP 1969	8.3	17.4	FEB 1969	7.4	DEC 1971

[a] Source: Bowen and Egami (1983a). Blanks indicate not applicable.

[b] H = most recent of multiple occurrences.

[c] T - trace (amount too small to measure).

[d] Average and peak speeds are for the period December 1964 through May 1969. The directions of the resultant wind are from a summary covering the period December 1964 through may 1969.

[e] Sky cover is expressed in the range from 0 for no clouds to 10 when the sky is completely covered with clouds. Clear, partly cloudy, and cloudy, are defined as average daytime cloudiness of 0.3, 4.7, and 8.10, respectively.

[f] * = one or more occurrences during the period of record but average less than one-half day.

TABLE 1

CLIMATOLOGICAL SUMMARY FOR YUCCA FLAT, NEVADA, 1962 TO 1971[a]

(PAGE 2 OF 2)

MONTH	RELATIVE HUMIDITY (%)				WIND[b,d] (SPEEDS IN MPH)					STATION PRESSURE (INCHES)			(e)	AVERAGE NUMBER OF DAYS[f]												
	HOUR (PACIFIC STANDARD TIME)				AVERAGE SPEED	PEAK SPEED		RESULTANT (DIR/SP)		AVERAGES	HIGHEST	LOWEST	AVERAGE SKY COVER SUNRISE TO SUNSET	SUNRISE TO SUNSET			PRECIPITATION				1.0 INCH OR MORE OF SNOW	THUNDERSTORMS	TEMPERATURE			
																							MAXIMUM		MINIMUM	
	04	10	16	22			YEAR	23-02 PST	11-14 PST					CLEAR	PARTLY CLOUDY	CLOUDY	.01 INCH OR MORE	.10 INCH OR MORE	.50 INCH OR MORE	1.00 INCH OR MORE			90° F OR MORE	32° F OR LESS	32° F OR LESS	0° F OR LESS
JAN	67	49	35	60	6.6	58	1965	233/0.7	135/2.8	26.10	26.54	25.42	4.9	13	8	10	2	1	*	*	*	*	0	1	29	*
FEB	67	45	32	56	6.9	52	1967	275/1.1	118/2.7	26.05	26.42	25.56	5.0	11	8	9	3	2	*	*	1	0	0	*	23	0
MAR	58	31	23	44	8.4	55	1971	240/1.8	186/4.5	25.99	26.43	25.40	4.0	12	9	10	3	1	0	0	1	1	0	0	24	0
APR	52	27	21	38	9.1	60+	1970#	250/2.2	198/5.1	25.96	26.39	25.50	4.5	13	9	8	3	1	*	*	*	1	0	0	12	0
MAY	46	22	17	31	8.3	60+	1967	260/1.5	179/7.2	25.94	26.39	25.47	4.3	14	11	6	2	1	*	0	0	1	4	0	2	0
JUN	39	19	14	26	7.9	60+	1967	272/1.9	185/8.2	25.92	26.20	25.56	3.0	19	7	4	2	1	0	0	0	2	14	0	*	0
JUL	40	20	15	28	7.5	55	1971	278/0.0	185/12.0	26.00	26.19	25.68	3.0	19	9	3	3	2	*	0	0	4	29	0	0	0
AUG	44	23	16	30	6.7	60+	1968	222/1.5	182/12.0	26.00	26.22	25.71	3.0	20	8	3	3	1	0	0	0	4	27	0	0	0
SEP	43	21	17	32	7.0	52	1970	281/1.3	163/6.4	26.00	26.30	25.56	2.1	22	6	2	2	1	1	*	0	2	11	0	1	0
OCT	46	24	19	36	6.8	60	1971	286/1.3	138/3.7	26.06	26.40	25.52	2.9	20	7	4	1	1	0	0	0	*	2	0	9	0
NOV	61	39	31	52	6.1	51	1970	234/1.2	152/4.1	26.08	26.58	25.64	4.8	13	7	10	3	2	*	*	*	*	0	0	23	0
DEC	68	50	41	64	6.6	53	1970	288/1.9	109/1.0	26.07	26.59	25.49	4.6	14	8	9	3	1	1	*	1	*	0	1	29	1
ANN	53	31	23	41	7.4	60+	APR 1970#	—	—	26.01	26.59	25.42	3.9	190	97	78	30	14	3	1	3	14	87	2	152	1

[a] Source: Bowen and Egami (1983a). Blanks indicate not applicable.

[b] # = most recent of multiple occurrences.

[c] T - trace (amount too small to measure).

[d] Average and peak speeds are for the period December 1964 through May 1969. The directions of the resultant wind are from a summary covering the period December 1964 through May 1969.

[e] Sky cover is expressed in the range from 0 for no clouds to 10 when the sky is completely covered with clouds. Clear, partly cloudy, and cloudy, are defined as average daytime cloudiness of 0-3, 4-7, and 8-10, respectively.

[f] * = one or more occurrences during the period of record but average less than one-half day.

TABLE 2-2 YUCCA FLAT AND BEATTY TEMPERATURE DATA[a]

	Temperature °F				
Month and Station[b]	Average daily maximum	Highest daily	Average daily minimum	Lowest daily	Monthly average
January					
Yucca Flat	52.1	73	20.8	-2	36.6
Beatty	57.5	78	26.7	7	40.6
February					
Yucca Flat	57.7	77	25.8	5	40.3
Beatty	58.2	80	24.6	1	43.9
March					
Yucca Flat	60.9	87	27.7	9	44.3
Beatty	65.6	85	33.9	16	49.7
April					
Yucca Flat	67.8	89	34.4	13	51.1
Beatty	74.0	98	41.0	17	57.5
May					
Yucca Flat	78.9	97	43.5	25	61.2
Beatty	82.0	103	47.9	26	65.2
June					
Yucca Flat	87.6	107	49.9	29	68.8
Beatty	92.3	112	55.5	33	74.0
July					
Yucca Flat	96.1	107	47.0	40	76.6
Beatty	99.5	114	62.1	36	80.8
August					
Yucca Flat	95.0	107	58.1	39	76.6
Beatty	97.2	113	59.9	41	78.6
September					
Yucca Flat	86.4	105	46.7	25	66.5
Beatty	90.5	109	53.4	34	72.0
October					
Yucca Flat	76.1	94	36.9	12	56.5
Beatty	77.4	98	43.6	22	60.5
November					
Yucca Flat	61.8	84	27.6	13	44.7
Beatty	65.3	86	33.5	10	49.4
December					
Yucca Flat	58.0	70	19.9	-14	35.3
Beatty	56.3	80	28.0	4	42.2
Annual average					
Yucca Flat	72.5	107	37.4	-14	54.9
Beatty	76.4	114	42.9	1	59.5

[a] Source: Eglinton and Dreicer (1984).

[b] Yucca Flat period of record: 1962 to 1971; Beatty period of record: 1922 to 1960.

2.2.3 Precipitation

Specific monthly and annual average and maximum precipitation amounts for the monitoring stations located in the vicinity of Yucca Mountain are presented in Table 2-3 (Eglinton and Dreicer, 1984). The data cover periods of record ranging from 5 years at tower T6 to 29 years at Beatty. The DOE considers the data presented thus far are a reasonable indication of overall precipitation cycles. They also believe that estimating precipitation at the Yucca Mountain site requires further analyses. The major variable that must be considered is elevation, as noted by several investigators (Quiring, 1983; Nichols, 1986). In addition, rainfall intensity and duration characteristics are needed for rainfall-runoff models and for recharge and infiltration studies. Modern meteorological conditions also form a basis for interpreting historical records and predicting future conditions.

2.3 HYDROGEOLOGIC STUDY AREA

The hydrogeologic study area shown on Figure 2-5 consists of three groundwater subbasins that together form a part of the Death Valley groundwater basin (Waddell et al., 1984). These subbasins are the Oasis Valley subbasin, Alkali Flat-Furnace Creek Ranch subbasin, and the Ash Meadow subbasin. The approximate boundaries of these groundwater subbasins have been estimated from potentiometric levels, geologic controls of subsurface flow, discharge areas, and inferred flow paths (Rush, 1970; Blankennagel and Weir, 1973; Winograd and Thordarson 1975; Dudley and Larson, 1976; Waddell, 1982; Waddell et al., 1984). In some areas, the boundaries are uncertain due to the lack of potentiometric data, the complexity of geologic structures, or the occurrence of interbasin flow of groundwater through the lower carbonate aquifer (Winograd and Thordarson, 1975). In the following sections, each subbasin is described by their flow paths, recharge, and discharge areas.

2.3.1 Oasis Valley Subbasin

The DOE states that flow paths are from the principal recharge areas, mostly in the central part of the subbasin southward, towards the discharge area near Beatty. This flow is principally through volcanic-rock aquifers to the valley-fill aquifer underlying the discharge areas. Groundwater discharge within the Oasis Valley subbasin occurs through evapotranspiration and spring flow near Beatty. This spring flow, caused by low-permeability rocks

TABLE 2-3

MONTHLY AND ANNUAL AVERAGE AND MAXIMUM PRECIPITATION FOR SITES IN THE VICINITY OF YUCCA MOUNTAIN[a]

	Precipitation (in.)[b,c]													
	BJY 1,241 mMSL (1960-1981)		Yucca Flat 1,196 mMSL (1962-1971)		Desert Rock 1,005 mMSL (1963-1981)		4JAn 1,043 mMSL (1967-1981)		4JAo 1,100 mMSL (1957-1967)		T6 902 mMSL (1958-1964)		Beatty 1,006 mMSL (1931-1960)	
Month	Avg.	Max.	Avg.	Max.[d]	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
January	0.76	3.41	0.53	4.02	0.64	2.15	0.63	2.29	0.27	0.62	0.37	0.88	0.60	NA[e]
February	0.87	3.42	0.84	3.60	0.78	2.57	1.08	3.45	0.39	1.01	0.59	1.20	0.70	NA
March	0.73	3.58	0.29	3.50	0.70	3.08	0.83	3.00	0.16	0.35	0.16	0.30	0.48	NA
April	0.34	2.40	0.45	2.70	0.33	1.45	0.18	0.63	0.34	1.91	0.10	0.45	0.47	NA
May	0.33	2.02	0.24	1.62	0.35	1.57	0.31	1.41	0.11	0.28	0.15	0.48	0.23	NA
June	0.21	1.22	0.21	2.66	0.14	0.56	0.13	0.67	0.07	0.26	0.14	0.55	0.09	NA
July	0.48	1.54	0.52	1.87	0.34	1.46	0.35	1.50	0.19	0.48	0.50	2.29	0.20	NA
August	0.45	2.38	0.34	2.52	0.52	1.57	0.31	1.97	0.25	0.71	0.22	0.54	0.20	NA
September	0.53	1.89	0.68	2.38	0.38	2.28	0.28	2.13	0.47	1.68	0.50	1.62	0.19	NA
October	0.36	1.49	0.13	1.69	0.25	1.05	0.32	1.42	0.21	0.63	0.22	0.76	0.30	NA
November	0.50	2.37	0.71	3.02	0.50	2.07	0.33	1.22	0.54	1.67	0.61	1.49	0.43	NA
December	0.57	2.61	0.79	2.66	0.46	2.45	0.33	1.78	0.63	3.03	0.44	1.14	0.58	NA
Annual	6.03	12.13	5.73	14.05	5.39	10.08	5.08	11.62	3.63	8.06	4.00	4.61	4.47	NA

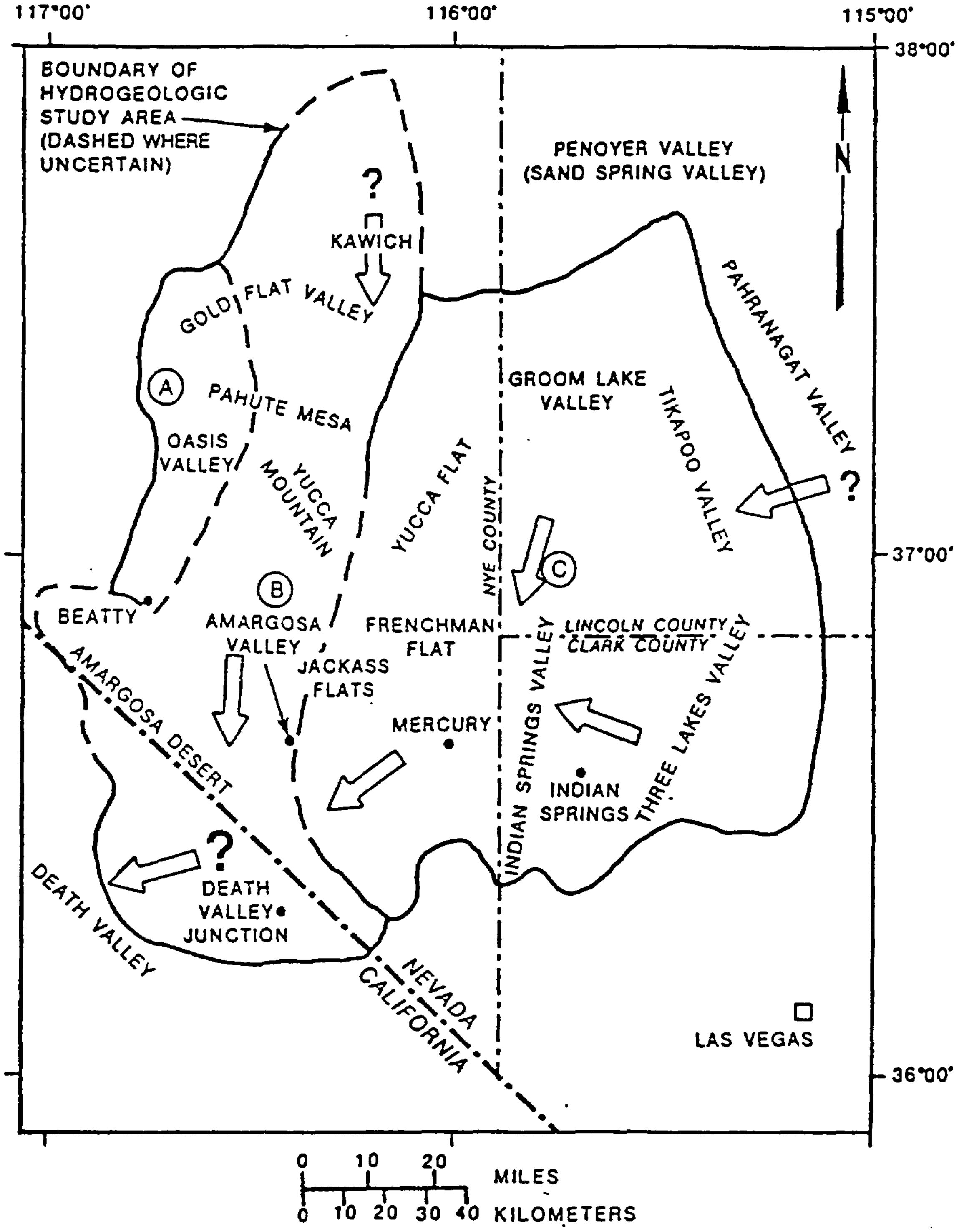
[a] Source: Eglinton and Dreicer (1984). The locations of the monitoring stations are shown on Figure 2-4.

[b] All values are monthly or annual averages. To convert in. to mm, multiply by 25.4.

[c] mMSL = meters above mean seal level; Avg.=average; Max.=maximum.

[d] Period of record is 1958-1981.

[e] NA = not available.



⇨ GENERAL DIRECTION OF REGIONAL GROUND-WATER FLOW (QUESTION MARK INDICATES UNCERTAINTY)

A. OASIS VALLEY SUBBASIN
B. ALKALI FLAT-FURNACE CREEK RANCH SUBBASIN
C. ASH MEADOWS SUBBASIN

SOURCE: RUSH (1970), BLANKENNAGEL AND WIER (1973), WINOGRAD AND THORDARSON (1975), DUDLEY AND LARSEN (1976), WADDELL (1982) AND WADDELL et al. (1984)

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FIGURE 2-5
HYDROGEOLOGIC STUDY AREA

Date:
Project: 4001

downgradient from Beatty, has been estimated to be 0.078 m^3/s (Malmberg and Eakin, 1962). Some of the spring discharge is warm, suggesting deep circulation. Water flows to the discharge area from the north and northeast (Pahute Mesa) as shown by Mifflen (1968), Rush (1970), Scott et al. (1971), Blankennagel and Weir (1973), Winograd and Thordarson (1975), Waddell (1982), and Waddell et al. (1984).

2.3.2 Alkali Flat-Furnace Creek Ranch Subbasin

Winograd and Thordarson (1975) believed that groundwater flows from the south-central Amargosa Desert, through the lower carbonate aquifer, discharging at springs and seeps at Furnace Creek Ranch. These springs are created by impermeable zones along the Furnace Creek fault system. Groundwater in the lower carbonate aquifer beneath the south-central Amargosa Desert may be derived from two sources--direct southwestward underflow from the Ash Meadows groundwater subbasin through the lower carbonate aquifer (assuming that the aquifer is extensive beneath the central Amargosa Desert) and downward leakage from the valley-fill aquifer beneath the central and south-central Amargosa Desert.

Discharge by natural processes in the Amargosa Desert was estimated by Walker and Eakin (1963) to be about 3×10^7 m^3/yr, based on mass-balance estimates, which they acknowledge are "crude". Groundwater outflow southward from the subbasin was estimated to be about 6.2×10^5 m^3/yr. Discharge near Furnace Creek Wash and Cottonball Marsh was estimated, based on some direct measurements of spring discharge and mapping of seeps in alluvium, to be about 6.3×10^6 m^3/yr (Hunt et al., 1966). Total flux (volumetric flow rate) in the Alkali Flat-Furnace Creek Ranch subbasin, not including the discharge in the Oasis Valley and Ash Meadows subbasins, is estimated to be about 2×10^7 m^3/yr (Waddell, 1982).

2.3.3 Ash Meadows Subbasin

Ash Meadows groundwater basin is in the eastern half of the study area. Flow is primarily in the lower carbonate aquifer, where it originates in the recharge areas in the Spring Mountains, Pahranagat, Timpahute, and Sheep Ranges, and Pahranagat Valley, and discharges at the Ash Meadows spring lineament (Waddell, 1982). Potentiometric gradients throughout much of the basin are low (commonly less than 0.0002) because of high transmissivities exhibited by soluble carbonate rocks (Winograd and Thordarson 1975).

The lower carbonate aquifer transmits most of the water in the subbasin, but other lithologies are locally important. Northeast of the Ash Meadows spring line, the saturated thickness of the valley fill aquifer probably is more than 100 m. Beneath Frenchman Flat, both valley fill and volcanic aquifers are saturated beneath the structurally deepest parts of the valley. Most of the valley-fill aquifer beneath Yucca Flat is unsaturated (Winograd and Thordarson, 1975).

Discharge from springs at Ash Meadows is estimated to be 2 x 10^7 m^3/yr (Walker and Eakin, 1963; Dudley and Larson, 1976). An additional unknown amount of groundwater flows to the Alkali Flat-Furnace Creek Ranch subbasin to the west, some of which discharges by evapotranspiration (Winograd and Thordarson, 1975). A normal fault, downthrown to the southwest (Healey and Miller, 1971), probably juxtaposes a low-permeability lakebed aquitard or eolian deposits on the downthrown side of the fault against the lower carbonate aquifer across the fault, forcing flow upward (Dudley and Larson, 1976). Discharge is from springs in alluvium downgradient (southwest) of the fault. Regional transmissivities of about 40,000 m^2/d have been calculated (Winograd and Thordarson, 1975) for the lower carbonate aquifer in the area northeast of Ash Meadows using estimated values for discharge, hydraulic gradient, and width of the aquifer; this figure is six to nine times greater than that determined from aquifer tests (Waddell, 1982).[1]

2.4 HYDROGEOLOGIC UNITS

The occurrence and movement of groundwater in the vicinity of Yucca Mountain is controlled in part by the regional hydrogeologic system. The

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[1] WWL Comment - Regional Transmissivity Values
There appears to be a broad range of transmissivity values for the principle regional aquifers of the Candidate Area, both between individual aquifers and within each aquifer. Regional flow models have assumed uniform hydraulic properties in their characterization of regional groundwater flow, (ie: transmissivity being held constant over the entire regional aquifer). These values may not represent the true field values found in this anisotropic system, thereby leading to misrepresentations of the regional flow system. Alternative three-dimensional models should be considered to include these variations in transmissivity values so that a better representation of regional groundwater flow paths and magnitudes can be obtained.

hydrogeologic units within this system have varied hydraulic characteristics and interrelationships and, hence, exert varying controls on groundwater flow rates and directions. In this section, the general aquifer properties and characteristics of these units, their lateral extent, and their interrelationships are described.

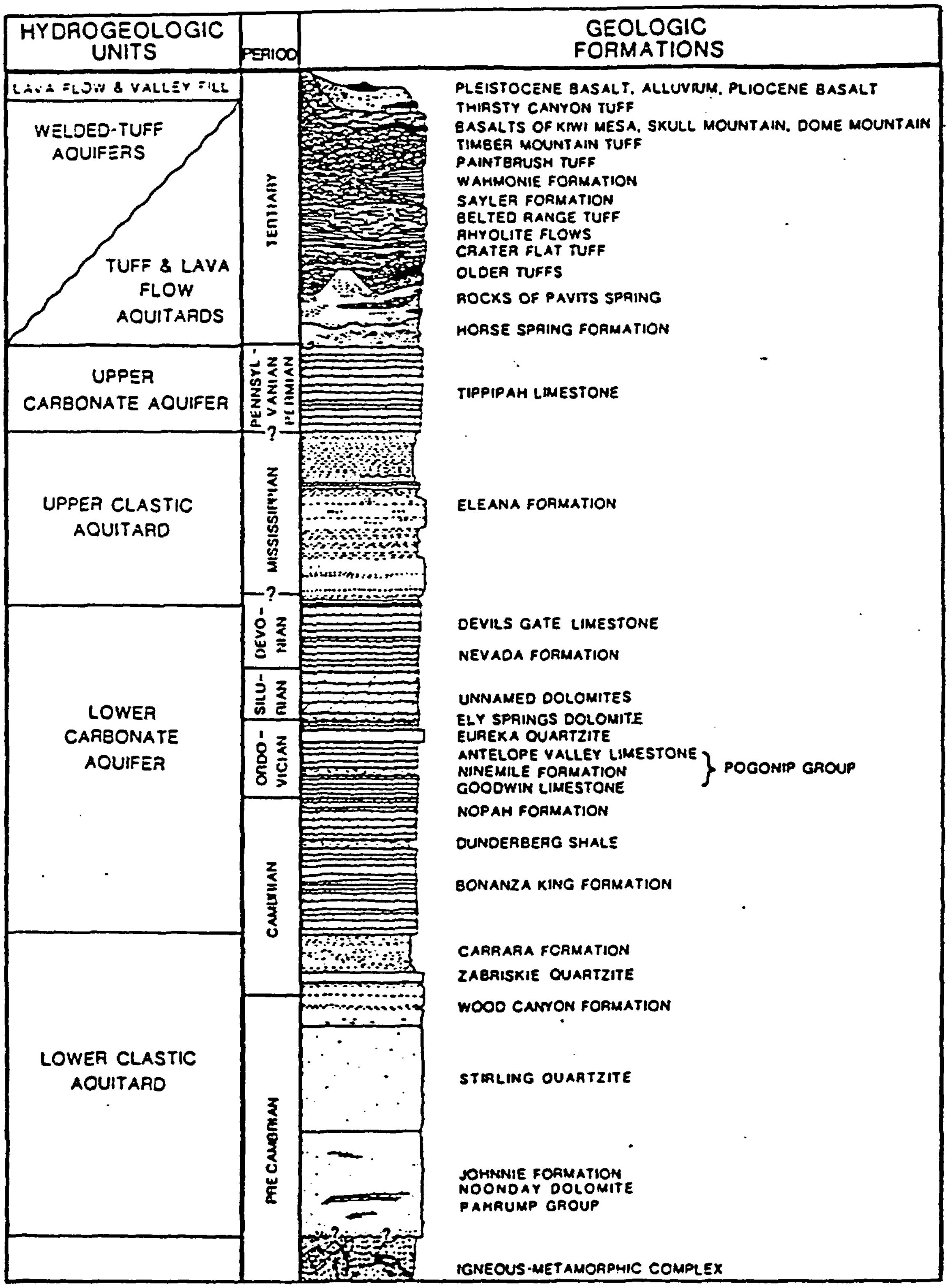
2.4.1 Description of Hydrogeologic Units

The studies conducted by Winograd and Thordarson (1975) and additional assessments summarized by Waddell et al. (1984) identify the regional hydrogeologic units discussed in the following sections. These discussions are limited to units that represent distinct hydraulic systems on a regional scale and do not necessarily represent the individual properties of those units specifically at the Yucca Mountain site. Figure 2-6 illustrates a generalized regional stratigraphic column with the principle hydrogeologic units characteristic of the region surrounding Yucca Mountain. A generalized map showing the distribution of these units in the hydrogeologic study area is provided on Figure 2-7. The areal distribution of the hydrogeologic units and their lithology and stratigraphy discussed in this section help to define the hydraulic communication on a regional scale. Details of the stratigraphic and hydrogeologic units are summarized in Table 2-4. The regional hydrogeologic units in descending stratigraphic order are; (1) the valley fill aquifer, (2) volcanic rock aquifers and aquitards, (3) the upper carbonate aquifer, (4) the upper clastic aquitard, (5) the lower carbonate aquifer, and (6) the lower clastic aquitard.

2.4.1.1 Valley Fill Aquifer

The valley fill aquifer is of Tertiary and Quaternary age and is composed of alluvial-fan, fluvial, fanglomerate, lake bed, and mudflow deposits. The thickness and stratigraphic interrelationships of these deposits are highly variable reflecting varying depositional environments.

Grain size of alluvial deposits decreases from the proximal to the distal ends of the alluvial fans and away from distributary channels on the fans. Because runoff intensities vary from event to event, interbedding of fine- and coarse-grained materials occur in the valley fill. This condition results in vertical hydraulic conductivities being much less than horizontal conductivities (DOE, 1988). The valley fill aquifer reaches thicknesses of



SOURCE: MODIFIED FROM SINNOCK (1982)

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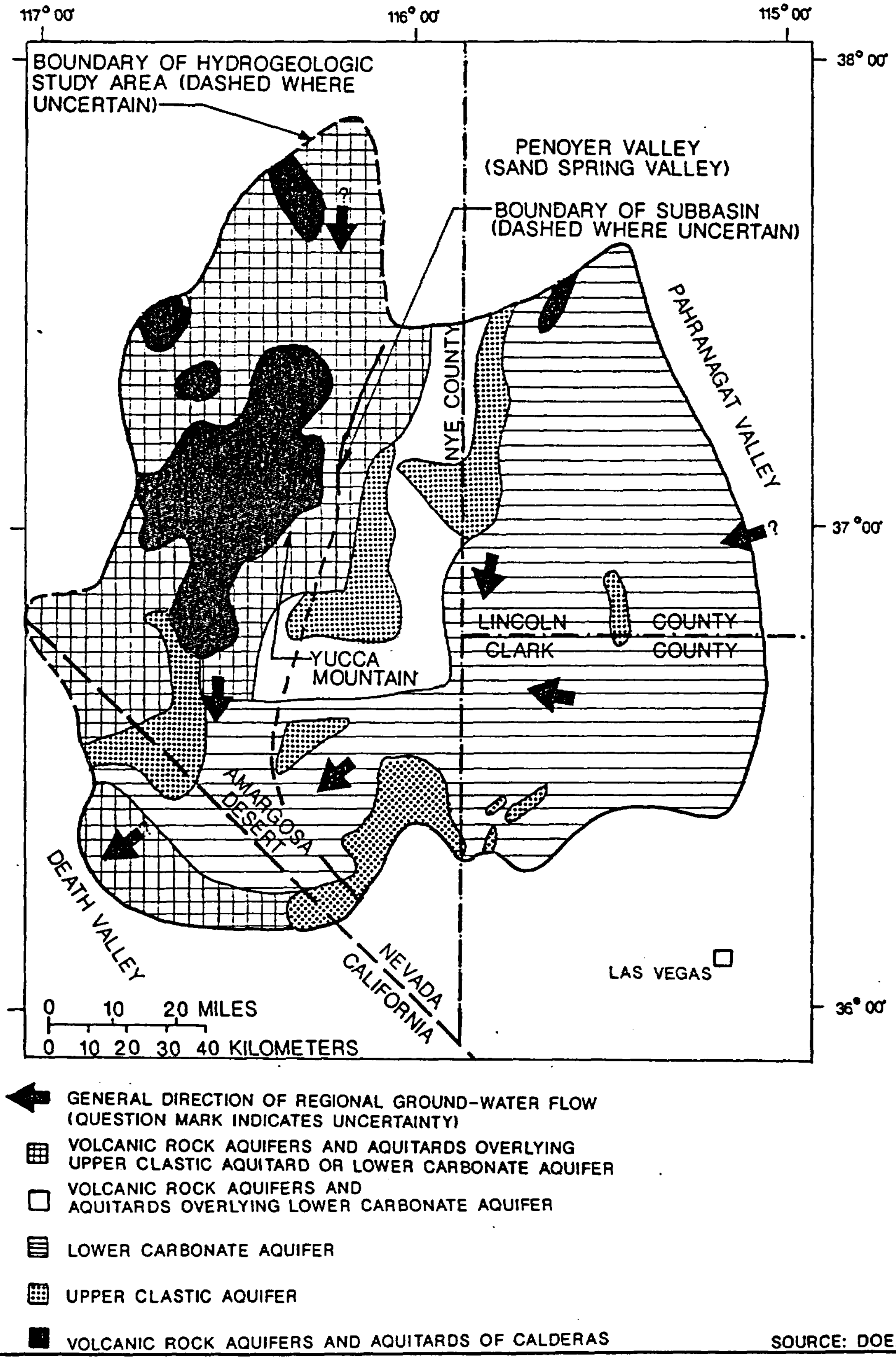
FIGURE 2-6
GENERALIZED REGIONAL STRATIGRAPHIC COLUMN
SHOWING GEOLOGIC FORMATIONS AND
HYDROGEOLOGIC UNITS

Date: SEPT 1988

Project: 4001



SOURCE: DOE, 1986

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FIGURE 2-7
GENERALIZED DISTRIBUTION OF HYDROGEOLOGIC UNITS

DATE: SEPT 1988

PROJECT: 4001

TABLE 2-4

RELATION OF STRATIGRAPHIC UNITS TO HYDROGEOLOGIC UNITS IN THE HYDROGEOLOGIC STUDY AREA[a]

(PAGE 1 OF 6)

System	Series	Stratigraphic Unit	Major Lithology	Maximum Thickness (m)	Hydrogeologic Unit (Underlined) and Hydrologic Characteristics
Quaternary and Tertiary	Holocene, Pleistocene, and Pliocene deposits	Valley fill	Alluvial fan, fluvial, fanglomerate, lakebed, and mudflow ranges from 0.21 to 2.9 m/d	600	VALLEY FILL AQUIFER Transmissivity ranges from 10 to 400 m^2/d average coefficient of interstitial permeability ranges from 0.21 to 2.9 m/d. Interstitial porosity controls flow of water.
Tertiary	Pliocene	Basalt of Kiwi Mesa	Basalt flows, dense and vesicular	75	LAVA-FLOW AQUIFER Water movement controlled by primary and secondary fractures and possibly by rubble between intercrystalline porosity and conductivity negligible; estimated transmissivity ranges from 4.2 to 1,200 m^2/d; saturated only beneath east-central Jackass Flats.
		Rhyolite of Shoshone Mountain	Rhyolite flows	600	
		Basalt of Skull Mountain	Basalt flows	75	
	?[b]	Thirsty Canyon Tuff	Ash-flow tuff, partially to densely welded; trachytic lava flows	230	No corresponding hydrologic unit. Generally unsaturated; present beneath Black Mountain, northwestern part of the basin.
	Miocene[c]	Piapi Canyon Group Timber Mountain Tuff Ammonia Tank Member	Ash-flow tuff, moderately to densely welded; thin ash-fall tuff at base	75	WELDED AND BEDDED TUFF AQUIFER Water movement controlled by primary and secondary joints in densely welded part of ash-flow tuff; transmissivity ranges from 1 to 1,200 m^2/d; intercrystalline porosity and conductivity negligible; nonwelded part of ash-flow tuff, where present, has relatively high interstitial porosity (35 to 50%) and modest permeability (0.08 m/d) and may act as a leaky aquitard; saturated only beneath deeper parts of Yucca, Frenchman, and Jackass flats.
		Piapi Canyon Group Timber Mountain Tuff Rainier Mesa Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff at base	175	
Tertiary	Miocene	Piapi Canyon Group Tiva Canyon Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff near here.	90-100	
		Paintbrush Tuff Topopah Spring Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff near base	275	

TABLE 2-4

RELATION OF STRATIGRAPHIC UNITS TO HYDROGEOLOGIC UNITS IN THE HYDROGEOLOGIC STUDY AREA[a]

(PAGE 2 OF 6)

System	Series	Stratigraphic Unit		Major Lithology	Maximum Thickness (m)	Hydrogeologic Unit (Underlined) and Hydrologic Characteristics
Tertiary	Miocene[c]		Bedded Tuff (informal unit)	Ash-flow tuff and fluvially reworked tuff	300	Transmissivity ranges from 2 to 10 m^2/d; saturated only beneath structurally deepest parts of Yucca, Frenchman, and Jackass Flats; occurs locally below ash-flow tuff members of Paintbrush Tuff and below Grouse Canyon Member of Belted Range tuff.
		Wahmonie Formation		Lava-flow and interflow tuff and breccia; locally hydrothermally altered	1,200	LAVA-FLOW AND TUFF AQUITARD Water movement controlled by connected fractures; interstitial thermally altered porosity and permeability negligible; transmissivity estimated less than 6 m^2/d; contains minor perched water beneath foothills between Frenchman and Jackass flats.
				Ash-fall tuff, tuffaceous sandstone, and tuff breccia all interbedded; matrix commonly clayey or zeolitic	500	Transmissivity ranges from 1 to 3 m^2/d; interstitial porosity is as high as 40%, but interstitial permeability is negligible; (3×10^{-4} to 3×10^{-6} m/d); owing to poor hydraulic connection of fractures, interstitial conductivity probably controls regional ground-water movement; perches minor quantities of water beneath foothills flanking valleys; fully saturated only beneath structurally deepest parts of Yucca, Frenchman, and Jackass flats; Grouse Canyon and Tub Spring members of belted Range Tuff may locally be aquifers in northern Yucca Flat.
		Salyer Formation		Breccia flow, lithic breccia, and tuff breccia, all interbedded with ash-fall tuff, sandstone, siltstone, claystone, matrix commonly clayey or zeolitic	600	
		Belted Range Tuff	Grouse Canyon Member	Ash-flow tuff, densely welded	60	
			Tub Spring Member	Ash-flow tuff, non-welded to welded	90	

TABLE 2-4

RELATION OF STRATIGRAPHIC UNITS TO HYDROGEOLOGIC UNITS IN THE HYDROGEOLOGIC STUDY AREA[a]

(PAGE 3 OF 6)

System	Series	Stratigraphic Unit	Major Lithology	Maximum Thickness (m)	Hydrogeologic Unit (Underlined) and Hydrologic Characteristics
		Local Informal Units	Ash-fall bedded tuff, nonwelded to semiwelded ash-flow tuff, tuffaceous sandstone. Siltstone, and claystone; all massively altered to zeolite or clay minerals; locally minor welded tuff near base; minor rhyolite and basalt	600	
Tertiary	Miocene[c]	Rhyolite flows and tuffaceous beds of Calico Hills	Rhyolite nonwelded and welded ash flow, ash-fall tuff, tuff breccia, tuffaceous sandstone; hydrothermally altered at Calico Hills; matrix of tuff and sandstone commonly clayey or zeolotic	600	TUFF AQUIFER/AQUITARD Rhyolite lavas and ash flows may be transmissive. Bedded tuffs may be zeolitized or argillized and less transmissive. Beneath Yucca Mountain the tuffaceous beds of Calico Hills are mostly unsaturated.
	Flat	Crater Bullfrog Tuff Prow Pass Member Member Tram Member	Ash-flow tuff, nonwelded to moderately welded, interbedded with ash-fall bedded tuff; matrix commonly clayey or	>600	TUFF AQUIFER/AQUITARD Transmissivity ranges from less than 0.1 to several hundred m^2/d. Interstitial hydraulic conductivity is small (8×10^{-4} to 3×10^{-1} m^2/d). At Yucca Mountain, unit commonly contains the water table.
		Lithic Ridge Tuff	Ash-flow tuff, partially to densely welded. Commonly argillized	300	TUFF AQUITARD Not well characterized. Transmissivity about 2×10^{-4} m^2/d. Interstitial hydraulic conductivity low (3×10^{-4} to 6×10^{-5} m/d).
Tertiary	Miocene (?) Oligocene (?)	Older tuffs and lavas beneath Yucca Mountain	Altered rhyolitic and altered bedded and ash-flow tuffs	?	

TABLE 2-4

RELATION OF STRATIGRAPHIC UNITS TO HYDROGEOLOGIC UNITS IN THE HYDROGEOLOGIC STUDY AREA[a]

(PAGE 4 OF 6)

System	Series	Stratigraphic Unit	Major Lithology	Maximum Thickness (m)	Hydrogeologic Unit (Underlined) and Hydrologic Characteristics
	Miocene and Oligocene	Rocks of Pavits Springs	Tuffaceous sandstone and siltstone, claystone; fresh water limestone and conglomerate; minor gypsum; matrix commonly clayey, zeolitic, or calcerous	425	See Salyer Formation.
Tertiary (continued)	Oligocene	Horse Springs Formation	Fresh-water limestone, conglomerate, tuff	300	See Salyer Formation
Cretaceous to Permian		Granitic stocks	Granodiorite and quartz monzonite in stocks, dikes and sills	---	<u>(A MINOR PLUTONIC-ROCK AQUITARD)</u> Complexly fractured by nearly impermeable.
Mississippian and Devonian		Eleana Formation	Argilliate, quartzite, conglomerate, limestone	2,400	<u>UPPER CLASTIC AQUITARD</u> Complexly fractured but nearly impermeable; transmissivity estimated less than 5 m^2/d; interstitial permeability negligible but owing to poor hydraulic connection of fractures probably controls groundwater movement; saturated only beneath western Yucca and Jackass Flats, interstitial porosity ranges from 2.0 to 18%.
Devonian	Upper	Devils Gate Limestone	Limestone, dolomite, quartzite	>425	<u>LOWER CARBONATE AQUIFER</u> Complexly fractured aquifer supplies major springs throughout easter Nevada; transmissivity ranges from 10 to 10,000 m^2/d; intercrystalline porosity, 0.4 to 12%; intercrystalline hydraulic permeability, 9 x 10^{-1} to 4 x 10^{-3} m/d; solution caverns are present locally but regional ground-water movement is controlled by fracture transmissivity; saturated beneath much of study area.
	---?---	Middle	Nevada Formation	Dolomite	
Devonian and Silurian		Undifferentiated	Dolomite	430	
	Upper	Ely Springs Dolomite	Dolomite	90	
		Eureka Quartzite	Quartzite, minor limestone	100	

TABLE 2-4

RELATION OF STRATIGRAPHIC UNITS TO HYDROGEOLOGIC UNITS IN THE HYDROGEOLOGIC STUDY AREA[a]

(PAGE 5 OF 6)

System	Series	Stratigraphic Unit		Major Lithology	Maximum Thickness (m)	Hydrogeologic Unit (Underlined) and Hydrologic Characteristics
	Middle		Antelope Valley Limestone	Limestone and silty limestone	460	
Ordovician	---?---					
	Lower	Pogonip Group	Ninemile Formation	Claystone and limestone interbedded	100	
			Goodwin Limestone	Limestone	>275	
Cambrian	Upper	Nopah Formation				
		Smoky Member		Dolomite, limestone	325	
		Halfpint Member		Limestone, dolomite silty limestone	220	
		Dunderberg Shale Member		Shale, minor limestone	70	
Cambrian	Middle	Bonanza King				
		Banded Mountain Member		Limestone, dolomite, minor siltstone	750	
		Papoose Lake Member		Limestone, dolomite, minor siltstone		
		Carrara Formation		Siltstone, limestone, interbedded (upper part predominantly limestone; lower part predominantly siltstone	320	
	Lower					

TABLE 2-4

RELATION OF STRATIGRAPHIC UNITS TO HYDROGEOLOGIC UNITS IN THE HYDROGEOLOGIC STUDY AREA[a]

(PAGE 6 OF 6)

System	Series	Stratigraphic Unit	Major Lithology	Maximum Thickness (m)	Hydrogeologic Unit (Underlined) and Hydrologic Characteristics
Precambrian		Zabriskie Quartzite	Quartzite	70	<u>LOWER CLASTIC AQUITARD</u> Complexly fractured but nearly impermeable; supplies no major springs; transmissivity less than 10 m^2/d; interstitial porosity and permeability is negligible but probably controls ground-water movement owing to poor hydraulic connection of fractures, saturated beneath most of area; interstitial porosity 0.2 to 10%; interstitial hydraulic conductivity range from 3×10^{-5} to 4×10^{-3} m/d.
		Wood Canyon Formation	Quartzite, siltstone, shale, minor dolomite	70	
		Stirling Quartzite	Quartzite, siltstone	1025	
		Johnnie Formation	Quartzite, sandstone, siltstone, minor limestone and dolomite	975	
		Noonday (?) Dolomite	Dolomite	---	

[a] Source: Waddell et al. (1984), which was modified from Winograd and Thordarson (1975).

[b] ? indicates uncertainty.

[c] The three Miocene sequences occur in separate parts of the region. Age correlations between sequences are uncertain.

more than 550 meters in some areas of the region; however, areas where the alluvium is saturated are limited. Therefore, this hydrogeologic unit is of minor importance in defining groundwater flow on a regional scale. The exception to this can be found beneath the Amargosa Desert, where valley fill is present in saturated thicknesses sufficient to constitute an important aquifer.

2.4.1.2 Volcanic Rock Aquifers and Aquitards

Volcanic rocks that occur in the study area consist of ash-flow and ash-fall tuffs (nonwelded to welded), and basaltic and rhyolitic flows of Tertiary and Quaternary ages. Some of these rocks are aquifers while others are aquitards. The volcanic aquifers form the uppermost water-bearing unit throughout most of the northwestern part of the hydrogeologic study area. The thickness of this unit is estimated to exceed several thousand meters in some places (Waddell et al., 1984). Because of the complex stratigraphy of these volcanics, individual rock types are not differentiated on a regional scale.

Rock properties of these volcanics are dependent on the eruptive history, the cooling history, post-depositional mineralogic changes, and the structural setting. Ash flow tuff permeability is in part a function of the degree of fracturing, and thus, the degree of welding (Winograd, 1971; Blankennagel and Weir, 1973). Densely welded tuff fractures readily while nonwelded tuff does not. Therefore, distribution of permeability is affected by the irregular distribution of tuff lithologies as well as a function of proximity to faults and fracture zones.

2.4.1.3 Upper Carbonate Aquifer

The upper carbonate aquifer, although more than 1000 meters thick, is of minor regional hydrologic significance because it is saturated only in western Yucca Flat (Waddell et al., 1984). This unit is composed of the Tippipah Limestone of Pennsylvanian and Permian age. This aquifer is not hydrologically separable from the underlying lower carbonate aquifer where the upper clastic aquitard is absent (eastern section of the hydrogeologic study area).

2.4.1.4 Upper Clastic Aquitard

The upper clastic aquitard is equivalent to the Eleana Formation (Devonian and Mississippian age) and consists predominantly of argillite, quartzite, and conglomerate. This unit is over 2400 meters thick in western Yucca Flat and northern Jackass Flats. The Eleana Formation stratigraphically and hydraulically separates the upper and lower carbonate aquifer (Winograd and Thordarson, 1975). Winograd and Thordarson (1975) have reported porosity ranges of this formation to be 2.0 to 18.3 percent with predominate groundwater movement through interstitial permeability due to poor hydraulic connection of fractures within the formation.

2.4.1.5 Lower Carbonate Aquifer

The lower carbonate aquifer is comprised of limestone in the upper part of the Carrara Formation and the succeeding limestones and dolomites of Cambrian, Ordovician, Silurian, and Devonian age. This aquifer represents the principal water transmitter in the eastern part of the hydrogeologic study area. Total thickness of the aquifer exceeds 4700 meters, with high transmissivities occurring where dissolution has increased fracture aperture or pore diameter (Waddell et al., 1984). Waddell et al. (1984) believe that variations in structural setting, proximity to faults, mechanical rock properties, depositional environments, and aquifer thickness account for the large variations in observed transmissivity values.

2.4.1.6 Lower Clastic Aquitard

The lower clastic aquitard is composed of the lower part of the overlying Carrara Formation, upper Proterozoic quartzite and shale of the Johnnie, Stirling, and Wood Canyon Formations, which are approximately 2700 meters thick (Winograd and Thordarson, 1975). The lower clastic aquitard probably significantly affects distribution of hydraulic potentials and locations of groundwater discharge areas due to low transmissivity values (Waddell et al., 1984).

2.4.2 Hydraulic Characteristics of Hydrogeologic Units

Estimates of groundwater flow paths and velocities require that the hydraulic characteristics of each of the important hydrogeologic units be known. The principal hydraulic characteristics discussed are transmissivity, porosity, and both interstitial and fracture hydraulic conductivity.

Table 2-5 presents data, based on information published by Winograd and Thordarson (1975), on the hydraulic properties of the regional units.

TABLE 2-5

PUMPING TEST DATA FOR AQUIFERS IN NEVADA TEST SITE AND VICINITY[a] (PAGE 1 OF 5)

Well	Strati-graphic Unit	Depth Interval (a)	Estimated Penetration of Aquifer (%)	Depth to Static Level (m)	Specific Capacity (L/s per Meter of Drawdown)[b]	Transmissivity (m^3/d) Estimated from Specific Capacity	Calculated from Drawdown Curve	Calculated from Recovery Curve	Remarks
79-69a	Carrara Formation	469-518	--[c]	469	110	1×10^4	--	--	Well 79 69a is 30 m northwest of well 79-59. During two pumping tests neither drawdown nor recovery could be measured owing to very high aquifer transmissivity and low pumping rates (3.7 and 13.4 L/s). Carrara Formation tapped by well is probably part of upper plate of low-angle thrust fault that crops out a few miles west of well.
69-59	Carrara	469-503	--	459	1.28	75	(d)	(d)	Step-drawdown analyses indicates specific capacity of 2.4 (L/s)/m of drawdown and water entry chiefly from interval 490 495 m. Carrara Formation tapped by well is probably part of upper plate of low-angle thrust fault that crops out a few miles west of well.
67-73	Bonanza King Formation (Banded Mountain Member)	311-397	5	256	0.99	100	250	660	Step-drawdown analysis indicates specific capacity of 2.3 (L/s)/m of drawdown.

TABLE 2-5

PUMPING TEST DATA FOR AQUIFERS IN NEVADA TEST SITE AND VICINITY[a] (PAGE 2 OF 5)

						Transmissivity (m^3/d)			
Well	Strati-graphic Unit	Depth Interval (a)	Estimated Penetration of Aquifer (%)	Depth to Static Level (m)	Specific Capacity (L/s per Meter of Drawdown)[b]	Estimated from Specific Capacity	Calculated from Drawdown Curve	Calculated from Recovery Curve	Remarks
67-73	Bonanza King (?) Formation	406-593							Step-drawdown analysis indicates specific capacity of 3.6 (L/s)/m of drawdown.
	Nopah Formation (?)	239-356	20	239	1.24	75	490	1,100	
56-75	Nopah Formation (Smoky Member)	225-454	10	225	0.93	50	140	330	Step-drawdown analysis indicates specific capacity of 2.2 (L/s)/m of drawdown.
	(?)	239-356	20	239	1.24	75	490	1,100	
88-66	Pogonip Group	777-1,942	10	626	0.08	9	16	66	Water yielded principally from
75-73	Pogonip Group	336-565	10	336	0.14	7	47	--	Interval 968-1040 m
73-66	Silurian (?) dolomite	956-1,036	<5	529	6.21[a]	740	--	--	Density changes in water column, due to anomalously high water temperature, completely
87-62	Devils Gate Limestone and Nevada Formation undifferentiated	1,128-1,280	<20	600	0.17	12	--	43	Masked water level fluctuations due to pumping. Air-line measurements permitted approximation of specific capacity.
84-68d	Devonian (?) dolomite and calcareous quartzite	860-922	<5	598	0.08	9	30	--	--

TABLE 2-5

PUMPING TEST DATA FOR AQUIFERS IN NEVADA TEST SITE AND VICINITY[a] (PAGE 3 OF 5)

Well	Strati-graphic Unit	Depth Interval (a)	Estimated Penetration of Aquifer (%)	Depth to Static Level (m)	Specific Capacity (L/s per Meter of Drawdown)[b]	Transmissivity (m^3/d)			Remarks
						Estimated from Specific Capacity	Calculated from Drawdown Curve	Calculated from Recovery Curve	
				BEDDED TUFF AQUIFER					
81-67	Bedded tuff (?) of Piapi Canyon Group	514-549	--	478	0.19	12	16	26	Aquifer is probably bedded tuff or non-welded ash-flow tuff.
81-67	Bedded tuff (?) of Piapi Canyon Group	149-204	--	149	0.08	2	--	--	Constant-rate pumping test not made; specific capacity based on measurements made after 90 min pumping; aquifer is probably bedded tuff on non-welded ash-flow tuff.
90-75	Bedded tuff (?) of Piapi Canyon Group	273-333	--	273	0.12	5	--	--	Constant-rate pumping test not made; specific capacity reported after 30 min of pumping; aquifer is probably bedded tuff or nonwelded ash-flow tuff.
75-58	Topopah Spring Member of Paintbrush Group	226-270	40	226	11.6	1,240	See remarks	See remarks	Drawdown of 2.1 m measured with air line and test pressure gage in first 3 min of pumping test at rate of 24.4 L/s. Additional drawdown not detectable in subsequent 67 min of pump test.

TABLE 2-5

PUMPING TEST DATA FOR AQUIFERS IN NEVADA TEST SITE AND VICINITY[a] (PAGE 4 OF 5)

						Transmissivity (m^3/d)			
Well	Stratigraphic Unit	Depth Interval (a)	Estimated Penetration of Aquifer (%)	Depth to Static Level (m)	Specific Capacity (L/s per Meter of Drawdown)[b]	Estimated from Specific Capacity	Calculated from Drawdown Curve	Calculated from Recovery Curve	Remarks
74-57	Topopah Spring Member of Paintbrush Group	283-444	100	283	4.6	500	850	--	Step-drawdown analysis suggests considerable head losses at face of bore; losses are probably due to poor gun perforation of casing.
75-58	Topopah Spring Member of Paintbrush Group	459-511	100	457	0.02	2.5	See remarks	0.6	Well tested by bailing.
LAVA-FLOW AND WELDED-TUFF AQUIFERS									
75-58	Basalt of Kiwi Member of Paintbrush Group	317-351	100	317	0.52	50	350	--	Combined test of lava flow and welded tuff aquifers. Measurements made with test pressure gage and air line.
	Topopah Spring Member of Paintbrush Group	351-465	45	--	--	--	--	--	
VALLEY FILL AQUIFER									
74-70b	Valley fill	210-366	60	210	0.35	12	30	31	Value of 21 m^2/d from recovery during 133-day shutdown; other values from 48-hour pumping test.

TABLE 2-5

PUMPING TEST DATA FOR AQUIFERS IN NEVADA TEST SITE AND VICINITY[a] (PAGE 5 OF 5)

Well	Strati-graphic Unit	Depth Interval (a)	Estimated Penetration of Aquifer (%)	Depth to Static Level (m)	Specific Capacity (L/s per Meter of Drawdown)[b]	Transmissivity (m^3/d)			Remarks
						Estimated from Specific Capacity	Calculated from Drawdown Curve	Calculated from Recovery Curve	
74-70a	Valley fill	208-274	15	208	0.83	37	95	136	--
75-72	Valley fill	218-265	--	218	0.27	10	--	--	Specific capacity and static water level reported by driller.
83-68	Valley fill	489-570	80-100	185	0.39	12	160	150	--
91-74	Valley fill	33-113	100	33	2.48	120	--	400	Specific capacity after about 211 hours of pumping; driller's log indicates mostly clay below 71.9 m.
91-74a	Valley fill	35-165	100	35	6.21	370	--	--	Specific capacity and static water level reported by driller; driller's log suggests chief aquifer in depth interval 34.7-61.0 m.

[a] Modified from Winograd and Thordarson (1975).

[b] Specific capacity computed at 100 min of pumping.

[c] -- indicates no data.

[d] Time drawdown curves in Winograd and Thordarson (1975) indicate a positive boundary of very high transmissivity at 35 min; the "zone" of high transmissivity probably is that tapped by adjacent well 76-69a.

[e] (?) indicates data uncertainty.

Transmissivity estimates are based upon aquifer testing. In many instances, transmissivity was estimated using specific capacity data from wells. In the absence of other aquifer test data, these estimates are useful to provide minimum values for transmissivity (Winograd and Thordarson, 1975).[2] The porosity and hydraulic conductivity estimates are based upon laboratory studies, including measurements of grain and bulk densities, and mercury-injection and water-saturation methods.

The transmissivity of the valley-fill aquifer ranges from about 10 to 400 m^2/d (Winograd and Thordarson, 1975). The saturated thickness data suggest that these transmissivities reflect interstitial permeability ranging from 0.21 to 2.9 m/d.

The volcanic rocks function locally as either aquifers or aquitards, depending on the presence or absence of open, unsealed fractures. Interstitial hydraulic conductivity of the volcanic units ranges from 2.8×10^{-7} to 1.6×10^{-1} m/d (Winograd and Thordarson, 1975). The DOE believes these data indicate that the interstitial hydraulic conductivity of the densely welded zones of the volcanic rock aquifers and aquitards is extremely low.

Data are limited concerning hydraulic properties of the upper carbonate aquifer as well as the upper clastic aquitard because of the limited areal extent of these units in the hydrogeologic study area. Winograd and Thordarson (1975) state that the upper clastic aquitard is analogous to the lower clastic aquitard and probably has a transmissivity less than about 6.0 m^2/d. No porosity data are available for either of these units.

High transmissivities have been found during testing of the lower carbonate aquifer. At well 79-69a (see Table 2-5), completed in the Carrara Formation, a transmissivity of about 1×10^4 m^2/d was estimated based on

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[2] WWL Comment - Transmissivity Tests

Transmissivity values obtained with specific capacity data from wells represent hydraulic properties specific only to that area in which the well is located. However, these transmissivity values are used in regional flow models, such as Waddell's 1982 model, where entire regions are designated with a single transmissivity value. This misrepresentation will lead to incorrect flow and transport characterization in and around the proposed site. A more widespread testing program is needed to determine representative values of transmissivity values in regions surrounding Yucca Mountain so that flow modeling can more adequately represent natural flow conditions. Such a program should include transmissivity values obtained from drawdown and recovery tests, which represent hydraulic properties over a more widespread area. An extensive number of these tests should be performed in the Yucca Mountain area.

specific capacity data. The total porosity of the lower carbonate aquifer ranges from 0.4 to 12 percent.

Values of the interstitial porosity and hydraulic conductivity of the lower clastic aquitard given in Table 2-4 are based on analyses of 43 cores. The DOE states that although restricted to cores from a single test hole, the data are considered representative of the lower clastic aquitard throughout the study area, because the borehole penetrated 1,072 m of the aquitard and the cores resemble examined outcrop specimens.[3] The total porosity of this unit averages about 4 percent and the effective porosity is about 2 percent.

The transmissivity values summarized above are based upon analyses that assume porous media rather than fracture flow conditions and which presume that the groundwater flow in the saturated rock satisfies Darcy's law (i.e., the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path). The DOE believes that for the purposes of regional characterization such analyses are appropriate. To determine the validity of the use of porous media solution for flow through fractured media in the hydrogeologic study area, additional evaluations will be performed by the DOE, as summarized in the CDSCP.

2.4.3 Spatial Relationships of the Hydrogeologic Units

The spatial relationships of these units are primarily a result of the depositional history of the sedimentary rocks, the volcanic history of the area, and the complex structural evolution of the region (DOE, 1988). Because of the complex geologic history, groundwater flow relationships within and between the hydrogeologic units are also complex. Based on knowledge of regional geology, sedimentary rocks of Precambrian and/or Paleozoic age probably underlie the entire study area, except where intruded by granitic bodies (Waddell et al., 1984). Thicknesses of the various overlying units range from zero to thousands of meters.

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[3] WWL Comment - Hydraulic Properties of the Lower Clastic Aquitard
The interstitial porosity and hydraulic conductivity of the lower clastic aquitard given in Table 2-4 is based on cores taken from one test hole. This characterization is deemed inadequate for a regional scale representation. Values of hydraulic properties should be obtained from a more extensive testing program (i.e., multiple well tests) which presents regional averages of interstitial porosity and hydraulic conductivity of the lower clastic aquitard.

2.5 BOUNDARY CONDITIONS

Boundary conditions discussed in this chapter have been divided into two separate subtopics: (1) boundary conditions used to delineate regional groundwater subbasins and (2) recharge and discharge areas. Boundary conditions used in delineating the subbasin boundaries are discussed in Section 2.5.1. Although the hydrogeologic study area has been broken up into three separate subbasins, no groundwater flow modeling has been performed to date which incorporates or recognizes these sub-divisions. Modeling that has been performed by Waddell (1982), Rice (1984), Czarnecki and Waddell (1984), and Czarnecki (1985) has either modeled regions closely resembling the entire hydrogeologic study area or only the Alkali Flat-Furnace Creek Ranch Subbasin.[4] Section 2.5.2 describes the recharge and discharge areas of the hydrogeologic study area. This discussion includes the regional locations of these areas, estimates of rates, and the mechanisms of recharge and discharge involved for the individual hydrogeologic units.

2.5.1 Regional Subbasin Boundaries

The study area's boundaries reported by the DOE (see Figure 2-5) is based on a synthesis of hydrogeologic reports which used controlling factors such as potentiometric levels, geologic controls of subsurface flow, discharge and recharge areas, and inferred flow paths (Czarnecki and Waddell, 1984; Rice, 1984; Waddell et al., 1984; Winograd and Thordarson, 1975; and Waddell, 1982). In some areas, the boundaries are uncertain due to lack of potentiometric data, the complexity of geologic structures, or the occurrence of interbasin flow of groundwater through the lower carbonate aquifer (Winograd and Thordarson, 1975).[5]

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[4] WWL Comment - Regional Groundwater Subbasins

Because there has been no regional flow modeling which incorporates the subbasins mentioned in the CDSCP, what is the purpose of delineating subbasins? In what way do these subbasins help understand the groundwater flow near Yucca Mountain?

[5] UGSG Comment -Studies to Provide a Description of the Regional System (p. 156).

In regards to the subbasin delineations, the CDSCP does not mention how the uncertainty of the lateral model boundaries will be assessed. Clarification of these boundaries will be needed in the regional flow system characterization.

2.5.1.1 Oasis Valley Subbasin

Figure 2-5 illustrates the subdivisions of each subbasin within the study area. Each subbasin is described by that region of the study area which contributes flow to the discharge area associated with that subbasin (much like that of a watershed discharge point). For the Oasis Valley subbasin, groundwater flows into Oasis Valley from western and central Pahute Mesa (Waddell, 1984) and discharges in the form of springs located just north of the town of Beatty. These springs are created by the presence of a low-permeability rock formation located downgradient from Beatty.

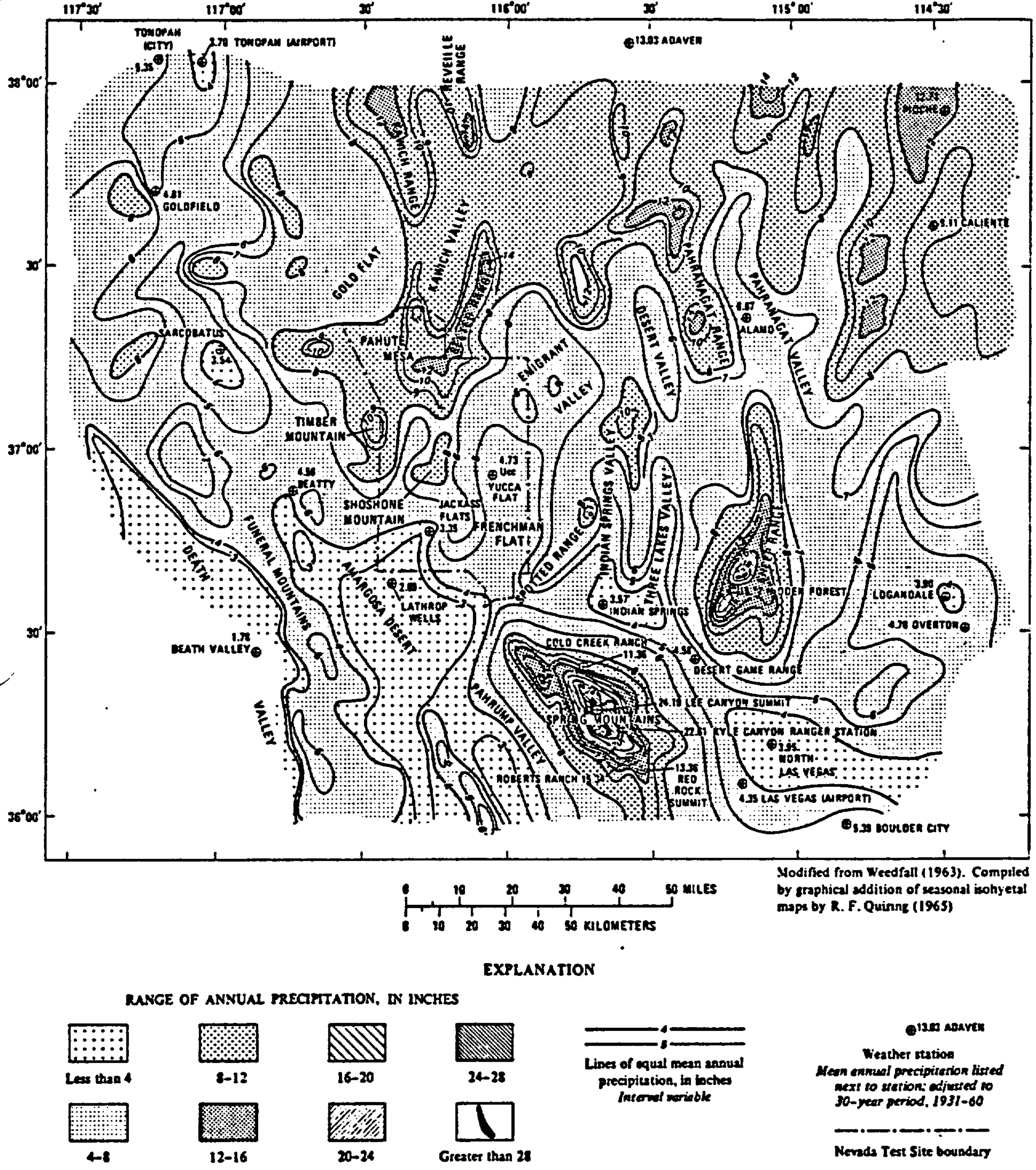
A potentiometric map of the Candidate Area is shown on Plate 1 (Waddell et al., 1984). By using the discharge area north of Beatty as the point reference for the basin, the DOE used flow lines (drawn perpendicular to the potentiometric contours) to delineate the subbasin. These flow lines pass through the Cactus Range, Quartz Mountain, and Sawtooth Mountain to serve as the western boundary, and likewise to the east through Beatty Wash, western Pahute Mesa, and the Timber Mountain region.

2.5.1.2 Ash Meadows Subbasin

The boundary for the Ash Meadow subbasin is taken from Winograd and Thordarson (1975). Winograd and Thordarson estimated the minimum area of Ash Meadows subbasin based on isohyetal and potentiometric evidence. Figure 2-8 depicts precipitation ranges for the hydrogeologic study area. This distribution of precipitation suggests that the Spring Mountains and the Sheep Range form the southern and eastern border of the Ash Meadows subbasin and that the Belted, Timpahute, and Pahranagat Ranges may form the northwestern, northern, and northeastern borders.

The approximate position of a groundwater divide on the northwest side of the Ash Meadows basin is also shown by the potentiometric contours for the volcanic rocks beneath Emigrant Valley and Pahute Mesa. Southeastward movement of groundwater is indicated beneath western Emigrant Valley and southwestward movement beneath Pahute Mesa. The groundwater divide between the basins may lie beneath the Belted Range, which separates the two areas contoured.

Two areas that are not tributary to the Ash Meadows groundwater basin are also delineated by the potentiometric contours for the valley fill aquifer. The potentiometric contours, the hydraulic barrier(s) extending from Lathrop Wells to Big Spring, and the position of the lower clastic aquitard east of



Modified from Weedfall (1963). Compiled by graphical addition of seasonal isohyetal maps by R. F. Quiring (1965)

SOURCE: WINOGRAD AND THORDARSON (1975)

Water, Waste & Land, Inc.

FIGURE 2-8

REGIONAL MEAN ANNUAL PRECIPITATION

Date: SEPT 1988

Project: 4001

Lathrop Wells indicate that groundwater beneath the central Amargosa Desert and southwestern Jackass Flats does not discharge at Ash Meadows and is therefore not considered part of the subbasin (Winograd and Thordarson, 1975). Head relations between Pahrump Valley and the Amargosa Desert also suggest a damming effect somewhere between the two areas. Based on the above information, the boundary of the subbasin shown on Figure 2-5 excludes the Spring Mountains and Pahrump Valley.

2.5.1.3 Alkali Flat-Furnace Creek Ranch Subbasin

The Alkali Flat-Furnace Creek Ranch Subbasin is centrally located between eastern Ash Meadows subbasin and western Oasis Valley subbasin. Groundwater flows predominantly southward from the Timber Mountain Area in the northern section of the subbasin, beneath Crater Flat and the Amargosa Desert, toward the south and southwest, and then to the discharge areas mentioned above. The principle discharge areas of the subbasin are located at Alkali Flats in southern Amargosa Desert and at Furnace Creek Ranch in Death Valley.

According to Waddell (1984), the northern boundary of the subbasin, which includes Yucca Mountain, is a line that crosses the Cactus, Kawich, and Reveille Ranges. It is unclear as to why the DOE chose to extend the subbasin boundary further north than the Kawich Range, although it is known that the northern boundary of the hydrogeologic study area was taken as a constant flow boundary (Czarnecki, 1985). The eastern boundary is well-established in the northern half of the subbasin, where it lies along a line running through the axis of the Reveille and Belted Ranges which was thought by Winograd and Thordarson (1975) to be a groundwater divide based on the potentiometric contours for volcanic rocks beneath Emigrant Valley and Pahute Mesa. To the south, the basin's boundary is more obscure. The boundary is best defined near Ash Meadows, extending from the Skeleton Hills northeastward to the northern end of the Specter Range. From there, its location is uncertain.

2.5.2 Characterization of Recharge and Discharge Areas

This section presents information on the (1) location of groundwater recharge and discharge areas within the hydrogeologic study area, (2) estimates of regional recharge and discharge rates, (3) surface water and groundwater interrelationships, and (4) recharge and discharge mechanisms for the identified aquifers.

2.5.2.1 Location of Groundwater Recharge and Discharge Areas

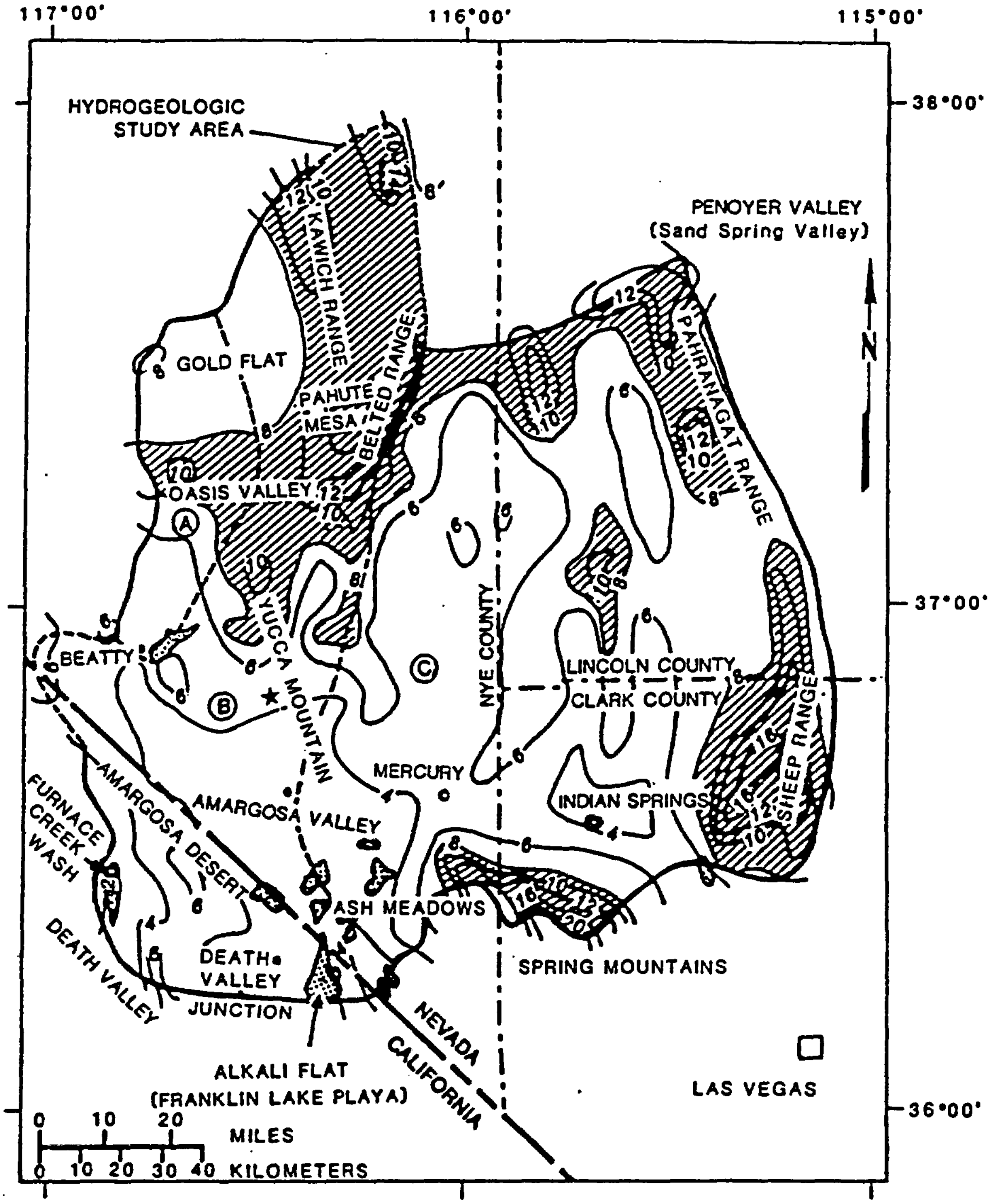
The recharge and discharge areas in the groundwater basin shown on Figure 2-9 are taken from Winograd and Thordarson (1975), Waddell (1982), and Waddell et al. (1984). The recharge areas shown are those areas of the basin that receive 150 mm to 200 mm or more average annual precipitation (Winograd and Thordarson, 1975) and are estimated by the DOE to have relatively significant groundwater recharge.

Surface water runoff along major stream channels, such as Fortymile Wash, probably results in significant recharge, under both modern and pluvial conditions of the Quaternary Period (Claassen, 1983; Czarnecki, 1985). The DOE has presented plans within the CDSCP to evaluate the significance of this recharge. In addition, subsurface inflow probably occurs from the northeast and may represent up to 58 percent of the total flow coming into the hydrogeologic study area (Czarnecki, 1985). The inflow across the northern and northeastern boundaries results from recharge in the higher areas to the north of the hydrogeologic study area.

Locations of springs within the Candidate Area are shown on Plate 1. Major discharge areas are the Ash Meadows spring lineament, Alkali Flat (Franklin Lake Playa), Furnace Creek Ranch area, and Oasis Valley. Minor discharge from regional aquifers occurs at Indian Springs and Cactus Springs. Numerous perched springs of minor and variable discharge are present throughout the area. Discharge at Alkali Flat is primarily by evapotranspiration rather than spring discharge. Data on springs within the Alkali Flat-Furnace Creek Ranch groundwater subbasin, including Yucca Mountain, are given in Tables 2-6 and 2-7. All but two of the springs listed in these tables are in California, either in or near Death Valley. These springs emerge from the lower carbonate aquifer, from volcanic rocks, or from alluvium. Springs emerging from volcanic rocks have low discharges and probably result from perched water (DOE, 1988).

2.5.2.2 Regional Recharge and Discharge Estimates

An empirical method of estimating average annual groundwater recharge from precipitation in desert regions was developed by Eakin et al. (1951). Recharge was estimated as a percentage of the average annual precipitation within an area. Geographic zones in which average precipitation ranges between specified limits were delineated on a map and a percentage of precipitation was assigned to each zone representing assumed average recharge. The degree of reliability



- ▨ RECHARGE AREAS
- ░ DISCHARGE AREAS
- — — — BOUNDARY OF HYDROGEOLOGIC STUDY AREA; DASHED WHERE UNCERTAIN
- - - - SUBBASIN BOUNDARY
- Ⓐ OASIS VALLEY SUBBASIN
- Ⓑ ALKALI FLAT-FURNACE CREEK RANCH SUBBASIN
- Ⓒ ASH MEADOWS SUBBASIN
- —6— LINE OF EQUAL AVERAGE ANNUAL PRECIPITATION, IN INCHES

SOURCE: WONOGRAD AND THORDARSON (1975), WADDELL (1982), AND WADDELL et al. (1984)

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FIGURE 2-9
REGIONAL RECHARGE AND DISCHARGE AREAS

Date: SEPT 1988

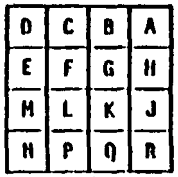
Project: 4001

BLE 2-6

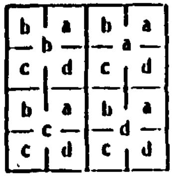
DATA FOR SELECTED SPRINGS IN DEATH VALLEY NATIONAL MONUMENT AND VICINITY, CALIFORNIA AND NEVADA

(PAGE 1 OF 2)

Location number: Based on location in the rectangular system for subdivision of public land. For example, in the number 17N/6E-5QS1, the part of the number preceding the slash indicates the township (T. 17 N.), the part between the slash and the hyphen is the range (R. 6 E.), the number between the hyphen and letter indicates the section (5). For sites in California, the first capital letter (Q) indicates the quarter-quarter section as shown in the accompanying diagram. For sites in Nevada, the first lower-case letter following the section number designates the quarter section (see accompanying diagram), and the second lower-case letter designates the quarter-quarter section. The letter S refers to spring, and the final number (1) is a serial number assigned to sites within the quarter-quarter section.



Section (California)



Section (Nevada)

Spring name	Spring number	Flow, in liters per second	Date of measurement	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in microsiemens (approximate)	Remarks
Sheep Creek	17N/6E-5QS1	0.6	4/25/67	800	1,200	
Saratoga	18N/5E-2ES1,2	4.7	4/27/67	3,100	4,700	Combined flow of two springs from large pool.
Rhodes	21N/4E-11MS1	.007	3/23/70	500-700	750-1,000	Perched spring in southern Black Mountains.
Willow (Gold Valley)	23N/3E-54JS1	.6	4/15/69	800	1,200	Flow varies between 0.1 and 1.2 liters per second.
Eagle Borax	24N/1E-15DS1	19	---	1,600	2,500	---
Tule	25N/1E-33FS1	Very low flow	5/06/67	2,000	3,000	---
Texas	27N/1E-23BS1	13.2	12/08/76	600	1,000	Discharge is from interbasin flow.
Travertine	27N/1E-23,25, 26S	44	1/06/77	600	1,000	Discharge is from interbasin flow; aggregate of several springs.
South Travertine	27N/1E-26BS1	31	1/06/77	640	1,020	Discharge is from interbasin flow; near Nevares Springs
Unnamed	28N/1E-36FS1	2.5	1/07/77	550	850	---
Nevares	28N/1E-36GS1	14	1/07/77	630	1,000	Discharge is from interbasin flow; aggregate of several springs.
Unnamed	7S/40E-15adS1	.01	---	300	500	Upgradient from Roosevelt Well in Magruder Mountain area, Nevada.
Sand	9S/41E-7RS1	.0025	5/01/68	850	1,300	Northern headwaters of Death Valley.
Grapevine	11S/42E-2,3,10S	28	---	650-800	1,000-1,200	Numerous outlets; flow given is aggregate.
Mesquite	11S/42E-27RS1	.57	---	900	1,300	Largest spring in floor of northern Death Valley.
Staininger s	11S/43E-18ES1	12.5	---	480	730	Supplies Scotty's Castle; probably interbasin flow.

TABLE 2-6

DATA FOR SELECTED SPRINGS IN DEATH VALLEY NATIONAL MONUMENT AND VICINITY, CALIFORNIA AND NEVADA

(PAGE 2 OF 2)

Spring name	Spring number	Flow, in liters per second	Date of Measurement	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in microsiemens (approximate)	Remarks
Surprise	11S/43E-18S1,2	.3	---	480	700	Supplies Grapevine Ranger Station; perched water in volcanic rocks.
Brier	11S/44E-32bcS1	.06	---	200	320	---
Quartz	13S/41E-26MS1	.001	2/14/67	480	800	Important to bighorn-sheep habitat.
Klare	13S/45E-4LS1	.1	11/17/68	570	880	---
Goldbelt	15S/42E-32CS2	.02	5/20/71	150-200	250-400	---
Keane Wonder	15S/46E-1RS1	1.9	11/17/68	3,100	4,500	---
Jackass	16S/42E-18RS1	.2	4/23/68	---	---	---
Cottonwood	16S/42E-25KS1	4.6	4/24/68	350	520	---
Tucki	16S/45E-29DS1	.6	6/10/57	---	---	---
Emigrant	17S/44E-27BS1	.12	11/09/71	350	550	---
Upper Emigrant	17S/44E-27KS1	.05	11/09/71	530	850	---
Wildrose	19S/44E-21RS1	.5	1/05/72	500	800	Supplies ranger station.
Greater View	23S/45E-23QS1	.02	4/27/67	350	520	At Russell Camp.
Willow (Butte Valley)	23S/46E-30CS1	.4	4/28/67	320	500	---
Squaw	23S/46E-33DS1	1.3	5/15/67	350	540	---

1/ Adapted from Miller, 1977.

TABLE 2-7

RECORDS OF SELECTED SPRINGS IN PARTS OF INYO COUNTY, CALIFORNIA AND NYE COUNTY, NEVADA

(PAGE 1 OF 3)

Location number: Based on location in the rectangular system for subdivision of public land; locations with townships south use the Mount Diablo Base Line, and locations with townships north use the San Bernadino Base Line. In the number 22N/07E-30E1, the part of the number preceding the slash indicates the township (T. 22 N.), the part between the slash and the hyphen is the range (R. 7 E.), the number between the hyphen and letter indicates the section (30), the letter (E) indicates the quarter-quarter section as shown in the accompanying diagram (California only), and the final number (1) is a serial number assigned to sites within the quarter-quarter section. All listed springs are in California except the last two, which are in Nevada.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Section (California)

Discharge: Some springs are intermittent; some are perennial.

Location name	Location number	Altitude, in meters	Water-bearing rock	Discharge rate, in liters per second	How determined	Date (month and year)	Water use	Temperature, in degrees Celsius
Unnamed	22N/3E	634	-------	--------	----------	---------	-------------	---------
Shoshone	22N/7E-30E1	494	-------	28	Estimated	---------	Public supply	33
Unnamed	22N/1E-01	-76	-------	--------	----------	---------	-------------	---------
Willow	22N/3E	817	-------	--------	----------	---------	-------------	---------
Greenwater	23N/3E	1,548	-------	--------	----------	---------	-------------	---------
Eagle Borax	20S/1E	-79	Valley fill	--------	----------	---------	-------------	---------
Unnamed	20S/2E	-79	do.	--------	----------	---------	-------------	25
Unnamed	29N/1E-35N1	-86	do.	0.3	Estimated	3-57	Unused	26
Tule	19S/1E	-79	do.	0.3	do.	---------	-------------	16
Lemonade	25N/2E	1,548	Volcanic rock	--------	----------	---------	-------------	---------
Navel	26N/2E-13	634	Valley fill	--------	----------	---------	-------------	---------
Unnamed	27N/1E-30B	-79	do.	--------	----------	---------	-------------	---------
Travertine	27N/1E	122	do.	139	Estimated	---------	-------------	32
Do.	27N/1E-25D1	122	do.	6	----------	1-57	-------------	33
Unnamed	27N/1E-26A7	98	do.	--------	----------	---------	Irrigation	36
Unnamed	27N/1E-26A6	98	do.	--------	----------	---------	do.	34
Travertine	27N/1E-26A5	98	do.	17	Estimated	11-56	do.	29
Do.	27N/1E-26A4	98	do.	0.3	do.	12-56	do.	34

RECORDS OF SELECTED SPRINGS IN PARTS OF INYO COUNTY, CALIFORNIA AND NYE COUNTY, NEVADA

(PAGE 2 OF 3)

Location name	Location number	Altitude, in meters	Water-bearing rock	Discharge rate, in liters per second	How determined	Date (month and year)	Water use	Temperature, in degrees Celsius
Do.	27N/1E-26A3	98	do.	0.3	do.	do.	-------------	32
Do.	27N1E-26A2	98	do.	14	do.	do.	Irrigation	33
Unnamed	27N/1E-26B5	98	do.	0.01	do.	---------	Unused	---------
Unnamed	27N/1E-26B4	98	do.	0.01	do.	---------	do.	---------
Unnamed	27N/1E-24N1	122	do.	0.01	do.	---------	-------------	---------
Travertine	27N/1E-23R1	122	do.	19	----------	1-57	-------------	33
Unnamed	27N/1E-23Q1	98	do.	0.01	Estimated	---------	Unused	---------
Unnamed	27N/1E-23Q6	98	do.	0.01	do.	---------	do.	---------
Unnamed	27N/1E-23Q5	98	do.	0.01	do.	---------	do.	---------
Unnamed	27N/1E-23Q4	98	do.	0.01	do.	---------	do.	---------
Unnamed	27N/1E-23Q3	98	do.	0.3	do.	12-57	do.	22
Unnamed	27N/1E-23Q2	98	do.	0.01	do.	---------	do.	---------
Unnamed	27N/1E-23K2	122	do.	0.3	do.	---------	do.	---------
Unnamed	27N/1E-23K1	125	do.	0.01	do.	---------	do.	---------
Unnamed	27N/1E-23L3	49	do.	0.01	do.	---------	do.	---------
Unnamed	27N/1E-23L1	49	do.	0.01	do.	---------	do	---------
Unnamed	27N/1E-23F1	49	do.	0.3	do.	2-57	do.	27
DV Hotel Tunnel	27N/1E-22H1	15	Valley fill	9	Estimated	3-57	----------	33
Texas	27N/1E-23B1	116	do.	14	do.	1-57	Domestic	33
Unnamed	17S/47E-10C	79	do.	--------	----------	---------	----------	---------
Unnamed	27N/1E-09	-73	do.	--------	----------	---------	----------	---------
Unnamed	27N/1E-03P1	-3	do.	0.3	Estimated	12-57	Unused	23
Unnamed	17S/46E-12	-79	do.	--------	---------	---------	---------	---------
Unnamed	27N/1E-03K1	30	do.	0.03	Estimated	---------	Unused	---------

TABLE 2-7

RECORDS OF SELECTED SPRINGS IN PARTS OF INYO COUNTY, CALIFORNIA AND NYE COUNTY, NEVADA *

(PAGE 3 OF 3)

Location name	Location number	Altitude, in meters	Water-bearing rock	Discharge rate, in liters per second	How determined	Date (month and year)	Water use	Temperature, in degrees Celsius
Unnamed	27N/1E-04B	-73	do.	--------	----------	---------	----------	---------
Cow	27N/1E-03A1	61	do.	1	Estimated	3-57	Unused	38
Unnamed	28N/1E-34N1	3	do.	0.06	do.	12-56	do.	23
Nevares	28N/1E-36K1	280	do.	0.01	----------	do.	----------	21
Do.	28N/1E-36M2	227	do.	--------	----------	---------	----------	29
Do.	28N/1E-36M1	219	do.	2	----------	12-56	----------	26
Unnamed	28N/1E-35K1	158	do.	0.01	Estimated	3-58	Unused	24
Salt	17S/46E	-73	do.	0.1	do.	---------	----------	31
Nevares	28N/1E-36G2	273	do.	1	---------	12-56	----------	39
Do.	28N/1E-36G1	286	do.	17	---------	do.	----------	40
Do.	28N/1E-36	280	do.	3	Estimated	---------	----------	39
Do.	28N/1E-36G1	280	do.	22	do.	12-55	Domestic	39
Warm	-----------	-79	do.	0.1	do.	---------	-----------	32
Unnamed	28N/1E-32A	-79	do.	-------	----------	---------	-----------	--------
Unnamed	16S/46E-33	-79	do	-------	----------	---------	-----------	--------
Salt	28N/1E-21N	-79	do.	0.06	Estimated	---------	Unused	16
Unnamed	----------	-79	do.	0.3	do.	---------	-----------	16
Unnamed	28N/1E-01	363	do.	-------	----------	---------	-----------	--------
Unnamed	29N/2E-30	631	---------	-------	----------	---------	-----------	--------
Specie	12S/48E-30	1,366	Sedimentary rock	-------	----------	---------	-----------	--------
Topopah	----------	1,768	Volcanic rock	0.01	----------	3-58	Unused	12

* MODIFIED FROM THORDARSON AND ROBINSON (1971).

of the estimate so obtained is related to the degree to which the values approximate actual precipitation and the degree to which the assumed percentage represents actual percentage of recharge. However, the smaller the scale examined, the greater is the uncertainty of this method.

Claassen (1985) suggests that recharge to the valley-fill aquifer in the west-central Amargosa Desert, based on hydrochemical data, resulted primarily from overland snowmelt runoff during late Pleistocene time, in or near present day stream channels such as Fortymile Wash. Today this area receives an average precipitation of less than 200 mm/yr. Recharge through Fortymile Wash may affect the water table altitude and gradient and flow path directions beneath Yucca Mountain.

The DOE states that although some uncertainty remains on the quantities and distributions of recharge over the region, the level of uncertainty does not appear significant in terms of affecting site specific analyses and interpretations for Yucca Mountain. Nonetheless, additional work is planned through regional modeling and water balance measurements as described in the CDSCP.

Groundwater discharge from the groundwater basin is by (1) spring flow, (2) evapotranspiration from phreatophyte areas where depths to groundwater are less than about 15 m, (3) evaporation from bare soil areas such as playas, where depth to groundwater is less than about 5 m (Rush, 1970), and (4) to a lesser extent, well withdrawals. At the major discharge areas in the basin, discharge is by evapotranspiration by phreatophytes and by natural springs that flow at the land surface contact between transmissive and less-transmissive hydrogeologic units. The less-transmissive units act as barriers to groundwater flow, causing groundwater to flow upward to the land surface (Winograd and Thordarson, 1975). Major groundwater discharge is summarized in Table 2-8.

2.5.2.3 Recharge and Discharge for Regional Aquifers

Areas and modes of recharge and discharge for the aquifers as presented within the CDSCP are discussed in the following sections. The recharge and discharge mechanisms discussed below are based on hydrochemical data for the tuff, carbonate, and valley fill aquifers.

TABLE 2-8

MAJOR GROUNDWATER DISCHARGE IN THE HYDROGEOLOGIC STUDY AREA

Area (see Figure 2-9)	Nature of Discharge	Estimated Average Discharge (m^3/yr)	Reference
Southern Amargosa Desert	Springs, evaporation, and evapotranspiration	3.0×10^7	Rush (1970) Walker and Eakin (1963),
Death Valley	Springs	6.3×10^6	Waddell (1982)
Near Beatty in Oasis Valley	Springs and evapotranspiration	2.7×10^6	Malmberg and Eakin (1962)
Indian Springs Valley	Springs	9.8×10^5	Maxey and Jameson (1948)
Total Discharge		4.0×10^7	

Recharge to the Tuff Aquifer

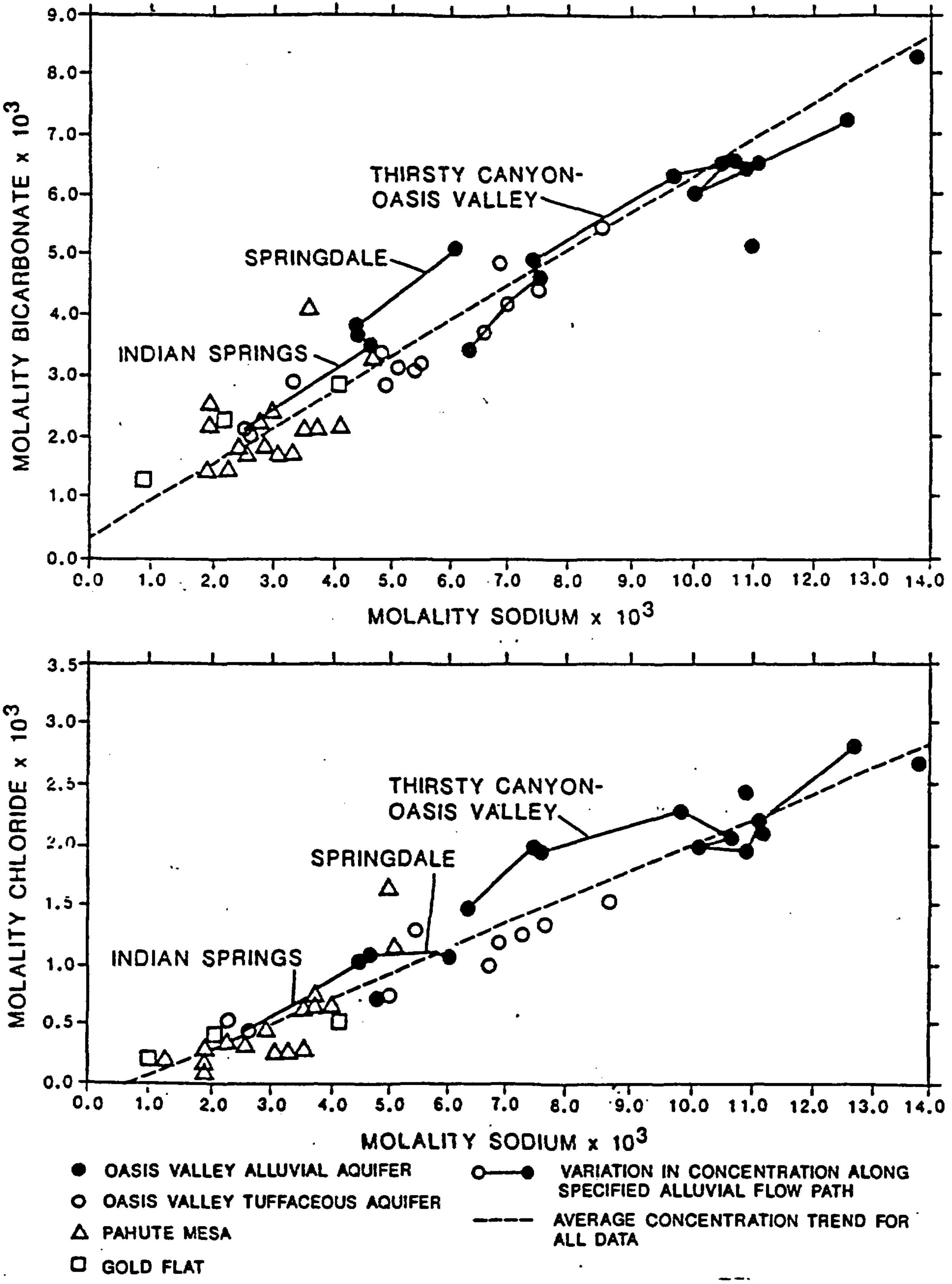
The highlands of Pahute Mesa and Gold Flat serve as probable recharge areas for the tuff aquifer in Oasis Valley based on analysis of water chemistry data. Figure 2-10 shows a linear trend for concentrations of bicarbonate and chloride plotted against sodium for groundwater in the tuffaceous aquifers of Oasis Valley, Pahute Mesa, and Gold Flat (White, 1979). Groundwater from the latter two areas plots in the dilute portion of the trend while water from Oasis Valley plots along a more concentrated part of the line. The similarity in composition supports the suggestion of Blankennagel and Weir (1973) that water beneath Pahute Mesa is related to Oasis Valley groundwater and merely represents a less advanced stage in the chemical reaction sequence farther upgradient (White, 1979). Other parts of the tuff aquifer may be recharged differently. Plans to evaluate the potential recharge to the Tuff aquifer through Fortymile Wash are described in the CDSCP.

Discharge from the Tuff Aquifer

There are three primary mechanisms for groundwater discharge from the tuffaceous aquifer in the vicinity of the NTS: 1) vertical leakage to the underlying lower carbonate aquifer, 2) subsurface flow migrating into the valley-fill aquifer, and 3) spring discharge. Hydrochemical evidence for the first mechanism is presented in the section addressing recharge to the lower carbonate aquifer. The second mechanism is supported by White (1979) where he showed that, through the effects of evapotranspiration, water in the tuffaceous alluvium could be produced from water in the tuff aquifer. The third mechanism, direct spring discharge, is most likely to occur where fracture systems are saturated, broken by recent faulting, or intersect the land surface.

Recharge to the Lower Carbonate Aquifer

The highlands of the Sheep Range, northwestern Spring Mountains, and southern Pahranagat Range are the primary source of recharge to the lower carbonate aquifer (see Figure 2-9). To a lesser extent the Pintwater, Desert, and Spotted ranges also contribute to the recharge (Winograd and Thordarson, 1975). A second source of recharge to the lower carbonate aquifer is downward leakage of water from the Cenozoic strata. Schoff and Moore (1964) concluded that based on the distribution of sodium, the water in the Paleozoic carbonate



SOURCE: WHITE(1979)

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FIGURE 2-10
CONCENTRATION TRENDS OF SODIUM, BICARBONATE, AND CHLORIDE OF TUFFACEOUS AQUIFERS

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rocks underlying the NTS is being recharged by downward percolation through the tuff and tuffaceous alluvium. A third source of recharge to the lower carbonate aquifer, possibly contributing as much as 35 percent (Winograd and Friedman, 1972), is the underflow (i.e., trans-basin regional groundwater movement) into the basin from the northeast. Winograd and Thordarson (1975) found that the chemical data supported the hypothesis that groundwater originating in the Pahranagat Valley moves southwestward through the lower carbonate aquifer into the Ash Meadows groundwater basin.

Discharge from the Lower Carbonate Aquifer

Ash Meadows is the primary discharge area for the lower carbonate aquifer. It is a fault controlled spring line in the southeastern and east-central part of the Amargosa Desert. Chemical and temperature data clearly show that although the major springs emerge from Quaternary deposits, the water feeding the spring pools is derived by upward leakage from the underlying and flanking lower carbonate aquifer (Winograd and Thordarson, 1975).

A second mechanism for discharge from the lower carbonate aquifer is direct upward crossflow into the valley fill. Claassen (1985) believes that water quality, temperature, and hydraulic potential indicate that in the eastern part of the Amargosa Desert upward leakage from the lower carbonate aquifer mixes with water that has been recharged directly to the valley fill.

Recharge to the Valley Fill Aquifer

There are three principal sources of recharge to the valley fill aquifer: 1) upward leakage from the tuff aquifer, 2) upward leakage from the lower carbonate aquifer, and 3) infiltration from overland flow. Surface runoff is considered the most likely recharge mechanism for tuffaceous alluvium in the west-central Amargosa Desert. Winograd and Thordarson (1975) suggested that the low dissolved solids content of water from six wells along Fortymile Wash reflected recharge primarily via infiltration along the arroyo rather than underflow from Pahute Mesa and Timber Mountain. Claassen (1985) found that sodium-calcium-magnesium concentrations of water in the tuffaceous valley fill in the Amargosa Desert were generally inconsistent with the composition of water in the bedrock aquifers to the north and concluded that valley fill recharge was primarily surface runoff from the tuffaceous highlands infiltrating along present day wash bottoms.

Discharge from the Valley Fill Aquifer

The most likely mechanism for discharge from saturated valley fill is evapotranspiration. White (1979) found that along a valley fill flow path, upgradient samples contained less than half the dissolved solids of the water in the alluvium at the lower end of the flow path (458 mg/l compared with 1040 mg/l) and concluded that the principle reason for this increase was due to direct evaporation and transpiration through the vegetative cover.

2.6 POTENTIOMETRIC LEVELS

The generalized locations of groundwater monitoring wells and the regional distribution of potentiometric levels referenced to mean sea level (msl) are presented on Figure 2-11. A more detailed map of potentiometric contours is presented on Plate 1 (Waddell et al., 1984). The DOE states that the distribution of wells provides an adequate data base for the general definition of the regional potentiometric surface.[6] Sources of potentiometric data include Eakin et al. (1963), Malmberg (1967), Mifflin (1968), Winograd and Thordarson (1968), Rush (1970), Thordarson and Robinson (1971), Naff et al. (1974), Winograd and Thordarson (1975), Miller (1977), Harrill (1982), Waddell (1982), Czarnecki and Waddell (1984), Robison (1984), and Robison (1986). Specific construction information for these wells is provided in the cited references and are not included here. The equipotential lines shown on Figure 2-11 are based upon composite water levels from several hydrogeologic units and

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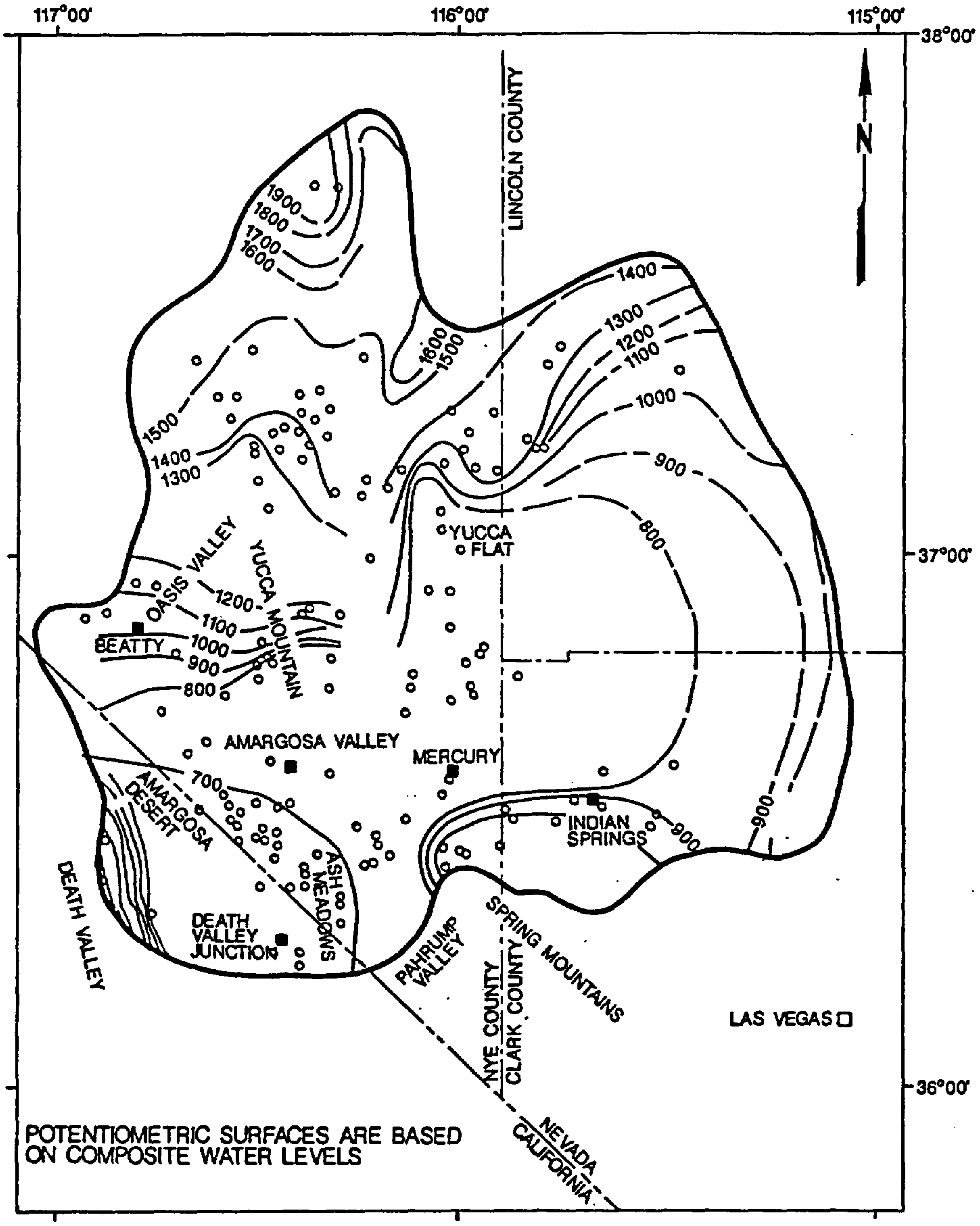
[6] USGS Comment - Potentiometric Contours (p. 133)
It should be stated that the hydraulic properties of the hydrogeologic units are unknown over large areas of the study area. In areas of no information, hydraulic properties may also vary greatly and may affect the concept of groundwater flow. The USGS disagrees with the interpretation of potentiometric surface contours drawn on Figure 2-11. The contours have no control (wells) for an area of 80 by 100 kilometers yet potentiometric contours have been approximated through the area whereas in areas of control, some contours have been omitted. What basis is used to draw the contours in the area of no control? The contours in areas of no control should be omitted from the figure.



KEY TO SYMBOLS

--1200-- LINE OF EQUAL POTENTIOMETRIC LEVEL, IN METERS ABOVE SEA LEVEL DASHED WHERE APPROXIMATE, CONTOUR INTERVAL 100 METERS

○ GROUND WATER MONITORING WELLS DISCUSSED IN THE TEXT

0 10 20 MILES

0 10 20 30 40 KILOMETERS

SOURCE: MODIFIED FROM WADDELL et al. (1984)

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FIGURE 2-11
POTENTIOMETRIC SURFACE OF THE HYDROGEOLOGIC STUDY AREA

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are averages of the hydraulic heads in the boreholes.[7] Contour lines in the illustration are drawn at 100 m intervals.

The altitude of the potentiometric surface ranges from over 1,900 m above mean sea level in the northernmost part of the hydrogeologic study area to below sea level in Death Valley. Steep hydraulic gradients occur in several areas, including north of Yucca Mountain, near Death Valley, southeast of Mercury, and north of Yucca Flat.[8] The DOE believes that these steep gradients may be due to stratigraphic, structural, thermal, or hydraulic conditions, or to a combination of these conditions. Additional synthesis and modeling of the regional hydrogeologic system will be performed by the DOE as part of site characterization activities. Two-dimensional and three-dimensional models of groundwater flow and sensitivity analyses performed during these studies will help to assess the relative importance of these steep gradients in the overall characterization of regional flow conditions.

2.7 FLOW AND TRANSPORT

Several numerical models were developed to characterize groundwater flow systems in the regional hydrogeologic study area. These models incorporated the use of existing hydrologic data and boundary conditions to simulate the flow regime in and around Yucca Mountain.[9] A brief description of each model

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[7] USGS Comment - Studies to Provide a Description of the Regional System (p. 157)
Can heads in an anisotropic aquifer be used to adequately define flow directions? How will the anisotropic conditions be addressed in the regional flow models?

[8] WWL Comment - Hydraulic Gradient near Yucca Mountain
The DOE states that an upward gradient exists north of Yucca Mountain. How does this affect radionuclide travel to the accessible environment? Has this gradient been taken into account in the flow models?

[9] USGS Comment - Studies to Provide a Description of the Regional Flow System (p. 154)
Regional groundwater modeling has only included horizontal heterogeneities, where known. It has not addressed vertical heterogeneities nor heterogeneities in areas of no information. Such vertical heterogeneities exist near Yucca Mountain, therefore, present flow modeling may not represent actual flow conditions near the proposed repository. Alternative three-dimensional modeling techniques should be analyzed to gain a better understanding of the complex flow conditions that exist both regionally and

developed will be presented in this section, including the type of model used, the area studied, boundary conditions associated with that area, and the results of each model.[10] In addition, regional groundwater velocities and residence times will be discussed in Section 2.7.5.

2.7.1 Waddell's Model - 1982

A two-dimensional, steady-state, finite-element model of the groundwater flow system of the Nevada Test Site and vicinity in Nye and Clark Counties, Nevada, and Inyo County, California, was developed By Richard Waddell in 1982 using parameter-estimation techniques. The study area for Waddell's model incorporates over 18,000 km^2, and is outlined on Figure 2-12. The purpose of this model was to estimate groundwater fluxes for use in predictions of transport of radionuclides and to study the effects of uncertainty in model parameters in these estimates.

The study area boundaries were determined by areal distribution of precipitation or lithology. However, boundary conditions associated with Waddell's 1982 model were discussed in a qualitative manner without actual values being presented. Boundary conditions used in the model including no-flow, known flux, and constant head boundaries are presented on Plate 2. Flux boundaries were applied internally and externally to the modeled area, while the constant head boundary was applied to only one node that represents a point in Alkali Flat to simulate groundwater discharge. No-flow boundaries coincide approximately with other boundaries of the regional groundwater basin. The modeled area was subdivided into 27 zones (Plate 2) based on estimated transmissivity values.

External flux boundaries correspond to areas where flux from outside the modeled area is thought to occur. An area along the boundary between zones 25 and 27 represents a region where flow, Qpr, into zone 4 from Pahranagat Valley occurs. Another area where flux into the area is treated as a boundary flux is

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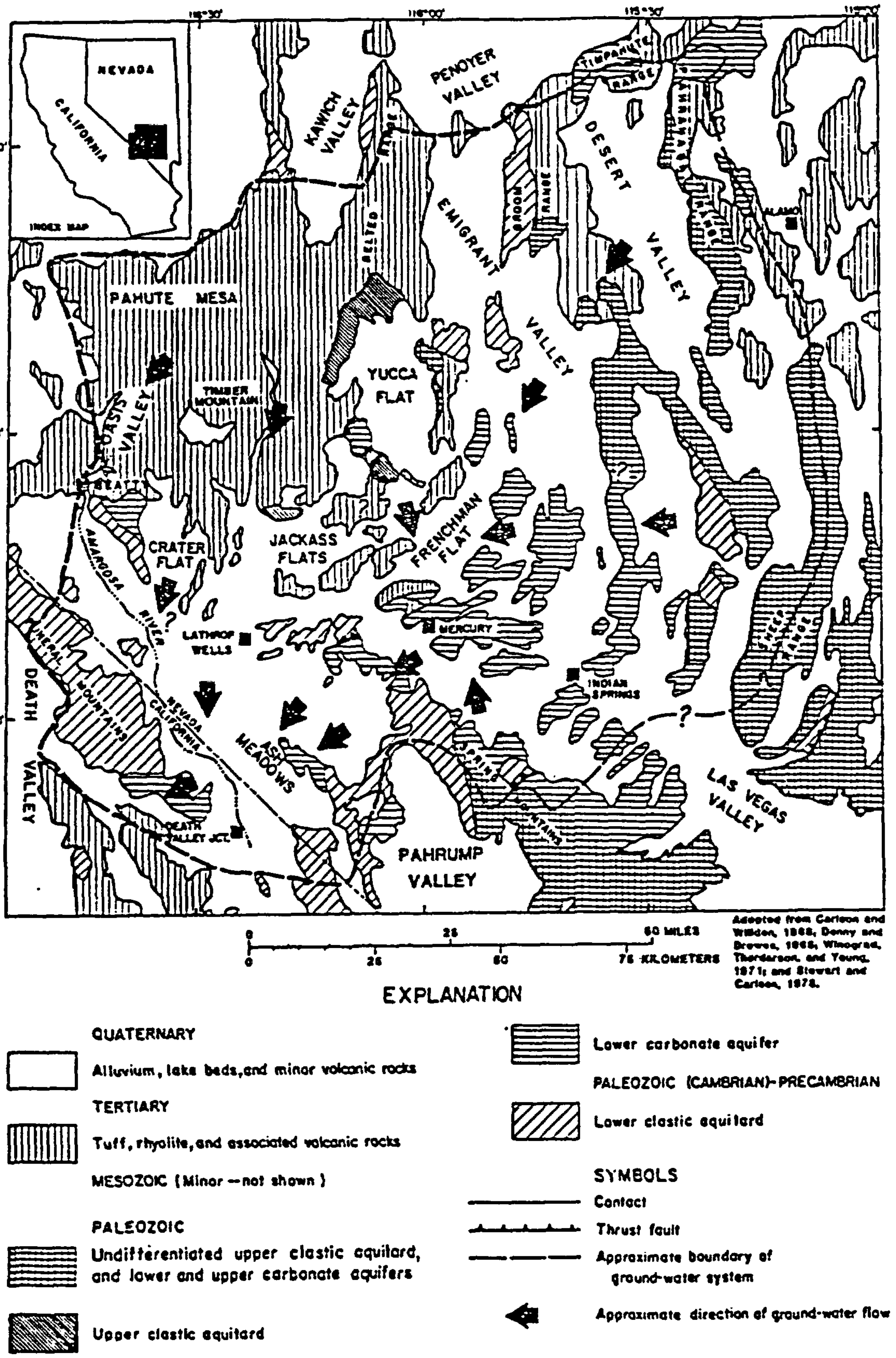
throughout Yucca Mountain.

[10] WWL Comment - Thermal Effects on Groundwater Flow
Large temperature ranges (22 to 56°C) may indicate deep circulation of the groundwater near the proposed repository site. Is the two-dimensional model used by the DOE to characterize the local groundwater flow adequate enough to account for this possible vertical migration of groundwater movement?



SOURCE: WADDELL (1982)

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FIGURE 2-12

WADDELL'S 1982 STUDY AREA

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across part of the Resting Springs Range, where flow from Pahrump Valley into the Amargosa Desert occurs. A boundary flux out of the area was applied near Furnace Creek Ranch in Death Valley. All other external boundaries were treated as no-flow boundaries by Waddell.

Internal flux boundaries represent areas of recharge or discharge. Recharge areas are represented by zones 18, 24, 25, 26, and 27. Waddell designated recharge areas as those regions which received over 200 mm of precipitation.[11] Discharge areas are represented by zones 7 and 13, and by specified nodes in zones 8 and 12. Recharge and discharge are assumed to be zero elsewhere.

Estimates of regional fluxes for twelve sites in the western part of the study area including Yucca Mountain are given in Table 2-9. These sites of flux estimation extend from near Beatty to Death Valley (see Plate 2). Waddell expressed flux as a unit flux (the flux through a cross section of the aquifer 1 m wide). Calculated unit fluxes range from approximately 4.4×10^{-7} m^2/s to 8.8×10^{-5} m^2/s. Waddell's model calculated fluxes for the Yucca Mountain repository block ranging from 2.33×10^{-6} m^2/s to 4.55×10^{-7} m^2/s, based on an assumed transmissivity of 7.71×10^{-5} m^2/s. Units with the smallest fluxes are those with the smallest transmissivities, namely the Eleana Formation and the tuffs represented in zone 1 (Plate 2). The greatest flux is in the carbonate aquifer beneath Amargosa Flat (zone 9). A more detailed evaluation of the direction and magnitude of calculated fluxes in and around Yucca Mountain will be discussed in a subsequent section (Czarnecki and Waddell's Model - 1984).

2.7.2 Rice's Model - 1984

A two-dimensional, finite difference, hydrologic model was developed by W. A. Rice in 1984 to simulate the groundwater flow system for the Nevada Test Site and vicinity. The study area considered for this model is located in

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[11] WWL Comment - Waddell's (1982) Areas of Recharge
Waddell designated areas of recharge as those regions which received 200 mm or more of precipitation, based upon empirical precipitation-recharge relationships developed from mass-balance estimates by Eakin, Schoff, and Cohen (1963) and Walker and Eakin (1963). However, Winograd and Friedman (1972) and Winograd and Thordarson (1975) have pointed out that the use of isohyetal maps for estimating amounts of recharge can lead to large errors. Differences in underlying lithology, thickness of soil zone, and topography are ignored in empirical relationships. Therefore, alternative methods will need to be evaluated to estimate recharge which take these factors into consideration.

TABLE 2-9

GRADIENT, TRANSMISSIVITY, AND UNIT-FLOW CALCULATIONS FOR SITES PERTINENT TO YUCCA MOUNTAIN (WADDELL, 1982)

[m^2/s = meters per second]

Site	Gradient	Transmissivity (m^2/s)	Unit flux (m^2/s)
A	4.97×10^{-3}	7.49×10^{-4}	3.72×10^{-6}
B	2.00×10^{-2}	2.19×10^{-5}	4.38×10^{-7}
C	3.03×10^{-2}	7.71×10^{-5}	2.33×10^{-6}
D	1.02×10^{-2}	2.19×10^{-5}	2.22×10^{-7}
E	6.30×10^{-3}	7.71×10^{-5}	4.85×10^{-7}
F	9.29×10^{-3}	7.71×10^{-5}	7.16×10^{-7}
G	8.30×10^{-4}	8.62×10^{-3}	7.15×10^{-6}
H	2.09×10^{-4}	9.44×10^{-2}	1.97×10^{-5}
I	1.26×10^{-3}	8.62×10^{-3}	1.08×10^{-5}
J	1.59×10^{-4}	5.57×10^{-1}	8.83×10^{-5}
K	1.30×10^{-2}	6.78×10^{-4}	8.81×10^{-6}
L	1.99×10^{-3}	8.62×10^{-3}	1.72×10^{-5}

REFER TO PLATE 2 FOR SITE LOCATIONS

southern Nevada, west of 115°00' west longitude, and central California, east of 118°00' west longitude. The modeled region encompasses approximately 7.7×10^4 km^2.

Figure 2-13 shows the flow boundaries of the hydrologic model. These boundaries were established along the following topographic highs: on the north -- the Palmetto Mountains, Cactus, Kawich, Reveille and Grant Ranges; on the east -- Pahranagat Range, Sheep Range, and Spring Mountain; and on the south -- Kingston Range and Saddle Hills. Death Valley, a topographic low, defines the western discharging boundary of the hydrologic model. The major discharging boundary, Death Valley, and the major recharging boundaries (the north and east boundary), were held at the water table elevations of a hand-contoured hydraulic head map provided by the Denver Office of the USGS. As shown on Figure 2-13, three zones along the boundary of the modeled area were assigned as no-flow boundary conditions. Results of Rice's model are presented in Table 2-10.

2.7.3 Czarnecki and Waddell's Model - 1984

A finite-element model was developed by Czarnecki and Waddell (1984) using parameter-estimation techniques to characterize the groundwater flow system in the vicinity of Yucca Mountain at the Nevada Test Site.[12] The model simulated steady-state groundwater flow occurring in tuffaceous, volcanic, and carbonate rocks, and alluvial aquifers. This model is in fact a subregional model of Waddell's 1982 study area. Figure 2-14 illustrates both the regional and subregional model areas.[13] The purpose of this model was to gain a better understanding of the groundwater flow system beneath Yucca Mountain, as well as for later use in simulating the change in position of the water table resulting from a change in future climatic conditions leading to increased precipitation

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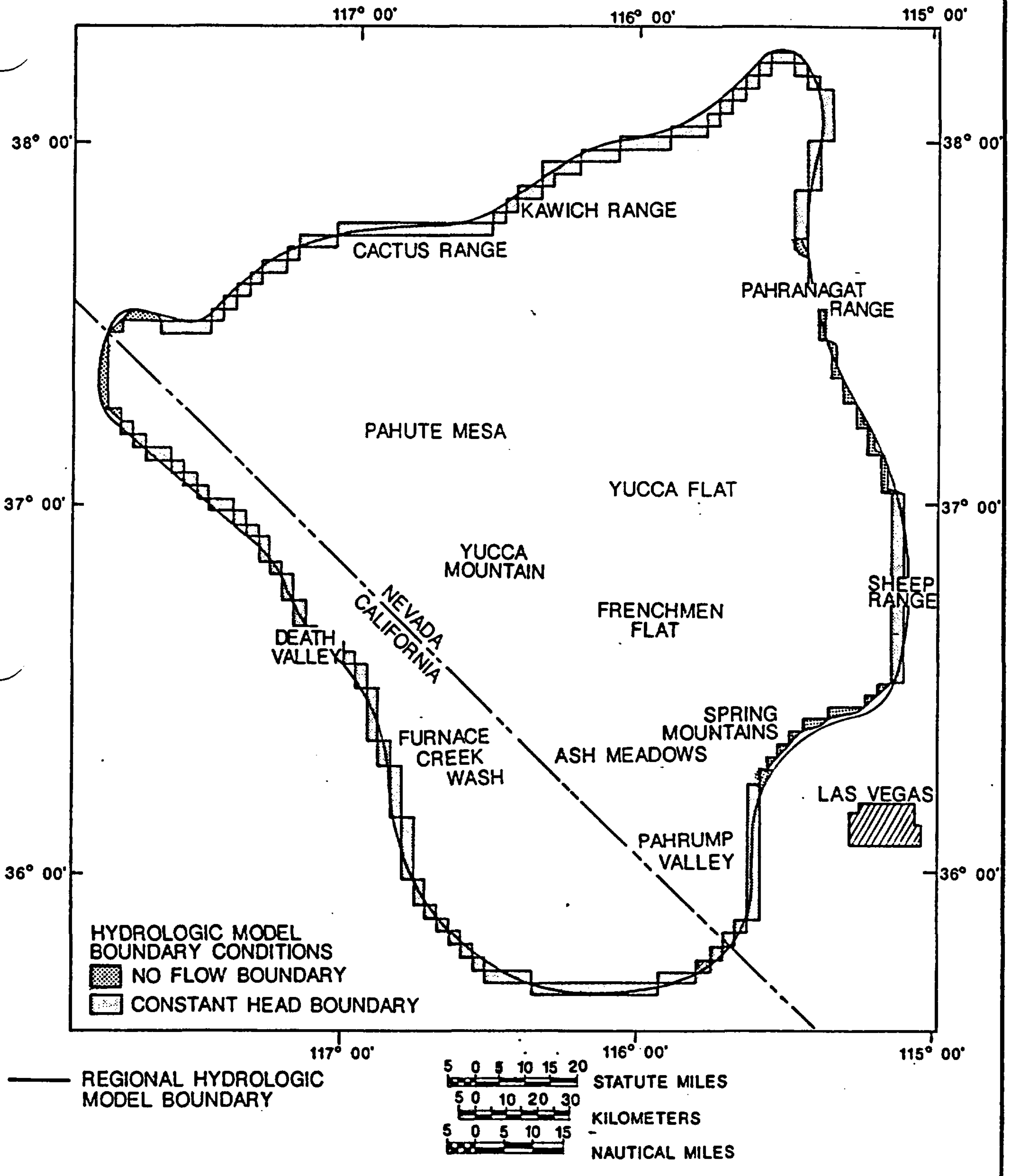
[12] USGS Comment - Regional Hydrologic System Synthesis and Modeling (p. 161)

An explanation needs to be given for using the two-dimensional groundwater flow model developed by Czarnecki and Waddell (1984) and why it is not being revised to three dimensions to account for leakage between the lower carbonate aquifers and the overlying volcanics and basin-fill deposits.

[13] USGS Comment - Studies to Provide a Description of the Regional System (p. 152)

On what basis is the boundary of the subregional model drawn?



SOURCE: RICE (1984)

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FIGURE 2-13

RICE'S 1984 STUDY AREA

Date: SEPT 1988

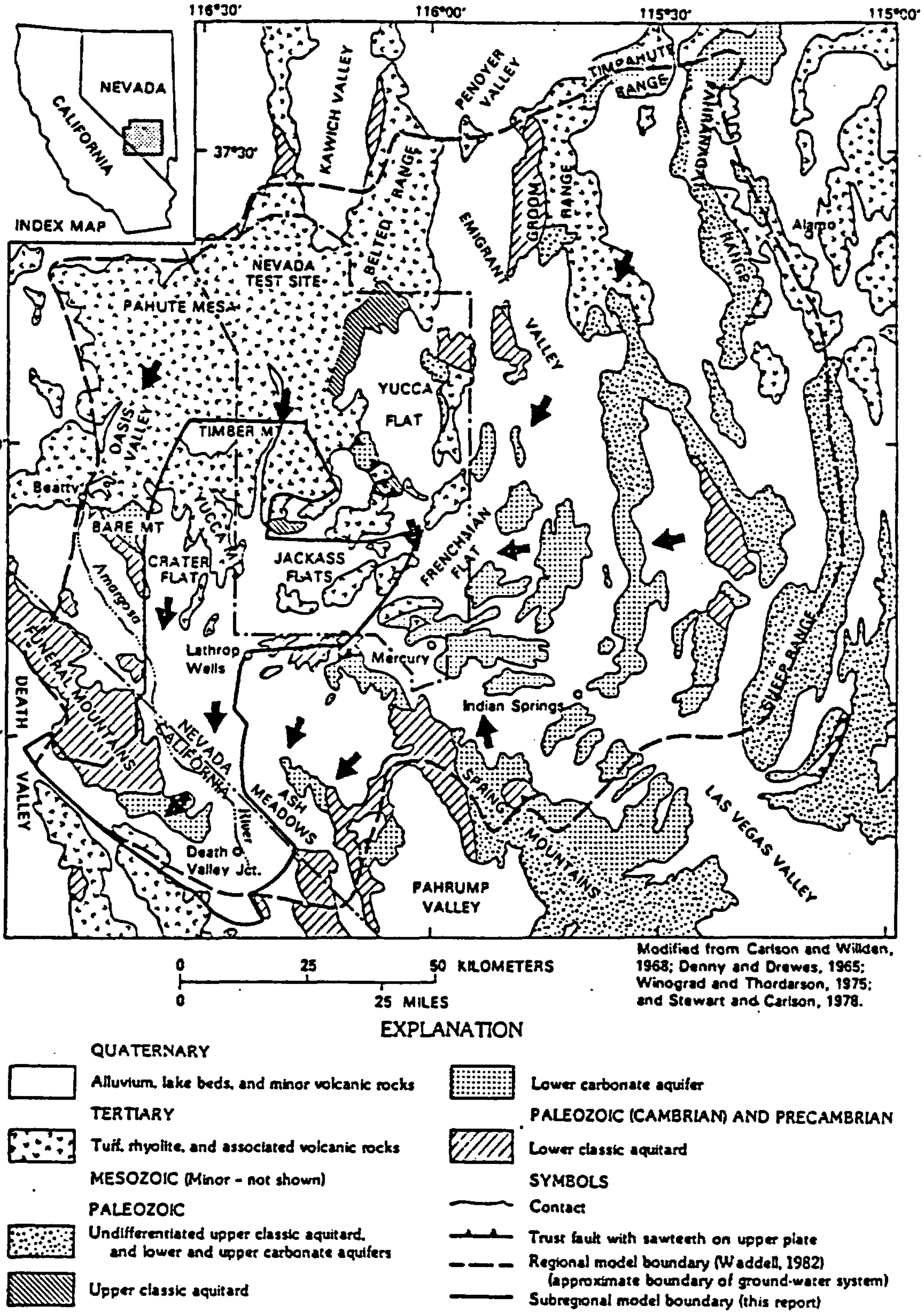
Project: 4001

TABLE 2-10

WATER BALANCE SUMMARY FOR RICE'S REGIONAL MODEL

	ESTIMATE OF PREDICTION (m^3/yr)
FLUX INTO THE MODEL	
Pacific National Laboratory's estimate of recharge from precipitation	1.641×10^8
Predicted underflow entering the model along the north and east boundaries (this includes flow entering along Spring Mountain)[a]	1.168×10^8
TOTAL	2.809×10^8
FLUX OUT OF THE MODEL	
Estimate of net dicharge from pumping, springs, and evapotranspiration	1.162×10^8
Predicted underflow leaving the model from Death Valley, and along the southern boundary	1.628×10^8
TOTAL	2.790×10^8

[a] Refer to Figure 2-13 for model boundaries.



Modified from Carlson and Willden, 1968; Denny and Drewes, 1965; Winograd and Thordarson, 1975; and Stewart and Carlson, 1978.

LOCATION OF REGIONAL AND SUBREGIONAL MODELED AREAS, WITH GENERALIZED GROUND-WATER FLOW DIRECTIONS, AND GENERALIZED GEOLOGY (MODIFIED FROM WADDELL, 1982

SOURCE CZARNECKI AND WADDELL (1984)

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FIGURE 2-14
CZARNECKI AND WADDELL'S
1984 STUDY AREA

Date: SEPT 1988

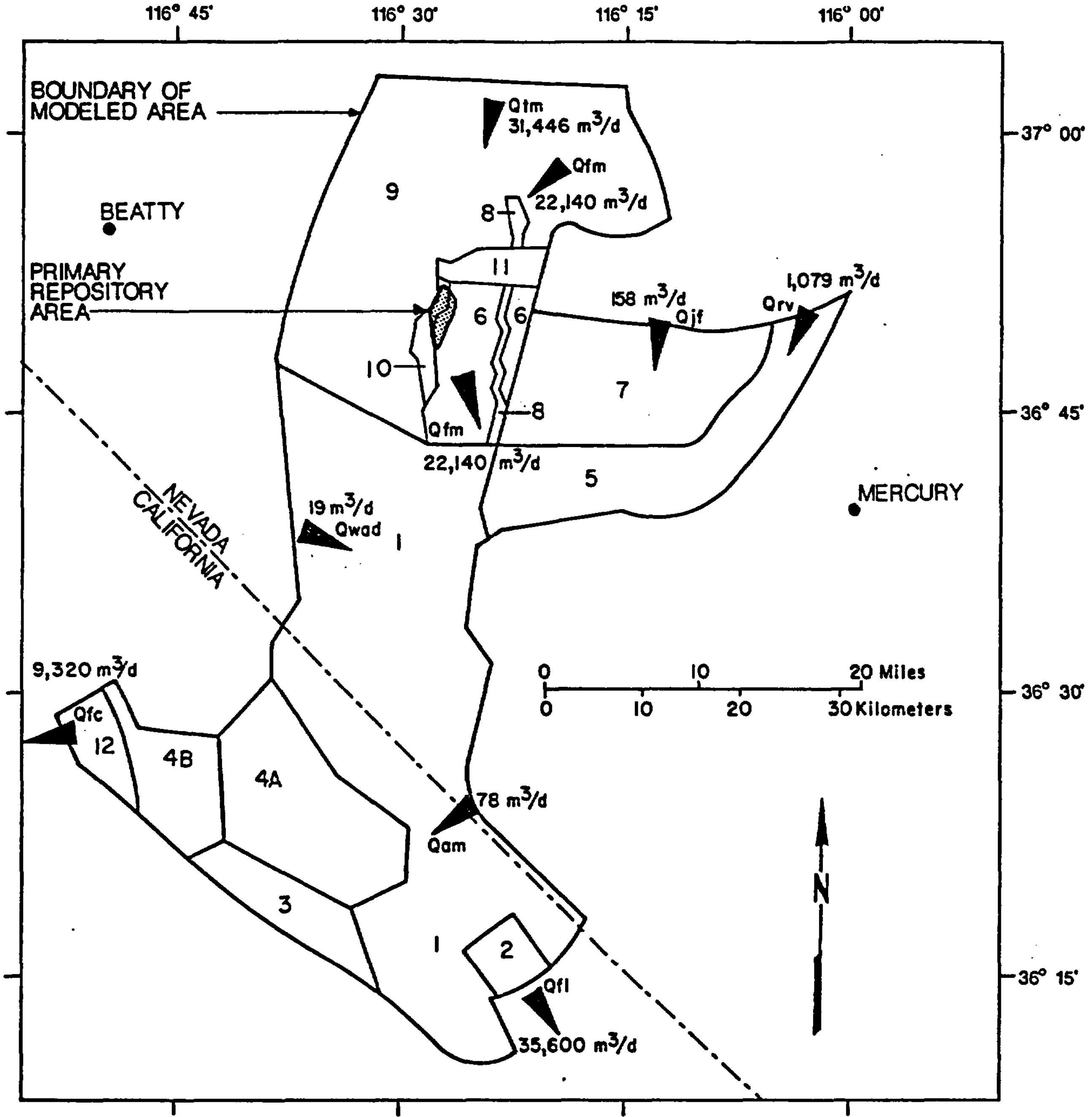
Project: 4001

and increased recharge. Figure 2-15 illustrates boundary conditions used in this model consisting of three types: known-flux, no-flow, and constant head. A summary of flux values is presented in Table 2-11.

Vectors of simulated vertically-integrated groundwater flux generated by Czarnecki and Waddell's model are shown on Plate 3. The length and head width of each vector is proportional to the magnitude of flux while the orientation is indicative of the direction of flux. Vector lengths are scaled; the maximum vector length is 12.7 mm, corresponding to a maximum flux of 9.36 x 10^{-5} m^2/s (8.09 m^2/d). Again, these are unit flux values. These fluxes vary in direction from southeast through the Yucca Mountain repository block to south away from the proposed site and in magnitude from about 2 to 3 m^2/d. These model-derived fluxes result from a parameter-estimation approach, in which an estimated transmissivity of 3340 m^2/d was applied.

Transmissivities calculated by Czarnecki and Waddell's model for Furnace Creek Ranch, Amargosa Desert, and Yucca Mountain are dependent, in part, on fluxes specified in the model. Because several flux values used in their model were estimates, a sensitivity analyses of calculated transmissivity values to changes in flux values was performed to help assess the importance of knowing a particular flux value. The relationship of these calculated transmissivities to specific fluxes are shown on Figures 2-16 through 2-18. Of all the fluxes specified in the model, the best known is the spring discharge near Furnace Creek Ranch. The next best estimate is that for the evapotranspiration flux at Franklin Lake playa. The remaining flux values are estimates.

Flux values were varied independently in multiples of 0.25, 0.50, 1, 2, and 4 times a baseline value. The estimate of transmissivity near Furnace Creek Ranch is affected only by changes in flux at Furnace Creek Ranch. The possible isolation of groundwater flow to Furnace Creek Ranch from groundwater flow beneath the Amargosa Desert (plate 3; flow-vector diagram) may explain the insensitivity of this transmissivity calculation to changes in other fluxes. Estimated transmissivity values in Amargosa Desert are linearly dependent (1 to 1 correspondence) with respect to changes in flux values specified for Franklin Lake playa. The manner in which this calculation is affected by changes in other fluxes is shown on Figure 2-17. Changes in the flux at Furnace Creek has the second largest effect on this calculation, but the effect is only large when this flux is quadrupled.



2 TRANSMISSIVITY ZONE

Qjf ▶ SPECIFIED FLUX

Qjf JACKASS FLATS

Qrv ROCK VALLEY

Qam ASH MEADOWS

Qwad WESTERN AMARGOSA DESERT

Qfm FORTYMILE WASH (AREALLY DISTRIBUTED OVER ZONE 8)

Qtm ▶ RESIDUAL FLUX

Qtm TIMBER MOUNTAIN, CALCULATED AS A RESIDUAL OF THE MASS BALANCE

Qfc ▶ DISCHARGE

Qfc FURNACE CREEK

Qfl FRANKLIN LAKE PLAYA

SOURCE: CZARNECKI AND WADDELL (1984)

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FIGURE 2-15
BOUNDARY FLUXES OF CZARNECKI AND WADDELL 1984 STUDY AREA

Date: SEPT 1988

Project: 4001

TABLE 2-11

SUMMARY OF FLUXES INTO AND OUT OF THE ALKALI FLAT-FURNACE CREEK RANCH SUBBASIN[a],[b]

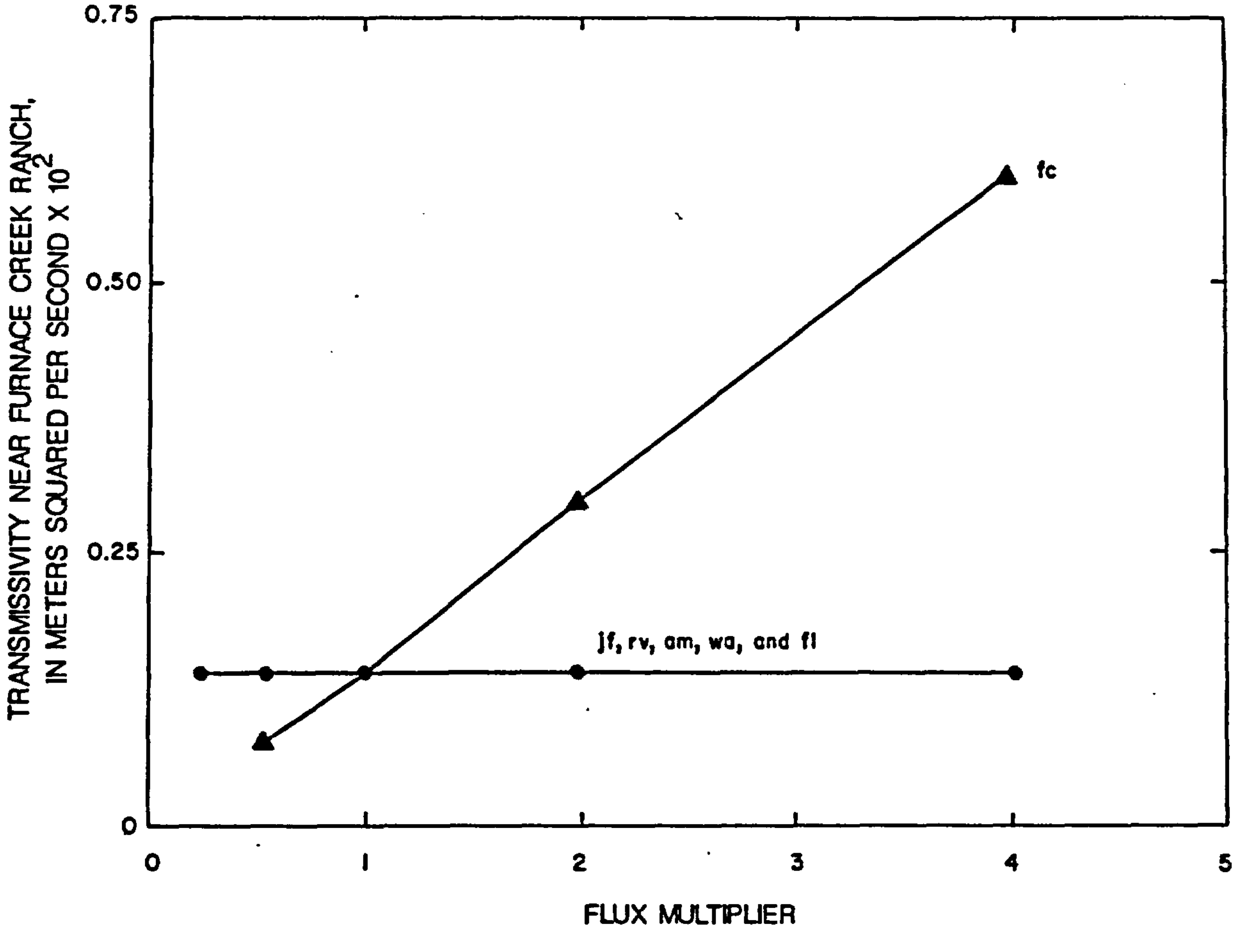
Flux Location	Rate[c] (m^3/d)	Percentage of Inflow and Outflow
Timber Mountain[d]	+ 31,446	57.3
Fortymile Wash	+ 22,140	40.3
Rock Valley	+ 1,079	2.0
Calico Hills	+ 158	0.3
Ash Meadows	+ 78	0.1
Western Amargosa Desert	+ 19	<0.01
Franklin Lake Playa	- 35,600	64.8
Furnace Creek Ranch, Death Valley	- 19,320	35.2

[a] Source: Czarnecki and Waddell (1984).

[b] Flux calculated as a residual of the mass balance.

[c] + indicates flow is into subbasin; - indicates flow is out of subbasin.

[d] Timber Mountain area was simulated as a constant head boundary in the model.



jf	JACKASS FLATS
rv	ROCK VALLEY
am	ASH MEADOWS
wa	WESTERN AMARGOSA DESERT
fc	FURNACE CREEK RANCH
fl	FRANKLIN LAKE PLAYA

SOURCE: DOE, 1988

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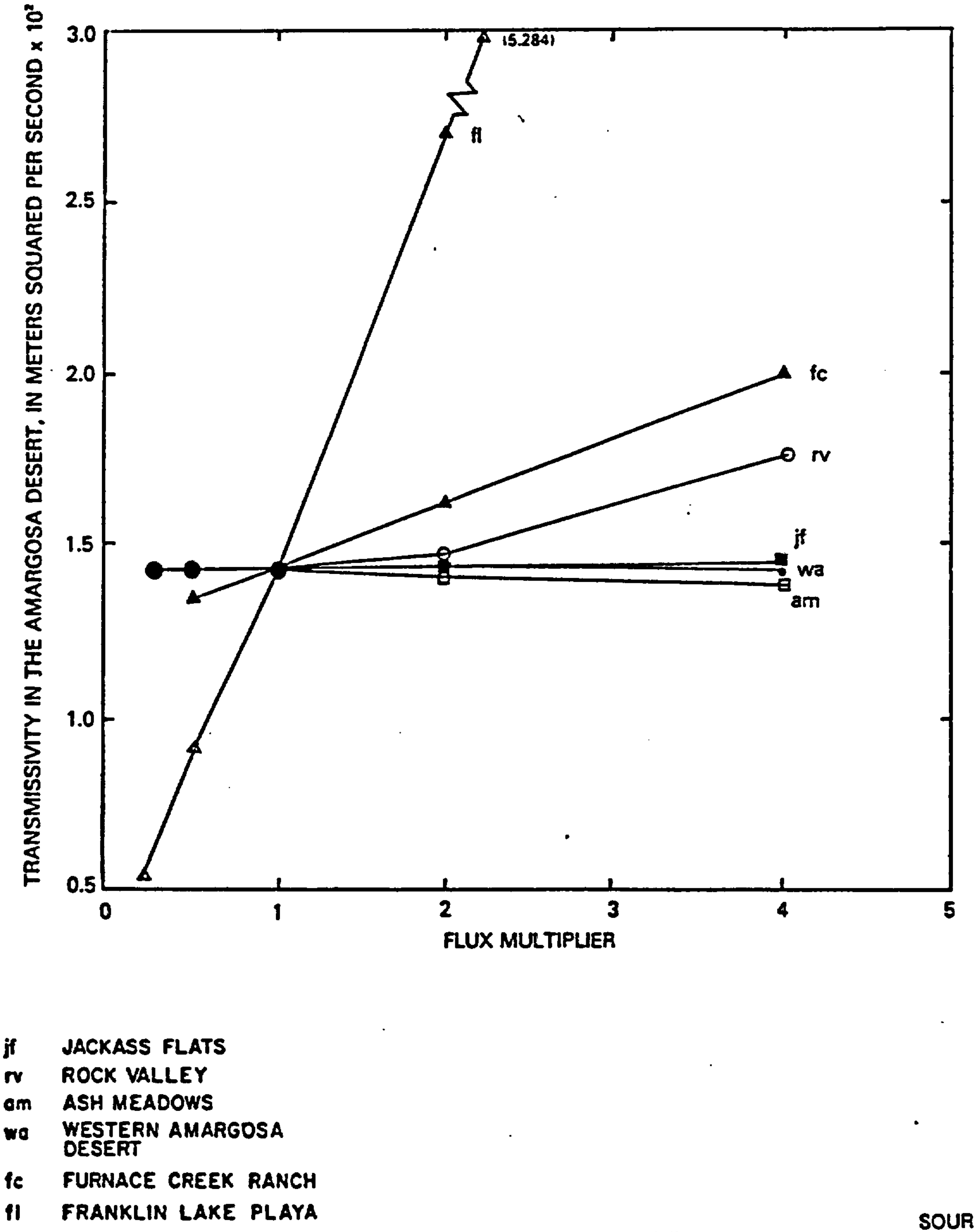
FIGURE 2-16
SENSITIVITY OF CALCULATED TRANSMISSIVITY NEAR FURNACE CREEK RANCH TO INCREASED FLUX VALUES

Date: SEPT 1988

Project: 4001



SOURCE: DOE, 1988

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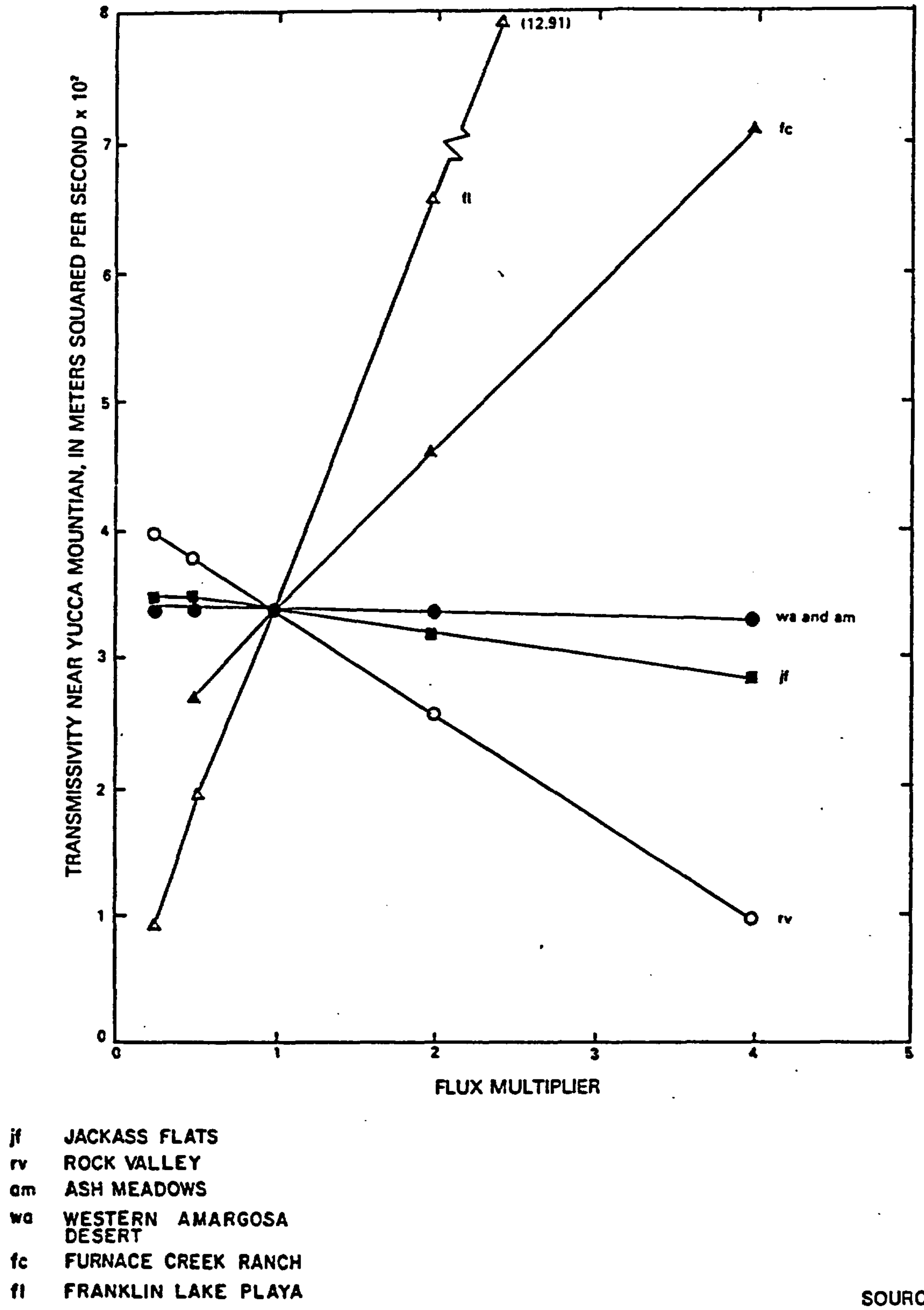
FIGURE 2-17
SENSITIVITY OF CALCULATED TRANSMISSIVITY IN THE AMARGOSA DESERT TO INCREASED FLUX VALUES

Date: SEPT 1988

Project: 4001



SOURCE: DOE, 1988

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FIGURE 2-18
SENSITIVITY OF CALCULATED TRANSMISSIVITY NEAR YUCCA MOUNTAIN TO INCREASED FLUX VALUES

Date: SEPT 1988

Project: 4001

The effect of changes in flux on the estimation of transmissivity near Yucca Mountain is shown on Figure 2-18. Again, changes in the flux at Franklin Lake playa have the greatest effect on this calculation, followed by changes in the flux at Furnace Creek Ranch.[14]

Plate 3 is a useful illustration for visualizing the direction and rate of flow throughout Czarnecki and Waddell's modeled area. However, the density of vectors in a given area does not indicate the magnitude of flow in an area but is a result of the density of elements from which these vectors were derived. Because transmissivity values are integral to the calculation of flux-vector magnitudes, adjacent zones with contrasting transmissivities may have flux vectors with contrasting lengths. Contrasting lengths may also occur where flow is forced around sharp corners of impermeable zones or boundaries, such as north of Yucca Mountain and south of Jackass Flats near Lathrop wells (Czarnecki and Waddell, 1984).

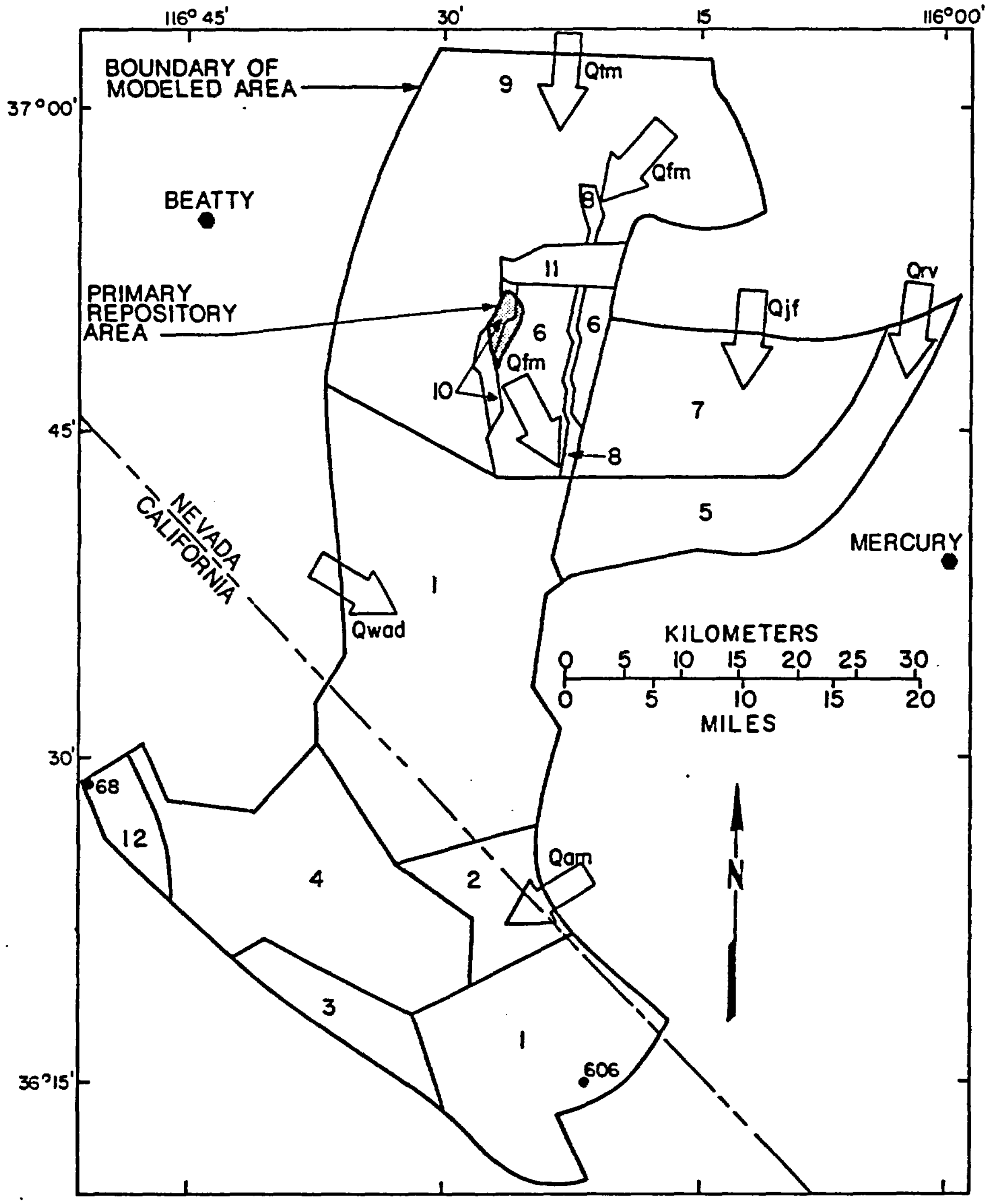
2.7.4 Czarnecki's Model - 1985

Czarnecki's two-dimensional, finite-element model was used to assess the potential effects of changes in future climatic conditions on the groundwater system in the vicinity of Yucca Mountain. These changes were believed by Czarnecki to result in an increase in the rates of precipitation and, consequently, greater rates of recharge. Figure 2-19 illustrates the modeled area used by Czarnecki (1985), which is the same region used by Czarnecki and Waddell (1984). Boundary conditions used by Czarnecki (1985) are listed in Table 2-12 and are graphically illustrated on Figure 2-19.

A 100-percent increase in modern-day precipitation was assumed by Czarnecki to be the probable maximum increase in the next 10,000 years. To obtain recharge volumes precipitation values from Rush (1970) were increased 100 percent (multiplied by 2), and then multiplied by the percentage of

---

[14] WWL Comment - Transmissivity Values at Yucca Mountain
How can a discharge flux located downgradient from Yucca Mountain have such a great impact on estimated transmissivity values for Yucca Mountain (Figure 2-17)? Why was the discharge at Franklin Lake Playa allowed to vary if data on its discharge is well understood?



2 - TRANSMISSIVITY ZONE. SOURCE: CZARNECKI AND WADDELL (1984)

606 • - POINT OF CONSTANT HYDRAULIC HEAD, IN METERS ABOVE OR BELOW (-) SEA LEVEL

⇨ Qjf - SPECIFIED FLUX -- Qjf, JACKASS FLATS; Qrv, ROCK VALLEY; Qam, ASH MEADOWS; Qfc, FURNACE CREEK; Quad, WESTERN AMARGOSA DESERT; Qtm, TIMBER MOUNTAIN; Qfm, FORTYMILE WASH (AREALLY DISTRIBUTED OVER ZONE 8)

SOURCE: CZARNECKI (1985)

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FIGURE 2-19

CZARNECKI'S 1985 STUDY AREA

Date: SEPT 1988

Project: 4001

TABLE 2-12

CZARNECKI'S (1985) MODEL VARIABLE VALUES

Model Variable[a]	Value		Dominant Lithology
Q_{rv}	0.1249E0-01	(1,079)	-------------------
Q_{jf}	.1835E-02	(158.5)	-------------------
Q_{wad}	.2244E-03	(19.39)	-------------------
Q_{fm}	.2563	(22,140)	-------------------
Q_{am}	.8990E-03	(77.67)	-------------------
Q_{tm}	.2959	(25,570)	-------------------
K1,K2	.1691E-04	(1.461)	Alluvium
K3	.1484E-05	(.1282)	Volcanic rocks
K4	.1000E-05	(.864)	Carbonate rocks
K5	.1480E-03	(12.790)	Dolomite
K6,K7,K8	.4229E-04	(3.654)	Tuffaceous rocks
K9	.1105E-05	(.0954)	Dolomite
K10	.9100E-06	(.0786)	Dolomite
K11	.4500E-07	(.0038)	Dolomite
K12	.1000E-08	(.00086)	Lakebeds, alluvium

[a] Refer to Figure 2-19 for location of variables.

[Q, flux, in cubic meters per second (cubic meters per day); K, hydraulic conductivity, in meters per second (meters per day); number following letter is zone number; rv, Rock Valley, jf, Jackass flats, wad, Western Amargosa Desert; fm, Fortymile Canyon; am, Ash Meadows; tm, Timber Mountain] precipitation occurring as recharge that is associated with similar precipitation values from Rush (1970).[15]

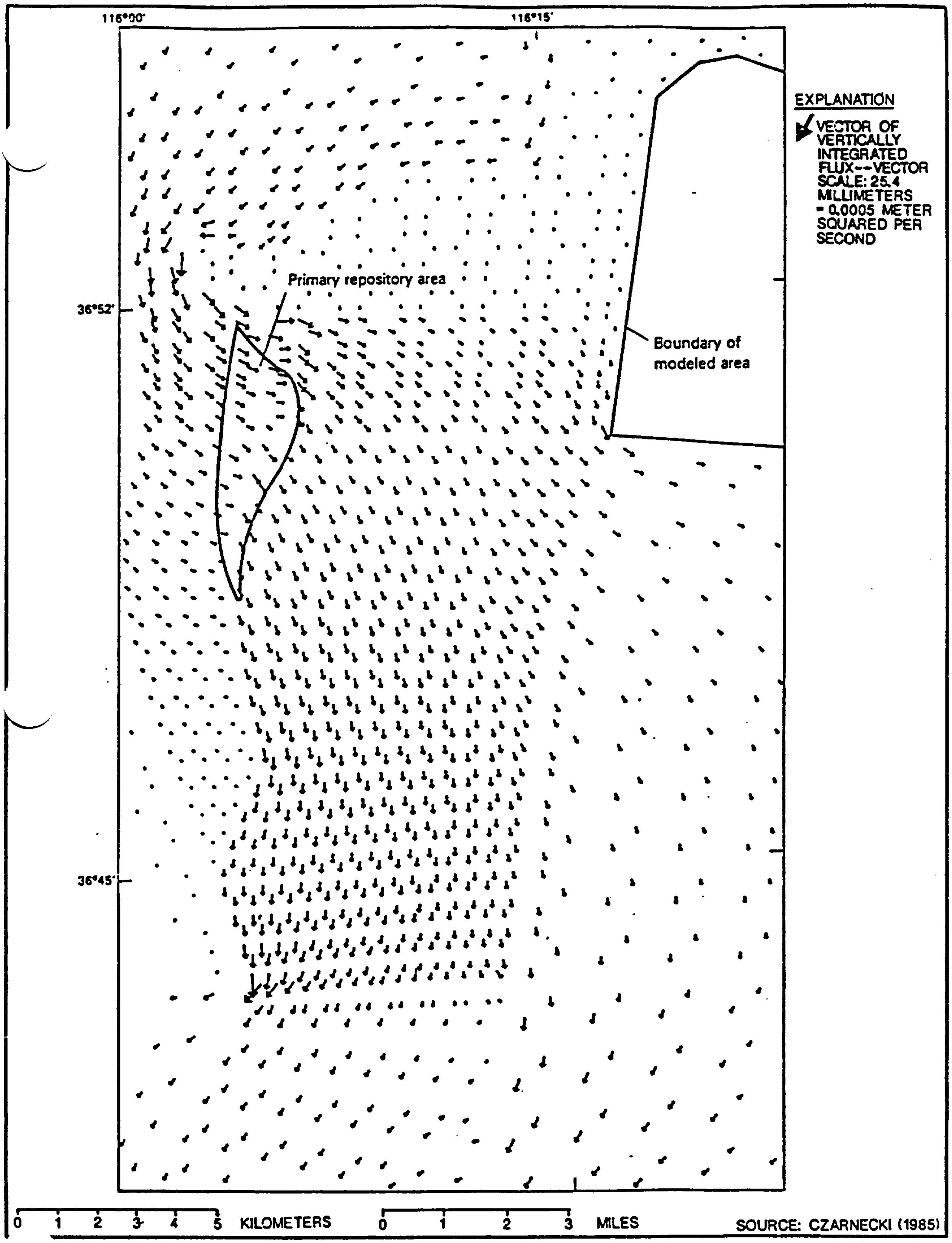
Results of Czarnecki's model indicated that the position of the water table near the primary repository area near Yucca Mountain rose as much as 130 meters for a simulation involving a 100-percent increase in precipitation compared to modern-day conditions. Despite the water table rise, no flooding of the potential repository would occur at its current proposed location (Czarnecki, 1985).

Changes in the direction and magnitude of the simulated groundwater flux conditions are presented in the form of vectors on Figures 2-20 and 2-21. Vectors of vertically integrated groundwater flux in the vicinity of Yucca Mountain that corresponds to the baseline simulation (taken from Czarnecki and Waddell, 1984), are shown on Figure 2-20. The flux vectors for simulations using the 100-percent increase in precipitation are shown on Figure 2-21. A comparison of the two figures shows that flow-path directions through the primary repository area generally were the same for both cases although vector magnitudes are substantially greater for the increased-recharge simulation. Vectors along the southeastern part of the primary repository area and immediately downgradient do have a more southerly component for the case of increased precipitation. According to the simulation, springs would discharge south and west of Timber Mountain along Fortymile Canyon, in the Amargosa Desert near Lathrop Wells and Franklin Lake playa, and near Furnace Creek Ranch in Death Valley, where they presently discharge. Large increases in recharge cause vectors to diverge away from Fortymile Wash, located east of the repository.

Ratios of vertically integrated fluxes obtained from the simulation using the 100-percent increase in precipitation versus those obtained for the baseline simulation are mapped on Figure 2-22. The largest ratios occur where groundwater flows around zones of contrasting hydraulic conductivity and where hydraulic gradients increased substantially (such as along Fortymile Wash).

---

[15] WWL Comment - Czarnecki's Recharge Value
As discussed earlier, empirical estimation of recharge based on a percentage of recharge may not be acceptable. Because determination of the repository's position relative to future pluvial water table levels is critical in the evaluation of the site, alternative estimations of recharge should be analyzed so that this performance objective can be properly addressed.



SOURCE: CZARNECKI (1985)

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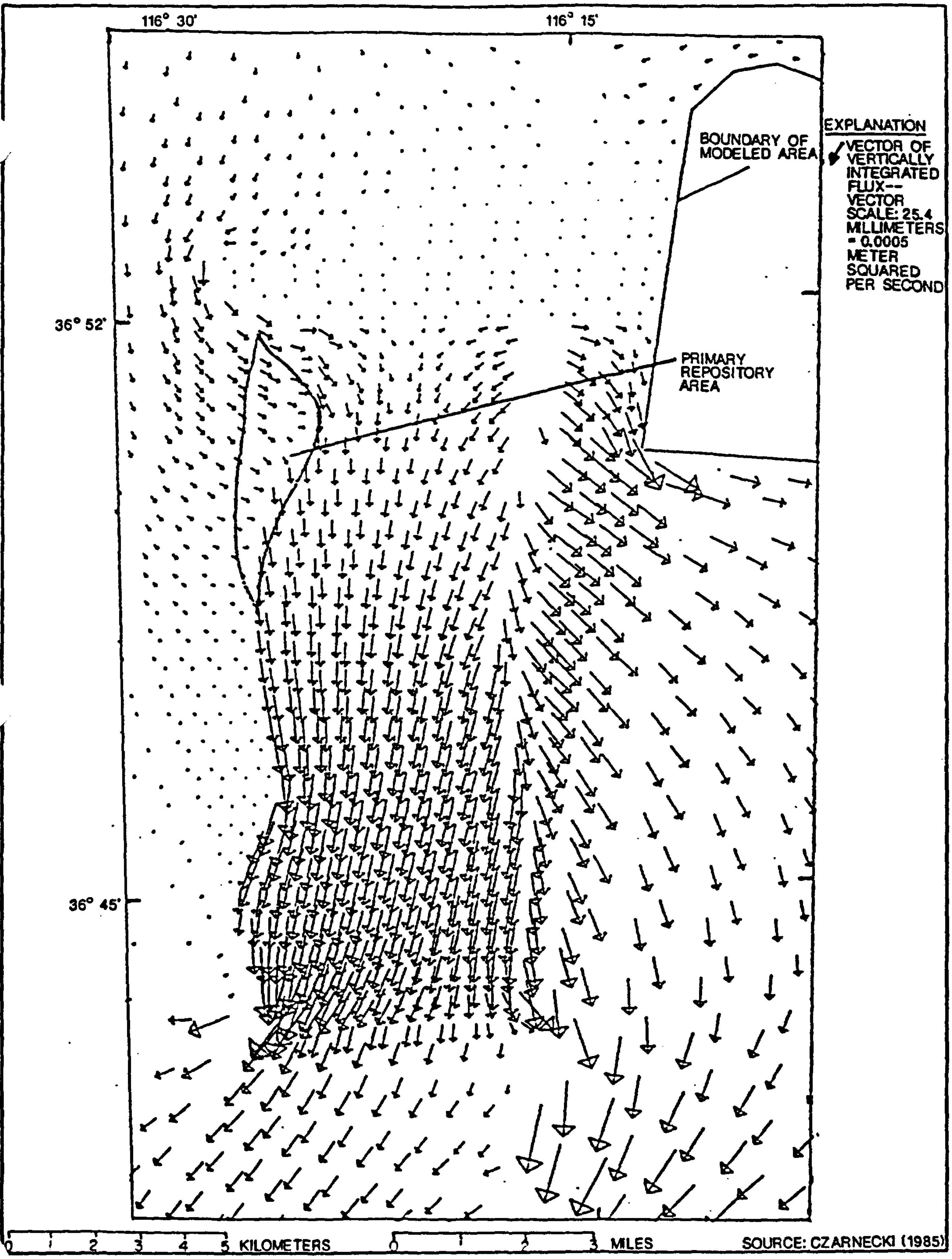
FIGURE 2-20
BASELINE VERTICALLY INTEGRATED
GROUND-WATER FLUX VECTORS

Date:	SEPT 1988
Project:	4001



SOURCE: CZARNECKI (1985)

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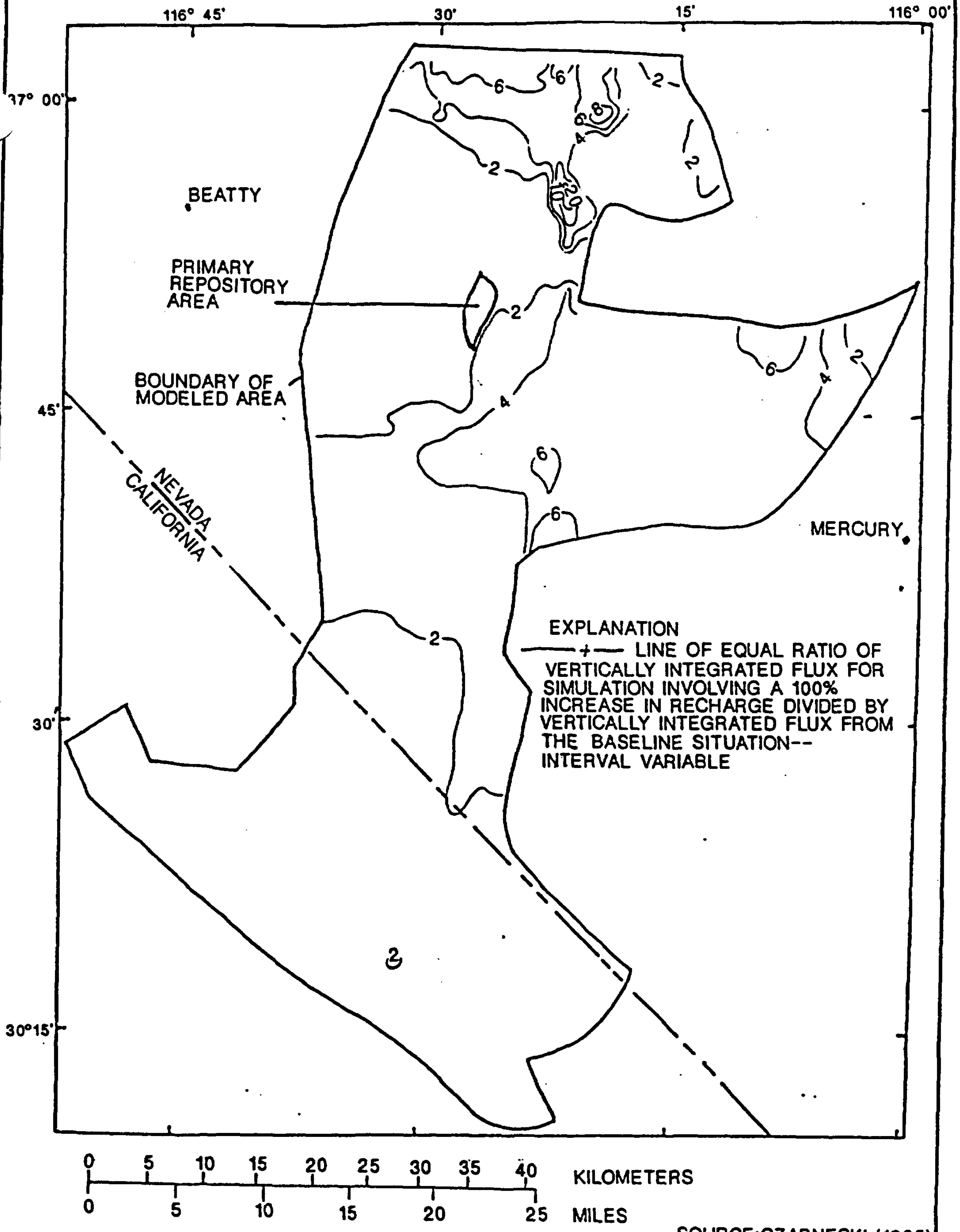
FIGURE 2-21
VERTICALLY INTEGRATED GROUND-WATER FLUX VECTORS FOR INCREASED RECHARGE SIMULATION

Date: SEPT 1988

Project: 4001



SOURCE:CZARNECKI (1985)

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FIGURE 2-22
RATIOS OF VERTICALLY INTEGRATED FLUXES

Date:	SEPT 1988
Project:	4001

The largest ratio (27:1) occurs along Fortymile Wash; the range in ratios near the primary repository area is from 2:1 to 4:1; that is, the vertically integrated flux for the simulation using the 100-percent increase in precipitation was two to four times larger than for the baseline simulation.

2.7.5 Residence Times of the Groundwater

Residence time of water in the hydrogeologic units is dependent on two factors: (1) groundwater velocities and (2) travel distances. Each of these factors is controlled by the highly complex hydrogeologic characteristics of the groundwater system. In a discussion of groundwater velocity, Winograd and Thordarson (1975) developed some estimates for residence and travel time for groundwater beneath parts of the basin:

1. "Beneath Yucca Flat, assuming an average saturated thickness of about 300 m and vertical movement, the time needed for a water particle to move from the top to the bottom of the tuff aquitard is about 6,000 to 2,000,000 yr, corresponding to velocities of 5×10^{-2} m/yr to 1.5×10^{-4} m/yr".

2. "A carbon-14 date of water from the valley-fill aquifer beneath Frenchman Flat suggests that the age of the groundwater in the tuff aquitard probably is in the range of several tens of thousands of years based on a sample with an apparent age of 13,000 yr. An age of several hundred thousand years is not beyond possibility for waters near the base of the tuff aquitard beneath Yucca or Frenchman Flats, because vertical flow velocities through the underlying aquitard are likely to be very small, based on current rock-property data and recharge estimates".

3. "Estimates of the velocity in the lower carbonate aquifer beneath central Yucca Flat range from about 6 to 600 mm/d, or from about 2 to 200 m/yr. Estimated average velocities beneath the Specter Range (15 km southwest of Mercury) are about 100 times larger than those for the lower carbonate aquifer beneath central Yucca Flat, or about 200 m to 20 km/yr and probably represent an upper limit of the groundwater velocities in the lower carbonate aquifer. Velocity estimates for the lower carbonate aquifer beneath Yucca Flat and the Specter Range principally reflect differences in the estimates of the volume of groundwater flowing through each area used in estimating these groundwater velocities. These velocities were calculated by dividing the estimated flow through the aquifer by the carbonate aquifer cross-sectional area and the estimated effective porosity of 0.01 to 1 percent".

2.8 ISOTOPIC AND REGIONAL HYDROCHEMISTRY

This section describes the hydrochemical and isotopic nature of the groundwater within the saturated zone in the hydrologic study area. Discussions are provided regarding (1) the chemical composition of principle aquifers, (2) the hydrochemical facies of the regional groundwaters, and (3) the regional isotope hydrology for the tuff and carbonate aquifers.

2.8.1 Regional Hydrochemistry

Major-ion chemistry of groundwater in the vicinity of Yucca Mountain was summarized by Winograd and Thordarson (1975), White (1979), Claassen (1983), and Benson et al. (1983). The chemical composition of groundwater in the region is principally determined by (1) reactions with carbonate and volcanic rocks or rock fragments, (2) concentrations of dissolved chemicals by evaporation, (3) formation of smectites, zeolites, and evaporite minerals, and (4) mixing of waters of different compositions.

Plate 4 presents the major hydrochemical facies of the NTS and vicinity (Winograd and Thordarson, 1975). These authors recognized five hydrochemical types of water, which DOE (1988) has summarized as follows:

1. "A sodium-potassium-bicarbonate facies is present in western Emigrant Valley, Yucca Flat, Frenchman Flat, Jackass Flat, Pahute Mesa, and Oasis Valley. Water of this facies is found in tuff, rhyolite, and valley fill aquifers rich in volcanic detritus. Subsequent to the Winograd and Thordarson (1975) studies, Benson and Mckinley (1985) provide data indicating that the water of Yucca Mountain is also of this facies".

2. "A calcium-magnesium-bicarbonate facies occurs in the Spring Mountains, southern Indian Springs, southern Three Lakes Valley, and Pahranagat Valley. In these areas, wells tapping either the lower carbonate aquifer or the valley fill aquifer rich in carbonate detritus draw water of this facies".

3. "The calcium-magnesium-sodium-bicarbonate facies is found in the lower carbonate aquifer between Ash Meadows and the eastern NTS. This facies is the result of mixing the first two facies".

4. "The playa facies is recognized to be quite variable, depending to some extent on the depth of the sampling well. Occurrences are restricted to playas where groundwater is discharged by evapotranspiration (near Death Valley Junction) or to shallow discharge areas".

5. "The sodium-sulfate-bicarbonate facies is found in a few wells in the west-central Amargosa Desert".

The DOE has stated that major-ion chemistry of groundwater in the region has been summarized but enough water chemistry data are not yet available to develop a hydrochemical model to support conceptual-flow models or to verify suggested groundwater flow paths.[16]

2.8.2 Regional Isotope Hydrology

Carbon-14, oxygen, and hydrogen isotopic data for the Candidate Area are presented on Plate 5 (Waddell et al., 1984).[17] Carbon-14 ages have not been corrected for dissolution of old or "dead" carbon. Interpretation of the carbon-14 data is complicated by possible mixing of waters of different ages and different origins, because of differences in depths of water-yielding intervals in wells. Where water is sampled from volcanic rocks, and where samples show no evidence of dissolution of calcite, the ages probably approximate true ages. However, caliche is present along Fortymile Wash and calcite occurs along fractures beneath Yucca Mountain, therefore, a minor correction may be appropriate. Problems resulting from mixing require that data be examined carefully, with an understanding of the influences of present and past hydrologic conditions, in order to make meaningful interpretations.

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[16] USGS Comment - Geochemical Reaction Modeling (p. 121)
For many of the potential applications throughout the CDSCP, geochemical reaction path calculations using EQ 3/6 or equivalent codes are the method of choice. However, in modeling efforts aimed at identifying reactions occurring in natural groundwater systems, given the existence of a geochemical data set for that system, an alternative modeling approach exists that should also be pursued. This alternative technique is an inverse modeling approach based on chemical mass balance calculations and is perhaps best discussed in Plummer, 1984. The USGS-WRD has found this approach to be a considerable value in its Regional Aquifer Systems Analysis Program. This alternative technique referenced by the USGS should be investigated.

[17] USGS Comment - Dissolved Oxygen in Groundwater (p. 117)
The analysis and interpretation of dissolved oxygen in groundwater, on both a regional and site-specific geographic scale, deserves far more attention that it is presently receiving. Although plagued by vagaries of sample collection and analysis, dissolved oxygen has one extremely important feature--in the absence of advection or diffusion, the concentration of dissolved oxygen can only decrease downgradient. Dissolved oxygen should provide a valuable adjunct to carbon-14 in defining directions of flow in areas of low hydraulic gradient.

2.8.2.1 Tuff Aquifer

Radiocarbon dates are available for samples of groundwater from the tuffaceous aquifer upgradient from Yucca Mountain. The samples are from wells UE-29a#1 and UE-29a#2 located in the bottom of Fortymile Canyon. The major ion composition of the water is very similar to the wells sampled at Yucca Mountain. However, water samples from wells UE-29a#1 and UE-29a#2 have threefold the radiocarbon content of those samples taken downgradient at Yucca Mountain as shown in Table 2-13. In these two wells the radiocarbon content of water ranges from 75.3 percent modern carbon (pmc) units in the shallower abandoned well UE-29a#1 (which was completed to 65.5 m) to 60.0 pmc in the 86.7 to 213.4-m interval of adjacent well UE29a#2 (Waddell, 1985). This stratification is consistent with occasional rapid wash bottom recharge from ephemeral flow (rain storm water) in Fortymile Canyon. Depth to water here is about 25 m and the upper layers of the section are composed of permeable alluvium and brecciated rhyolite. This recharge hypothesis is confirmed by the high tritium content of the shallower water (62 TU), which could only be derived from precipitation bearing bomb-test tritium recharging the aquifer since the mid-1960s. Since the carbon-14 activity is below 100 pmc, appreciable dilution of these recent recharge waters must have occurred, indicating that the recharging water must have had an even higher tritium concentration.[18]

Figure 2-23 is a δD-$\delta^{18}O$ diagram of the analyses on water samples from the tuff aquifers. The radiocarbon content is plotted (in pmc) at each δD-$\delta^{18}O$ coordinate. The younger, wash-bottom recharge samples fall higher on the plot than does the older, high altitude, cold continental recharge samples from the same formations under Yucca Mountain. This is consistent with rainstorm runoff rather than snow melt recharge. The low $\delta^{13}C$ values in both instances suggest that the recharge has always occurred in poorly vegetated areas.

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[18] USGS Comment - Environmental Tracers (p. 122)
The use of various radioactive isotopes as estimators of age occurs throughout the CDSCP. The degree of understanding associated with these discussions of age unfortunately varies considerably and complete misunderstanding occurs often. A greater detail is required on the use of various isotopes for age calculations. The age of a substance or phase containing a radioactive isotope can be calculated only if all of the possible sources and sinks that can add or remove isotopes from the phase in question are known, as well as the rates of transfer of isotopes between phases. This sort of complexity is often unrecognized in the CDSCP.

TABLE 2-13

ENVIRONMENTAL ISOTOPE DATA FOR GROUNDWATER SAMPLES FROM THE TUFF AND TUFFACEOUS VALLEY FILL AQUIFERS IN THE REGION NEAR YUCCA MOUNTAIN[a]

Well designation	Collection date	δD (o/oo SMOW)[b]	$\delta^{18}O$ (o/oo SMOW)[b]	$\delta^{13}C$ (o/oo PDB)[c]	^{14}C (pmc)[d]	HTO (TU)[e]
UE-29a#1[f]	01/29/82	-92.0	-12.4	-12.6[g]	75.3	62.0
UE-29a#2[f] [h]	01/08/82	-93.5	-13.0	-12.6[g]	62.3	11.0
UE-29a#2[f] [h]	01/15/82	-93.0	-13.1	-13.1[g]	60.0	11.0
J-12[j]	03/26/71	-97.5	-12.8	-7.9	32.2	<68.0
J-13[j]	03/26/71	-97.5	-13.0	-7.3	29.2	<68.0
UE-25c#1	09/30/83	-102	-13.5	-7.1	15.0	<0.3
UE-25c#2	03/13/84	-100	-13.4	-7.0	16.6	<0.6
UE-25c#3	05/09/84	-103	-13.5	-7.5	15.7	0.6
USW H-6	10/16/82	-106	-13.8	-7.5	16.3	<3.0
USW H-6	06/20/84	-105	-14.0	-7.3	10.0	1.2
USW H-6	07/06/84	-107	-14.0	-7.1	12.4	0.3
USW VH1[l]	02/11/81	-108	-14.2	-8.5	12.2	6.0
AM-4	03/04/74	-103	-13.2	-7.1	19.3	--
AM-9	03/01/74	-102	-12.6	--[i]	28.4	--
AM-11	03/05/74	-101	-13.1	--	20.8	--
AM-13	03/05/74	-102	-13.0	--	19.3	--
AM-15	03/05/74	-104	-13.0	--	18.4	--
AM-18	03/06/74	-102	-13.0	--	27.8	--
AM-20[k]	03/06/74	-102	-12.4	--	13.8	--
AM-21	06/25/74	-99	-13.2	-8.4	27.4	--
AM-23	03/31/71	-103	-13.4	-7.1	17.1	--
AM-25	03/31/71	-102	-13.4	-5.6	15.6	--
NTS#8[l]	03/24/71	-104	-13.0	-12.1	25.4	--

[a] Sources: Data from Benson and McKinley (1985) and as noted in footnotes. AM-samples from Claassen (1985).

[b] δ deuterium and δ oxygen-18 are reported in parts per thousand relative to the standard mean ocean water (SMOW) standard.

[c] δ carbon-13 is reported in parts per thousand relative to the Peedee belemnite (PDB) carbonate standard.

[d] Carbon-14 activity is reported as a percent of the modern carbon (pmc) standard.

[e] HTO = tritium; reported in tritium units (TU).

[f] Waddell (1985).

[g] Value reported as positive in reference.

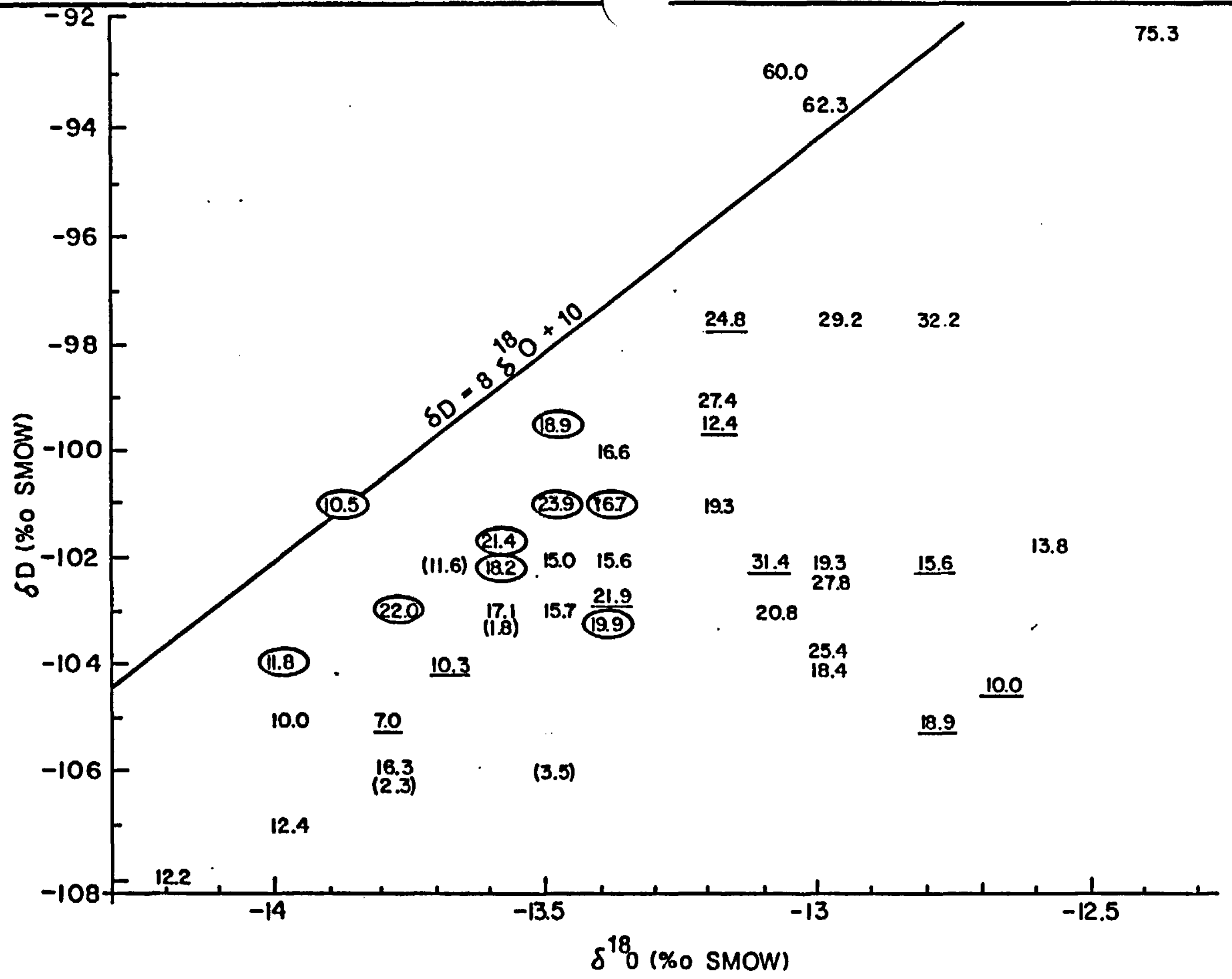
[h] Also reported by Benson and McKinley (1985).

[i] Also reported by Claassen (1985).

[j] --indicates no data.

[k] Completion in tuffaceous material unsure.

[l] Claassen (1985).



VALUES IN PARENTHESIS ARE FROM THE LOWER CARBONATE AQUIFER. UNDERLINED VALUES ARE FROM MIXED CARBONATE/TUFF ORIGIN. THE REMAINING VALUES ARE FROM THE TUFF FORMATIONS, WITH THE YUCCA MOUNTAIN SAMPLES CIRCLED. DATA SAMPLES TAKEN FROM TABLES 2-13 AND 2-14

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FIGURE 2-23
$\delta D - \delta^{18}O$ TUFF AQUIFERS

Date: SEPT 1988

Project: 4001

2.8.2.2 Carbonate Aquifer

Environmental isotope data for groundwater samples from the carbonate aquifer and from mixed carbonate-tuff sources are listed in Table 2-14. Benson and Mckinley (1985) have reported isotopic data for groundwater from the carbonate aquifer in the area around Yucca Mountain (drillhole UE-25p#1). Claassen (1985) reports two carbonate aquifer analyses and several analyses on mixed carbonate-tuff systems from the Amargosa Desert. Winograd and Pearson (1976) and Riggs (1984) report analyses of spring water from Ash Meadows, which primarily drains the area to the east of Yucca Mountain and the Amargosa Desert.

All samples from the carbonate aquifer show low carbon-14 contents (<4 pmc except for Crystal Pool, which is discussed in the following paragraphs) as would be expected at the distal end of a regional carbonate aquifer system. The use of "apparent, uncorrected radiocarbon ages" which may be justified in the tuff aquifer is insupportable in the carbonate system. The modeling of the carbon-14 content of the recharge waters is extremely complicated in a semiconfined carbonate aquifer system. The carbon-13 analyses show that interaction has occurred between the relatively carbon-14-free carbonate minerals of the aquifer and the flowing groundwater. Small adjustments of the isotopic balance to account for this dilution process can greatly affect the resulting radiocarbon dates in such systems (Muller and Mayo, 1986). Without further modeling, these waters can only be taken to be "old" with 30,000 yr before present as the conservative upper limit.

The carbon-14 content of groundwater at the center of a 16-km-long fault-controlled spring line at Ash Meadows is five times greater than that in water from other major springs along the lineament. Winograd and Pearson (1976) have examined the radiocarbon anomaly of Crystal Pool. They have shown it to probably be caused by megascale channeling, with water moving to this discharge point at velocities appreciably greater than those of water moving to adjacent springs. Such channeling is consistent with the known flow regime of karstic aquifers.

The data from Claassen (1985) for wells penetrating both tuff and carbonate lithologies show a variability in isotopic compositions expected in mixed systems. Several of these wells are shallow, with waters also probably derived from valley fill sediments. There are insufficient data available to assess the extent and direction of mixing.

TABLE 2-14

ENVIRONMENTAL ISOTOPE DATA FOR GROUNDWATER SAMPLES FROM THE CARBONATE AQUIFER AND FROM MIXED CARBONATE-TUFF SOURCES[a]

Well or spring designation	Collection date	δD o/oo SMOW[b]	$\delta^{18}O$ o/oo SMOW[b]	$\delta^{13}C$ o/oo PDB[c]	^{14}C (pmc)[d]	HTO (TU)[e]
CARBONATE AQUIFER						
UE-25p#1[f,g]	02/09/83	-106	-13.5	-4.2	3.5	<3.1
UE-25p#1[f,h]	05/12/86	-106	-13.8	-2.3	2.3	3.1
16S/51E-23[i]	--[j]	--	-13.6	-4.6	1.8	--
Fairbanks Spring NE[k]	12/13/74	--	--	-5.2	2.2 ± 0.3	0.1 ± 0.2
Fairbanks Spring SW[k]	--	-103	-13.6	-4.9	1.8 ± 0.2	0.0 ± 0.4
Rogers Spring[k]	--	-102	--	-4.6	1.5 ± 0.3	0.0 ± 0.2
Longstreet Spring[k]	--	-103	--	-4.8	2.7 ± 0.4	0.0 ± 0.2
Scruggs Spring[k]	03/10/75[l]	-103	--	-4.7	1.1 ± 0.3	0.2 ± 0.2
Crystal Pool[k,m]	--	-102	-13.7	-5.0	11.6 ± 0.7	0.6 ± 0.4
Devils Hole[k]	--	--	-13.6	-5.0	2.8 ± 0.4	0.3 ± 0.2
King Spring[k,m]	--	-104	--	-4.7	1.7 ± 0.4	0.4 ± 0.2
Big Spring[k,m]	03/09/75	-102	--	-4.6	2.9 ± 0.4	0.3 ± 0.1
MIXED SYSTEMS						
AM-3[n]	10/20/72	-102	-12.8	--	15.6	--
AM-5[n]	11/17/72	-99.5	-13.2	-6.8	12.4	--
AM-8[n]	03/01/74	-103	-13.4	-7.3	21.9	--
AM-10[n]	06/26/79	-97.5	-13.2	-5.2	24.8	--
AM-16[n]	03/01/74	-104	-12.7	--	10.0	--
AM-17[n]	03/01/74	-105	-12.8	--	18.9	--
AM-19[n]	03/06/74	--	--	--	40.3	--
AM-27[o]	08/18/62	-105	-13.8	-3.6	7.0	--
AM-29[p]	03/31/71	-105	-13.8	-3.4	--	--
AM-30[o]	06/24/79	-104	-13.7	-4.4	10.3	--
AM-47[o]	03/31/71	-102	-13.1	-6.2	31.4	--
AM-50[o]	06/25/79	-104	-13.6	-5.7	--	--
AM-60[p]	12/16/68	--	--	-5.9	28.8	--

[a] Data from Claassen (1985) unless otherwise indicated.

[b] δD and δ oxygen-18 ($\delta^{18}O$) are reported in parts per thousand relative to Standard Mean Ocean Water (SMOW) standard.

[c] Carbon-13 ($\delta^{13}C$) is reported in parts per thousand relative to the Peedee belemnite (PDB) carbonate standard.

[d] Carbon-14 (^{14}C) activity is reported as a percent of the modern carbon standard (pmc).

[e] HTO = tritium; T is reported in tritium units (TU).

[f] Benson and McKinley (1985).

[g] Sampled from the 381 to 1,197 m interval.

[h] Sampled from 1,297 to 1,805 m interval.

[i] Claassen (1985) reports this well as "Amargosa Tracer Well #2."

[j] Data from multiple collection dates.

[k] Winograd and Pearson (1976).

[l] Representative of multiple samplings.

[m] Similar values reported by Riggs (1984).

[n] Tuffaceous lithology, possible carbonate influence.

[o] Carbonate lithology, possible tuff influence.

[p] In both tuff and carbonate formations.

Few deuterium and oxygen-18 data are available for the carbonate aquifer (Figure 2-23 and Table 2-14). The waters show no hydrothermal fractionation and do not resemble expected modern precipitation. Additional stable isotopic data from the carbonate aquifer in the vicinity of Yucca Mountain is expected to provide further information on the interconnection of the tuff and carbonate aquifers.

2.9 REGIONAL PALEOHYDROLOGY

The purpose of paleohydrologic studies is to determine hydrologic conditions during the Quaternary Period that have differed significantly from present conditions. This information will be used to evaluate the likelihood of episodic conditions recurring that may affect the regional groundwater flow system over the next 100,000 years. Of specific interest are (1) the maximum altitude of the water table during pluvial periods of the Quaternary Period, (2) the effects of pluvial water table rises on shortening of groundwater flow paths to discharge areas, and (3) the magnitude of increases in recharge during pluvial periods. With such information, questions such as the following can be addressed: What is the possibility of the repository being flooded by a rising water table during a return of pluvial conditions? How large an infiltration flux might move through the repository in the future?

Evidence for former, higher water tables, changes in length of groundwater flow paths, and the presence and absence of pluvial lakes in the south-central Great Basin are described by the DOE in the following conclusions. A more detailed description of paleohydrologic studies for the proposed site is presented in Section 4.6. In summary, the following conclusions are drawn by the DOE:

1. "Evidence from dated calcitic veins and marsh deposits indicates that the regional water table (more correctly the potentiometric surface) in the south-central Great Basin has apparently declined 50 to perhaps 130 m during the Quaternary Period and that this decline has been accompanied by a lengthening of groundwater flow paths to points of discharge by 14 to perhaps 60 to 70 km. Considerations of the neotectonics of Death Valley, regional interbasin flow through the lower carbonate aquifer, and of the probably increasing aridity in the region during the Quaternary, collectively suggest that an actual and progressive water table decline occurred in the region during this period".

2. "Superimposed on the indicated long-term decline of water table are rises reflecting pluvial climates. In Devils Hole, at Ash Meadows,

preliminary uranium-series dating of calcitic cave deposits indicates that about 30,000 yr ago the water table in the lower carbonate aquifer stood about 10 m above modern level. In southern Indian Springs Valley, marsh deposits, of presumed groundwater origin, occur as much as 20 to 50 m above the modern water table in the valley-fill aquifer; these deposits probably are late(?) Wisconsin in age".

3. "Reconnaissance observations indicate that pluvial lakes of late Pleistocene age were not present in Yucca Flat or Frenchman Flat, though such lakes apparently existed in Gold Flat, Kawich Valley, and Emigrant Valley, 70 km north and northeast of Yucca Mountain".

4. "Groundwater of late Wisconsin age is present in the uppermost part of saturated volcanic rocks beneath Yucca Mountain and in the valley fill aquifer in the Amargosa Desert. The valley fill aquifer was recharged by surface water runoff along the distributaries of Fortymile Wash. A quantitative interpretation of the carbon-14 data to measure groundwater velocity will require test wells that permit water to be sampled selectively from several depths in the zone of saturation".

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CODES AND REGULATIONS

10 CFR Part 60 (Code of Federal Regulations), 1987. Title 10, "Energy," Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," U.S. Government Printing Office, Washington, D.C.

3.0 SITE UNSATURATED HYDROGEOLOGIC SYSTEM

Flow in the unsaturated zone at Yucca Mountain begins as precipitation on the surface of the mountain. Some of this water infiltrates into the soil, rocks and open fractures of the various surface units. The water not removed by evapotranspiration is currently believed to flow in the vertical direction to the water table located many hundreds of meters below the surface. However, a great deal of uncertainty exists as to the actual flow mechanisms and phenomena which can occur within the unsaturated zone. Differences between the hydrologic characteristics of some of the hydrogeologic units may cause deviation of the vertical flow of water. In particular, lateral diversion may occur due to permeability contrasts and/or capillary barriers both above and below the proposed repository horizon.

Several of the geologic units in the unsaturated zone are highly fractured with large bulk permeability and low matrix permeability. In these highly fractured units, gaseous phase flow be an important mechanism for the movement of water and radionuclides. However, the understanding of such flow in an unsaturated, highly fractured system is limited.

The Site Unsaturated Hydrogeologic System has been divided into five major components:

(1) Site Location - Physiographic Setting

(2) Hydrogeologic Setting

(3) Flow Mechanisms in the Unsaturated Zone

(4) Boundary and Initial Conditions

(5) Flow and Transport

Each of these components, along with their elements and sub-elements, are described in the following sections.

3.1 SITE LOCATION - PHYSIOGRAPHIC SETTING

Yucca Mountain is an irregularly shaped volcanic upland, 6 to 10 km wide and about 40 km long. It extends from the valley of Beatty Wash on the north to the northeastern side to the Amargosa Desert on the south. The crest of the mountain ranges between altitudes of 1500 and 1930 m, about 650 m higher than the floor of Crater Flat, which is located to the west.

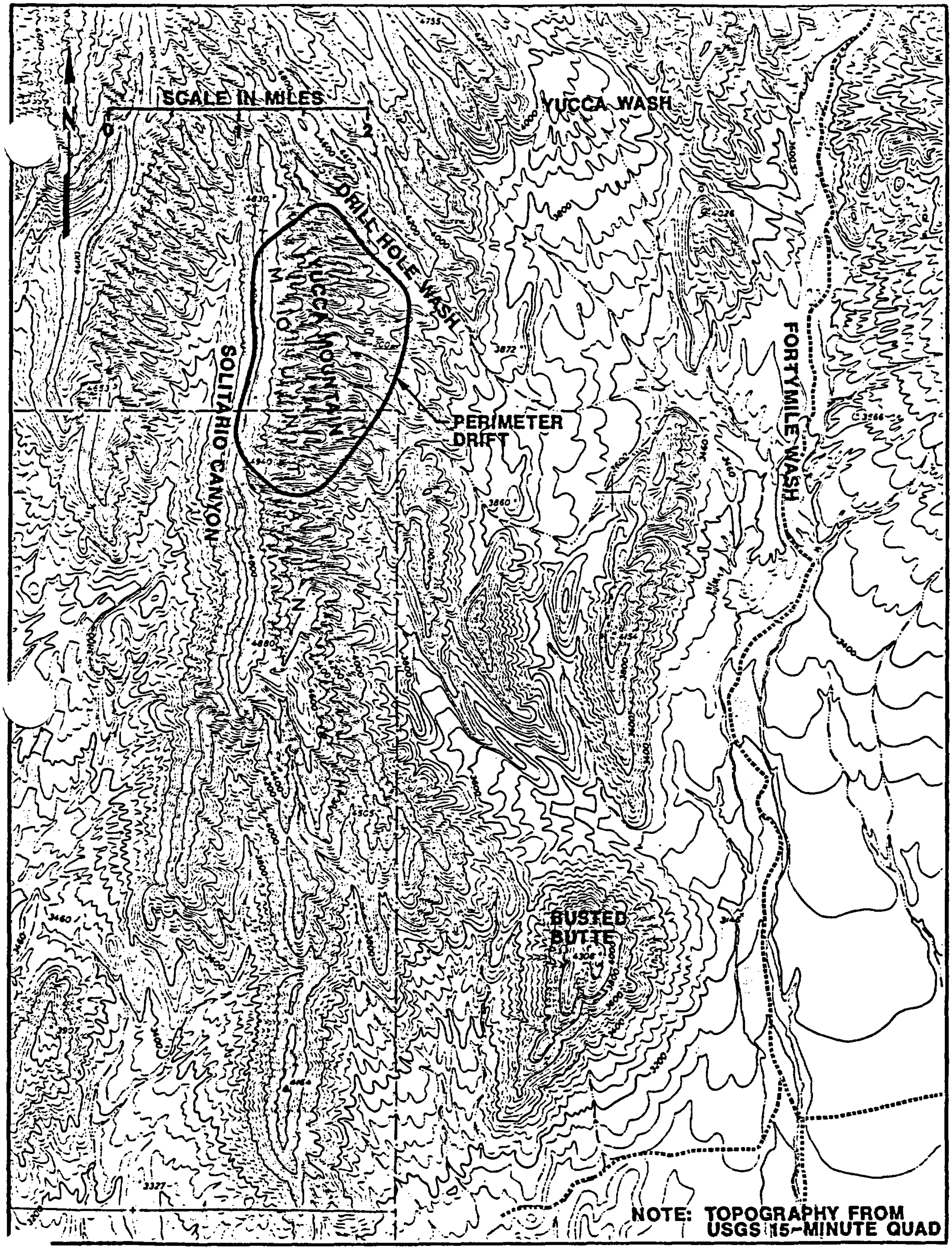
The mountain is dominated by a subparallel series of en echelon, north-trending ridges and valleys controlled by high-angle faults. These fault blocks are tilted eastward so that the fault-bounded west-facing slopes are generally high, steep, and straight, whereas the east-facing slopes are more gentle and deeply dissected by subparallel systems of linear valleys.

The uplands of the Yucca Mountain area are composed of three general landform types: (1) ridge crests, (2) valley bottoms, and (3) the intervening hillslopes. With the exception of the caprock-protected dip slopes that characterize the crestal areas of Yucca Mountain, the ridge crests are mostly angular and rugged. The valleys are generally narrow and V-shaped along their upper and middle reaches but locally contain flat, alluviated floors in their lower reaches.

The open basins surrounding Yucca Mountain, including Crater Flat and Jackass Flats, are floored almost entirely by gentle piedmont slopes. They can be divided into three general areas: (1) proximal slopes adjacent to the range fronts, (2) intermediate slopes, and (3) distal slopes along and adjacent to the basin axes.

There are no perennial streams in or near the Yucca Mountain area. The eastern slopes of Yucca Mountain drain to Fortymile Wash and the northern slopes drain to Beatty Wash. These washes are major tributaries to the Amargosa River. The southern and western slopes of Yucca Mountain drain to the Amargosa River through a smaller unnamed drainage system. The area of Yucca Mountain immediately surrounding the perimeter drift is shown on Figure 3-1.

Fortymile Wash is the major surface drainage flowing along the axis of the groundwater subbasin, draining an area of approximately 620 square kilometers north and east of Timber Mountain and south of Pahute Mesa. The wash then flows almost directly southward through Fortymile Canyon. After leaving the mouth of Fortymile Canyon, the wash continues southward down the south-sloping piedmont that forms the west end of Jackass Flats. Along this latter reach, the wash has cut a nearly linear trench, 150 to 600 m wide and as much as 25 m deep, into the Quaternary alluvial deposits of the piedmont. This entrenchment gradually decreases downslope until the wash merges with the general level of the piedmont near the northeastern margin of the Amargosa basin.



NOTE: TOPOGRAPHY FROM USGS 15-MINUTE QUAD

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FIGURE 3-1

TOPOGRAPHY OF YUCCA MOUNTAIN AREA

Date: SEPT 1988

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Groundwater modeling of the saturated groundwater flow system has supported the inference that the Fortymile Wash drainage channel may be an important zone of regional groundwater recharge (Czarnecki and Waddell, 1984). Thus, it may affect the movement and accumulation of groundwater at the repository site near Yucca Mountain.

The area to the west of Yucca Mountain is bounded by a large fault zone along Solitario Canyon. Solitario Canyon is a steep, north-south trending canyon the head of which is near the northern portion of the perimeter drift. Vertical displacement along the Solitario Canyon fault diminishes from about 200 m at the southern end to about 20 m at the northwestern corner.

3.2 HYDROGEOLOGIC SETTING

This section describes the geologic and hydrogeologic units at and near Yucca Mountain. Information on stratigraphy and lithology characterizes the surficial deposits and bedrock and provides a framework for considering the physical and chemical properties of the host rock and surrounding units. Information on the hydrogeologic units provides the background necessary for the description of flow mechanisms which is presented in section 3.3.

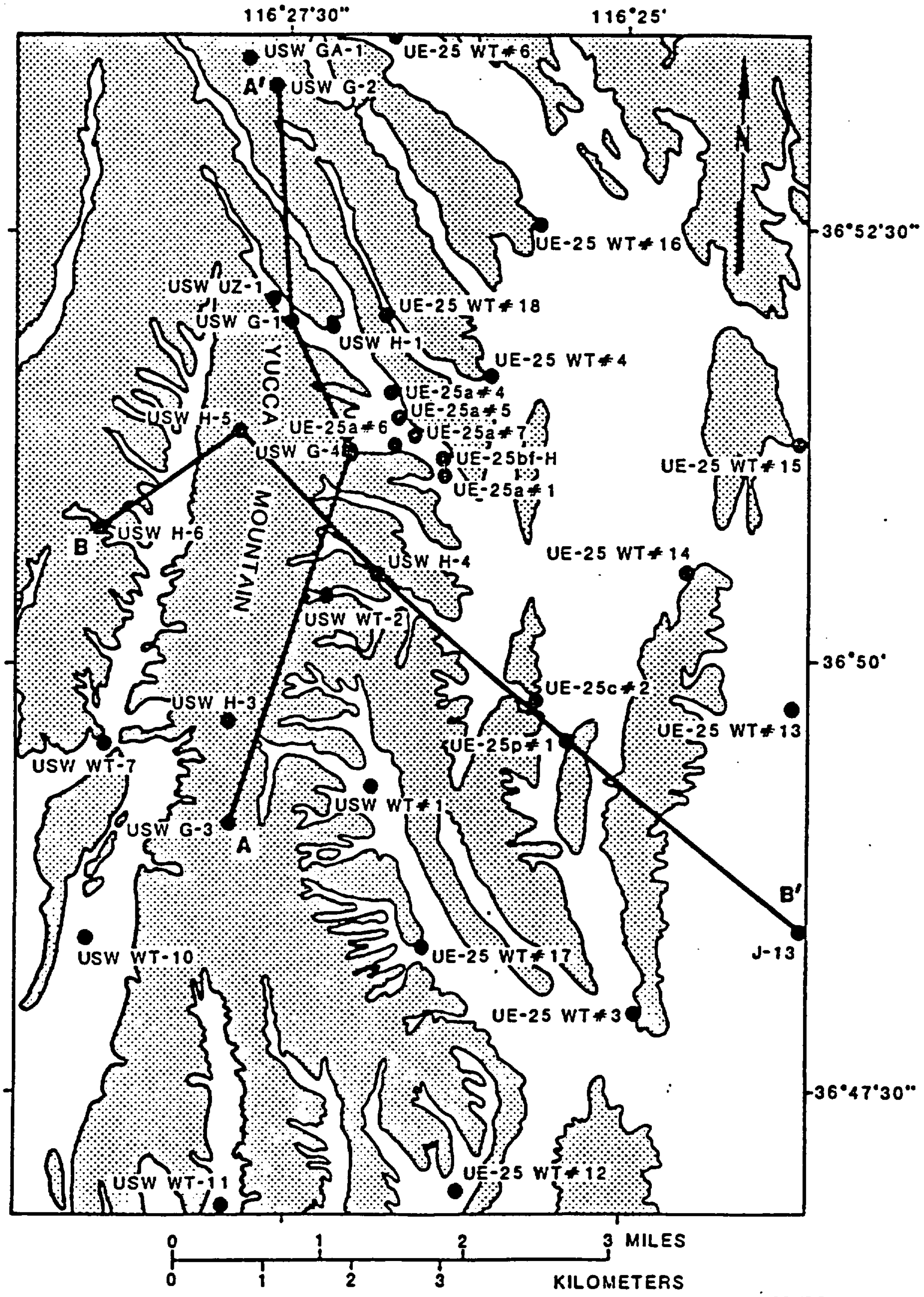
3.2.1 Stratigraphy and Lithology

Yucca Mountain is the erosional remnant of a volcanic plateau. It consists of a series of north-trending structural blocks that have been tilted eastward along major west-dipping, high-angle normal faults. This section describes the stratigraphic framework and characteristic lithologies of rocks and surficial deposits in the Yucca Mountain area. Descriptions of rocks proceed from youngest to oldest.

A map showing the drillholes in the vicinity of Yucca Mountain is shown on Figure 3-2. Also shown on this map are cross-section locations. These cross-sections are presented in Figure 3-3 and Figure 3-4 and present the north-south and east-west stratigraphic correlation between selected drillholes at Yucca Mountain.

3.2.1.1 Surficial Deposits

The late Tertiary and Quaternary surficial sedimentary deposits of the Yucca Mountain area have been divided into five major units:



SOURCE: USGS (1984)

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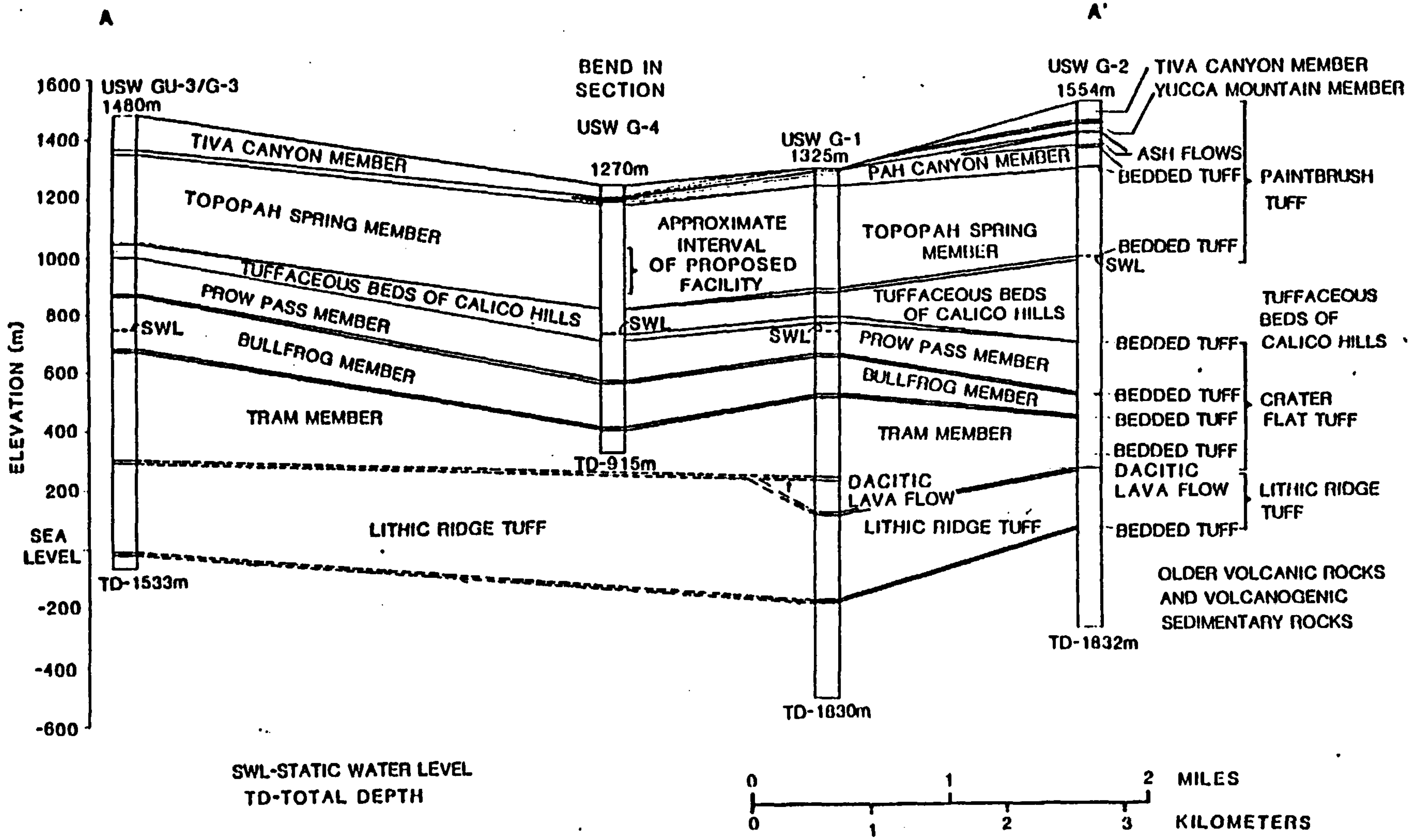
FIGURE 3-2
DRILLHOLES IN THE VICINITY
OF YUCCA MOUNTAIN

Date:	SEPT 1988
Project:	4001



SOURCE: USGS (1984)

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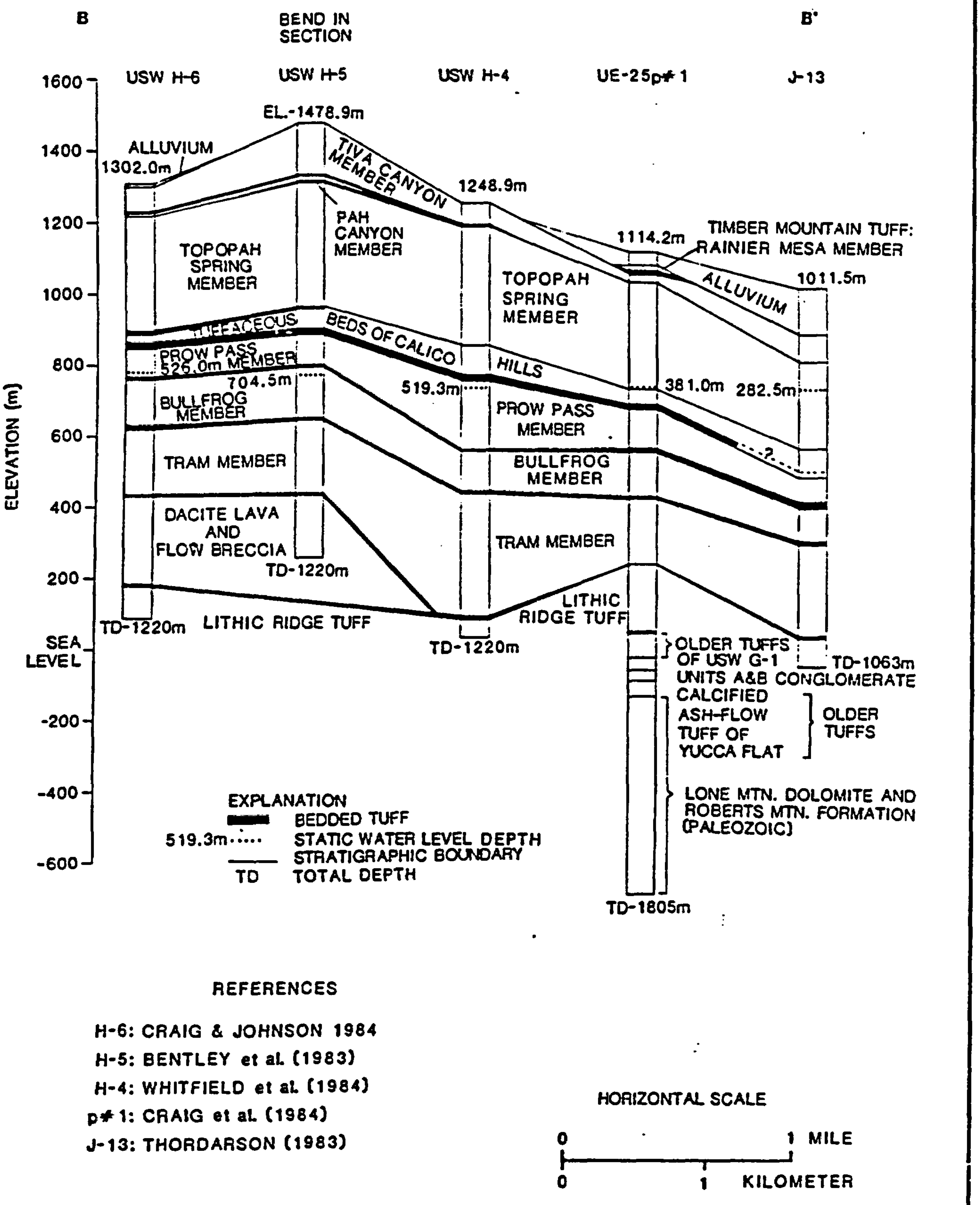
FIGURE 3-3
NORTH-SOUTH STRATIGRAPHIC CORRELATION BETWEEN SELECTED DRILLHOLES AT YUCCA MOUNTAIN

Date: SEPT 1988

Project: 4001



REFERENCES

H-6: CRAIG & JOHNSON 1984
H-5: BENTLEY et al. (1983)
H-4: WHITFIELD et al. (1984)
p# 1: CRAIG et al. (1984)
J-13: THORDARSON (1983)

SOURCE: USGS (1984)

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FIGURE 3-4
EAST-WEST STRATIGRAPHIC CORRELATION BETWEEN SELECTED DRILLHOLES AT YUCCA MOUNTAIN

Date: SEPT 1988
Project: 4001

(1) Late Pliocene and early Pleistocene lacustrine deposits. These are the oldest deposits in the area and consist of lacustrine deposits of unconsolidated to moderately indurated marl and silt that locally contain beds of limestone, sand, and fine grained volcanic ash.

(2) Late Pliocene (?) and early Pleistocene alluvial deposits. These deposits consist of debris flows with sparse, bedded, fluvial sediments. The deposits are moderately indurated, coarse, angular, unsorted gravel with minor amounts of sand to clay sized material. In most exposures they are partly cemented with calcium carbonate.

(3) Middle to late Pleistocene alluvial and Eolian deposits. These deposits consist of fan alluvium, fluvial and eolian sands, and local lenses of volcanic ash. These deposits have been divided into five mappable units on the basis of relative age and lithology.

(4) Holocene Alluvial and Eolian deposits. Deposits in the Yucca Mountain area consist of fluvial sand and gravel and eolian sand. Fluvial sand and gravel deposits typically are poorly to well bedded and moderately well sorted. Gravel deposits locally contain numerous thin beds of sand.

(5) Spring and Marsh Deposits. Marsh deposits are found at several localities in the Amargosa Valley. Several spring deposits are located near Crater Flat.

3.2.1.2 Basalt

Basalt dikes less than 1 m thick are the youngest rocks at Yucca Mountain (10 million years old). These dikes intrude a fault and nearby fracture in the northwest part of Yucca Mountain at the head of Solitario Canyon.[1]

3.2.1.3 Timber Mountain Tuff

The 11.3 million years old Rainier Mesa Member of the Timber Mountain Tuff is locally present in valleys on the flanks of Yucca Mountain with a maximum thickness of approximately 46 m. It is a series of ash flows and ash falls, nonwelded and glassy at the base, grading upward into partly welded devitrified tuff near the interior.

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[1] WWL Comment - Extent of Basalt Dikes
Because the basalt dikes are usually found by surface mapping, it may be difficult to determine the extent of such features. These features may have low permeability, therefore their importance to groundwater flow could be important.

3.2.1.4 Post-Paintbrush Ash-Flow Tuffs

A nonwelded ash-flow and ash-fall tuff sequence exists between the top of the Tiva Canyon Member of the Paintbrush Tuff and the base of the overlying Rainier Mesa Member of the Timber Mountain Tuff. This sequence ranges in thickness from zero to 61 m and is present in the subsurface beneath alluvial deposits on the eastern flank of Yucca Mountain in the area proposed for the surface facilities of the repository.

3.2.1.5 Paintbrush Tuff

The Paintbrush Tuff makes up nearly all of the exposed rocks at Yucca Mountain, is more than 460 m thick, and was erupted from 13.1 to 12.5 million years ago. The four members of the Paintbrush Tuff are listed in descending order in the following paragraphs.

The uppermost unit of the Paintbrush Tuff at Yucca Mountain is the Tiva Canyon Member which is from 90 to 140 m thick in outcrop. The multiple ash flows which make up this compound cooling unit erupted approximately 12.5 million years ago from the Claim Canyon caldera north of Yucca Mountain. The Tiva Canyon Member is almost entirely densely welded and caps most of the surface of Yucca Mountain. Ten mappable units are distinguished in the Tiva Canyon.

The Pah Canyon and the Yucca Mountain members are relatively thin, nonwelded ash-flow tuffs, which are the distal edges of flow sheets that thicken to the northwest. The Pah Canyon and the Yucca Mountain members attain maximum thickness of 71 and 29 m, respectively.

The Topopah Spring Member is a multiple-flow compound cooling unit. The Topopah Spring Member has been divided into seven composite zones and subzones. Thickness data was obtained from drillholes USW G-1, USW G-3, UE-25a#1, USW H-3, USW H-4, and USW H-5. From the top to the base the seven zones are:

(1) Caprock Zone. This is the quartz-latitic upper part of the Topopah Spring member and is between 39 to 62 m thick. The caprock consists of four subzones. In descending order these are:

    (a) a nonwelded to partially welded, pumiceous tuff
    (b) a densely welded, black vitrophyre
    (c) a pale-red devitrified densely welded tuff
    (d) A rounded subzone

(2) Upper lithophysal zone. This zone is rhyolitic, devitrified, moderately to densely welded, and is 54 to 96 m thick.

(3) Middle nonlithophysal zone and laterally equivalent subzones. This zone is rhyolitic, devitrified, and moderately to densely welded and is distinguished by an absence of lithophysae and conchoidal-fractured weathered surfaces. It is 20 to 50 m thick.

(4) Lower Lithophysal zone and laterally equivalent subzones. This zone, 43 to 117 m thick, is rhyolitic, devitrified, and moderately to densely welded. Lithophysae account for 10 to 15 percent of the rock, are from 5 to 15 cm in diameter, and have oblate spheroidal shapes.

(5) Lower nonlithophysal zone. This is the probable host rock for the proposed repository. It is 27 to 56 m thick, rhyolitic, devitrified, and moderately to densely welded. The percentage of lithophysae ranges from 0 to 2 percent.

(6) Basal vitrophyre zone. This zone is rhyolitic, glassy, and moderately to densely welded. It is 10 to 25 m thick.

(7) Lower nonwelded to moderately welded zone. This zone is rhyolitic, glassy, nonwelded to partially welded and is 13 to 42 m thick.

3.2.1.6 Rhyolite of Calico Hills

The rhyolite of Calico Hills comprises a sequence of ash-flow and ash-fall tuff, volcaniclastic sediment, and rhyolitic lava. Tuffaceous units commonly occur in this unit beneath the central part of Yucca Mountain and are informally referred to as the tuffaceous beds of the Calico Hills. The rock unit consists of massive, homogeneous, nonwelded ash-flow tuffs totaling 27 m (drillhole USW H-3) to 289 m (drillhole USW G-2) in thickness. Underlying most of the northern part of Yucca Mountain, the entire unit is zeolitized but it remains vitric in the southern part (drillholes USW GU-3 and USW G-3). Zeolites (predominantly clinoptilolite and mordenite) constitute 60 to 80 percent of the rock volume. Ash-fall-tuff and reworked-tuff beds from 1 to 17 m thick separate the tuffaceous beds of Calico Hills from the overlying Paintbrush Tuff. Several lines of evidence suggest that the sequence of tuffs found in the core from drillhole USW GU-3 may differ from the tuffaceous beds of the Calico Hills at drillholes USW G-2 and USW G-1.

3.2.1.7 Crater Flat Tuff

Three rhyolitic ash-flow-tuff sheets have been assigned to the Crater Flat Tuff on the basis of stratigraphic relations and petrologic and geochemical characteristics. They are, in descending order, the Prow Pass Member, the Bullfrog Member, and the Tram Member.

The ash-flow tuff of the Prow Pass Member is from 80 m to 193 m thick. Generally the Prow Pass is devitrified and only slightly welded, and locally it is zeolitized. The top and bottom parts are commonly altered to clay and zeolites. The upper part of the Prow Pass is vitric to partly vitric in several drillholes.

The ash-flow tuff comprising most of the Bullfrog Member is from 68 m to 187 m thick. In drillholes north of drillhole USW G-4 it seems to be a simple cooling unit, in which nonwelded to partially welded zones enclose a moderately to densely welded core, but in the south (drillholes USW GU-3, USW G-3, and USW G-4) it is compound, composed of two welded zones separated by a 1 m-thick bed of welded ash-fall tuff. Most of the upper part of the member is devitrified or shows evidence of vapor phase crystallization. The Bullfrog member is separated from the overlying Prow Pass Member by as much as 10 m of ash-fall tuff and tuffaceous sediments, which are commonly zeolitized.

The ash-flow tuff of the Tram Member ranges in thickness from 104 m to 370 m, is moderately welded to nonwelded, and is underlain by 3 to 50 m of reworked and bedded tuff. The Tram is separated from the overlying Bullfrog Member by 5 to 22 m of ash-fall and reworked tuff. In drillhole USW G-2 parts of the Tram are conspicuously different.

3.2.1.8 Dacitic lava and Flow Breccia

Dacitic lava and autoclastic flow breccia are present in the northern and western parts of Yucca Mountain but are absent elsewhere. The thickness of the unit is 22 m in drillhole USW G-2, 112 m in drillhole USW H-1 and 249 m in drillhole USW H-6.

3.2.1.9 Lithic Ridge Tuff

The Lithic Ridge Tuff ranges in thickness from 185 m north of the proposed repository to 304 m at the south end of the repository. The unit is nonwelded to moderately welded and has been extensively altered to smectites and zeolites. The Lithic Ridge Tuff is separated from the overlying dacitic lava and flow breccia (where present) by as much as 14 m of bedded tuff.

3.2.1.10 Pre-Lithic Ridge Volcanic and Volcanogenic rocks

Rocks beneath the Lithic Ridge Tuff are difficult to correlate because of their heterogeneity and varied degree of alteration. They are not known to crop out in the Yucca Mountain area.

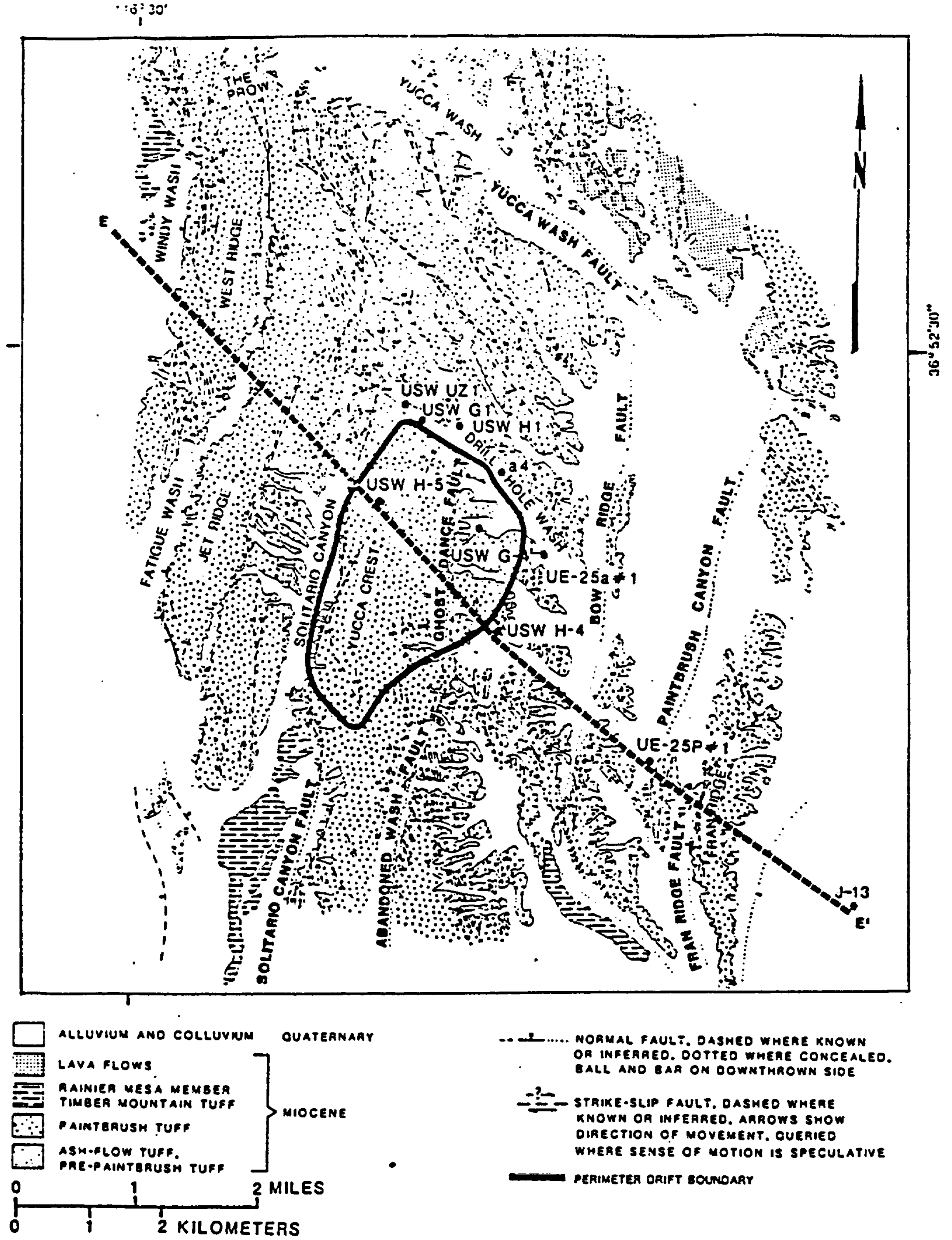
3.2.1.11 Pre-Cenozoic Rocks

Information on the pre-Cenozoic rocks in the Yucca Mountain are based on information from one borehole, UE-25p#1. This drillhole penetrated dolomite at a depth of 1,244 m below the surface and continued in carbonate rocks to a total depth of 1,805 m. Rocks within the interval are assigned to the Lone Mountain Dolomite and the Roberts Mountain Formation. On the basis of data collected at this drillhole, at least part of Yucca Mountain is underlain by silurian carbonate rocks, which are part of the lower carbonate aquifer of Winograd and Thordarson (1975). Gravity data suggest that pre-Cenozoic rocks are at least 3,000 m beneath the surface under much of Yucca Mountain.

3.2.2 Structural Features

The central block of Yucca Mountain is bounded on its west side by a major north-striking normal fault (Solitario Canyon fault) with greater than 100 m of offset (Scott and Bonk, 1984). Solitario Canyon is shown on Figure 3-5. West of this fault is a chaotic, brecciated and faulted west-dipping zone representing drag on the fault. Although the normal fault has significant dip-slip offset, minor superimposed oblique slip is indicated by oblique slickensides. The Ghost Dance fault within the Yucca Mountain block is likewise a west-dipping, north-striking normal fault with a displacement of about 25 m. A zone of imbricate normal faults forms the eastern boundary of the central block. These faults are west dipping and have vertical offsets of about 2 to 5 m. Northwest-striking strike-slip faults also occur in the area, such as the one forming the northern boundary of the central block, beneath Drill Hole Wash. These faults probably have less than 200 m of horizontal offset.

Because these major faults and fault zones transect the full thickness of the unsaturated zone, they may be hydrologically significant either as flow barriers or as flow pathways. The unsaturated hydraulic properties of these features have not been measured. Open faults have been observed in cores even from below the water table. Fault zones greater than 1.5 m wide and characterized by the presence of breccia have been observed in cores of the Topopah Spring welded unit.



SOURCE: SCOTT AND BONK (1984)

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FIGURE 3-5
GENERALIZED GEOLOGIC MAP OF YUCCA MOUNTAIN, SHOWING MAJOR FAULTS AND STRATIGRAPHIC UNITS

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3.2.3 Hydrogeologic Units of the Unsaturated Zone

The division of the geological sequence into hydrogeologic units is based on the divisions developed by Montazer and Wilson (1984) and by Ortiz et al. (1985). The hydrogeologic units belong to one of three broadly based hydrogeologic rock types distinguished qualitatively as follows:

1. Densely to moderately welded tuffs that are highly fractured and are characterized by low saturated hydraulic conductivity of the rock matrix and relatively high fracture densities. The rocks of this group are characterized by relatively low matrix porosities of about 10 percent.
2. Nonwelded vitric tuffs containing few fractures. This group is characterized by relatively high saturated hydraulic conductivity of the rock matrix and low fracture densities. These rocks have relatively high matrix porosities (about 30 to 45 percent).
3. Nonwelded zeolitized tuffs containing few fractures. A tuff sample need not be completely zeolitized to belong in this classification.

The hydrogeologic units are identified by symbols and are listed in descending order from the surface as follows:

Alluvium	QAL
Tiva Canyon welded unit	TCw
Paintbrush nonwelded unit	PTn
Topopah Spring welded unit	TSw
Calico Hills nonwelded unit	CHn
Calico Hills nonwelded vitric facies	CHnv
Calico Hills nonwelded zeolitic facies	CHnz
Crater Flat unit	CF

Two cross-sections across the Yucca Mountain central block are shown on Figure 3-6 and Figure 3-7. These cross-sections show the relative positions of the hydrogeologic units, the major faults, zones containing abundant breccia, and the boreholes used for control. The correlation of the hydrogeologic units with the rock-stratigraphic units is shown in Table 3-1.

3.2.3.1 Alluvium

The alluvium can be quite variable in thickness, lithology, sorting and permeability. There is a large range in the particle size, from clay to

EXPLANATION

QAL	ALLUVIUM AND COLLUVIUM	QUATERNARY AND TERTIARY
RM	RAINIER MESA MEMBER OF TIMBER MOUNTAIN TUFF	TERTIARY (MIOCENE)
TCw	TIVA CANYON WELDED UNIT	
PTn	PAINTBRUSH NONWELDED UNIT	
TSw	TOPOPAH SPRING WELDED UNIT	
CHn	CALICO HILLS NONWELDED UNIT	
CF	CRATER FLAT UNIT	

CONTACT

FAULT WITH MAJOR DIP-SLIP DISPLACEMENT--Position known or concealed at land surface; arrows show direction of relative displacement. *Average dip of fault planes at surface* is 70° and subsurface drill-hole data indicate a decrease to about 60° below a depth of 1 kilometer. Some faults cut older A but do not cut younger Quaternary deposits shown by partial penetration of fault through A to surface

FAULT WITH MINOR DIP-SLIP DISPLACEMENT--Position known or concealed at land surface; No evidence to indicate a decrease in dip with depth; average dip is 76° at land surface and in drill holes

UNMAPPED AND INFERRED FAULTS OF SMALL DISPLACEMENT REQUIRED BY GEOMETRIC CONSTRAINTS IN LAND-SURFACE EXPOSURES AND DRILL HOLES

STRIKE-SLIP FAULTS--

⊕ Indicates displacement toward the reader;

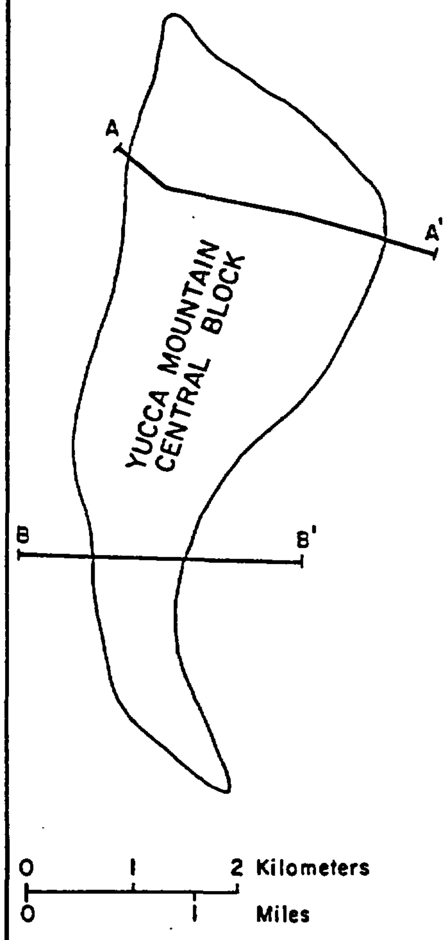
⊙ Indicates displacement away from the reader;

? *Queried where relative displacement is doubtful*

ZONE OF WEST-DIPPING STRATA CONTAINING ABUNDANT BRECCIA AND FAULTS TOO COMPLEX TO DRAW INDIVIDUALLY--Stratigraphic units shown only near surface

USW H-5 BOREHOLE USED FOR CONTROL

?...... WATER TABLE--Queried where extended beyond drill-hole data control; measured prior to December 1983



Hydrologic Sections Location Map

From: Montazer and Wilson(1984)

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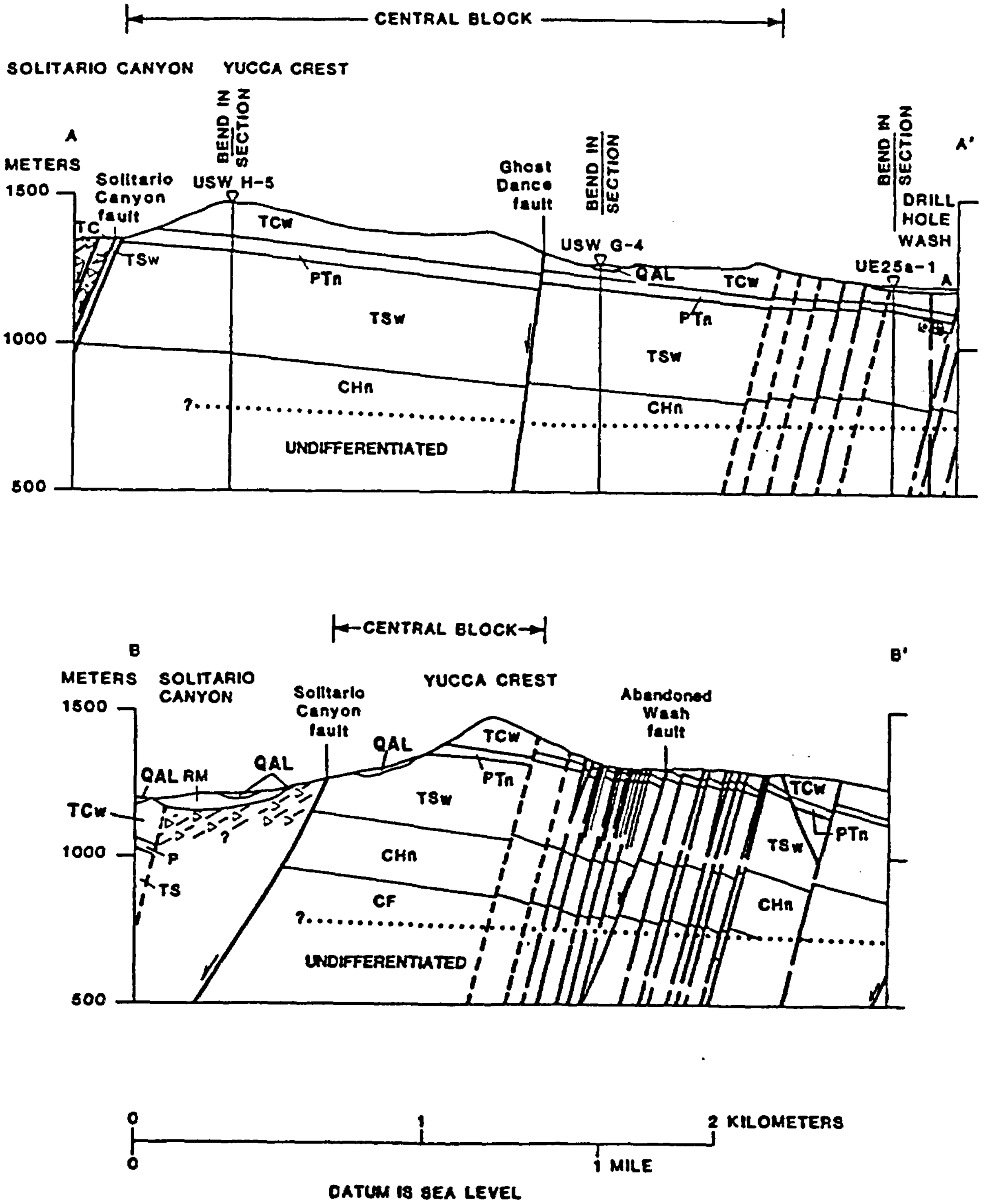
FIGURE 3-6

HYDROLOGIC SECTIONS LOCATION MAP

Date: SEPT 1988

Project: 4001



From: Montazer and Wilson (1984)

Water, Waste & Land Inc.

FIGURE 3-7

EAST-WEST HYDROLOGIC CROSS-SECTIONS

Date: SEPT 1988

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TABLE 3-1

DEFINITION OF UNSATURATED ZONE HYDROGEOLOGIC UNITS AND CORRELATION WITH ROCK-STRATIGRAPHIC UNITS[a]

<table>
<tr><th colspan="2">Rock-Stratigraphic Unit</th><th>Hydrogeologic Unit</th><th>Approximate Range of Thickness (m)</th><th colspan="2">Lithology [b]</th></tr>
<tr><td colspan="2">Alluvium</td><td>QAL</td><td>0-30</td><td colspan="2">Irregularly distributed surficial deposits of alluvium and colluvium</td></tr>
<tr><td rowspan="4">Paintbrush Tuff</td><td>Tiva Canyon Member</td><td>TCw</td><td>0-150</td><td colspan="2">Moderately to densely welded, devitrified ash-flow tuff</td></tr>
<tr><td>Yucca Mountain Member</td><td rowspan="2">PTn</td><td rowspan="2">20-100</td><td colspan="2" rowspan="2">Partially welded to nonwelded, vitric and occasionally divitrified tuffs</td></tr>
<tr><td>Pah Canyon Member</td></tr>
<tr><td>Topopah Spring Member</td><td>TSw</td><td>290-360</td><td colspan="2">Moderately to densely welded, devitrified ash-flow tuffs that are locally lithophysae-rich in the upper part, includes basal vitrophyre</td></tr>
<tr><td colspan="2">Tuffaceous beds of Calico Hills</td><td rowspan="2">CHn
CHnv
CHnz</td><td rowspan="2">100-400</td><td rowspan="2">Nonwelded to partially welded ash-flow tuffs</td><td rowspan="2">Vitric
Zeolitized</td></tr>
<tr><td rowspan="2">Crater Flat Tuff</td><td>Prow Pass Member</td></tr>
<tr><td>Bullfrog Member</td><td>CFu</td><td>0-200</td><td colspan="2">Undifferentiated, welded and nonwelded, vitric, devitrified, and zeolitized ash-flow and air-fall tuffs</td></tr>
</table>

[a] Sources: Montazer and Wilson (1984)

[b] Lithology summarized from Ortiz et al. (1985).

QAL - Quaternary Alluvium
TCw - Tiva Canyon welded unit
PTn - Paintbrush nonwelded unit
TSw - Topopah Spring welded unit
CHn - Calico Hills nonwelded unit
CHnv - Calico Hills nonwelded vitric unit
CHnz - Calico Hills nonwelded zeolitized unit
CFu - Crater Flat undifferentiated unit

boulders. Compared to the highly fractured welded tuffs, the alluvial and colluvial deposits generally have small effective hydraulic conductivity, large specific retention, and large effective porosity. The alluvial deposits are found at the base of Yucca Mountain, in Solitario Canyon, Drill Hole Wash, and other washes around the mountain.

3.2.3.2 Tiva Canyon Welded Unit

The Tiva Canyon welded unit is the densely to moderately welded part of the Tiva Canyon Member of the Paintbrush Tuff. It dips 5 to 10 degrees eastward within the central block, resulting in a relatively planar eastward-sloping, dissected land surface. The unit is absent in some washes and is about 150 m thick beneath Yucca Crest. This unit is believed to have a fracture density of 10 to 20 fractures per cubic meter and small matrix permeability.

3.2.3.3 Paintbrush Tuff Nonwelded Unit

The Paintbrush nonwelded unit consists of the nonwelded and partially welded base of the Tiva Canyon Member, the Yucca Mountain Member, the Pah Canyon Member, the nonwelded and partially welded upper part of the Topopah Spring Member, and associated bedded tuffs. All are part of the Paintbrush Tuff stratigraphic unit. Within the central block, the unit consists of thin, nonwelded ash-flow sheets and bedded tuffs that thin to the southeast from a maximum thickness of 100 m to a minimum thickness of about 20 m. Tuffs of this unit are vitric, nonwelded, very porous, slightly indurated, and, in part, bedded. The unit is believed to have fracture density of 1 fracture per cubic meter.

3.2.3.4 Topopah Springs Welded Unit

The Topopah Spring welded unit consists of a very thin upper vitrophyre, a thick central zone consisting of several densely welded devitrified ash-flow sheets, and a thin lower vitrophyre of the Topopah Spring Member of the Paintbrush Tuff. Because of the densely fractured nature of this unit, bulk hydraulic conductivity is substantially greater than matrix hydraulic conductivity. The effect of lithophysal cavities on the hydrologic properties of this unit is not well understood, because of lack of laboratory test data.

The unit is believed to have a fracture density of 8 to 40 fractures per cubic meter and small matrix permeability.

3.2.3.5 Calico Hills Nonwelded Unit

Both vitric and devitrified facies occur within the Calico Hills nonwelded unit. The permeability of the vitric facies is substantially greater than that of the devitrified facies. Beneath the southern two-thirds of the central block, the Calico Hills nonwelded unit contains some vitric facies. However, even in this area, the lower part of the unit is devitrified and altered, whereas the upper part is vitric. Thus, the entire central block is underlain by a devitrified and altered layer of small permeability (Montazer and Wilson, 1984). Alteration products in the devitrified facies include zeolites (most abundant), clay, and calcite (rare). Because this facies commonly is pervasively zeolitic, this facies of the unit is hereafter referred to as the zeolitic facies.

Zeolitization probably is the result of a water table that formerly occurred higher in the section, according to Scott et al. (1983). Thickness of the zeolitic facies generally increases from the southwest to northeast beneath Yucca Mountain. Beneath the northern and northeastern parts of the central block, the entire unit is devitrified and altered. The Calico Hills nonwelded unit is believed to have a fracture density of 2 to 3 fractures per cubic meter.

3.2.3.6 Crater Flat Unit

The lowermost unit in the unsaturated zone in the southern one-half of the central block is the Crater Flat unit. This unit consists of the unsaturated welded and underlying nonwelded parts of the Bullfrog Member of the Crater Flat Tuff. No differentiation is made between the welded and nonwelded components of the Crater Flat unit. The components of the unit are undifferentiated because of the limited extent of the unit in the unsaturated zone beneath the central block, and, therefore, its probable limited effect on the unsaturated flow system. Beneath the central block, thickness of the Crater Flat unit ranges from 0 to about 160 m. Little is known about the unsaturated hydrologic properties of the unit, but it is assumed that the properties are similar to those of the nonwelded and welded counterparts higher in the section.

3.2.4 Hydrologic Properties of the Unsaturated Zone Units

Mean values of hydrologic properties for most of the hydrogeologic units are shown in Table 3-2. These data were based on analyses of core samples from test wells USW G-1, USW G-4, USW GU-3, USW H-1, J-13, and UE-25a#1. The range of mean values among the hydrologic properties reflects the effects of lateral and vertical spatial heterogeneity within each unit. The DOE considers these data to be based, in general, on too few samples to permit meaningful statistical analyses to be performed for each hydrogeologic unit.

The hydrologic property data must be supplemented by developing sets of moisture characteristic curves. These curves relate the dependence of liquid water saturation and relative hydraulic conductivity on the liquid water potential within the rock matrix and fractures appropriate for each hydrogeologic unit. In unfractured rocks, these relations refer to the storage and movement of liquid water within and through the interstitial pore space. In fractured rocks, allowance must be made for the storage and movement of water within the interconnected fracture openings as well as for the movement of water between the fracture openings and the rock matrix pore space.

Techniques for the measurement of relative hydraulic conductivity on very low permeability tuffs, such as welded tuff matrix material from the TSw, are not yet available. Theoretically based methods have been formulated to estimate relative hydraulic conductivity in unconsolidated porous media from matrix potential, saturation, and pore-size-distribution data.

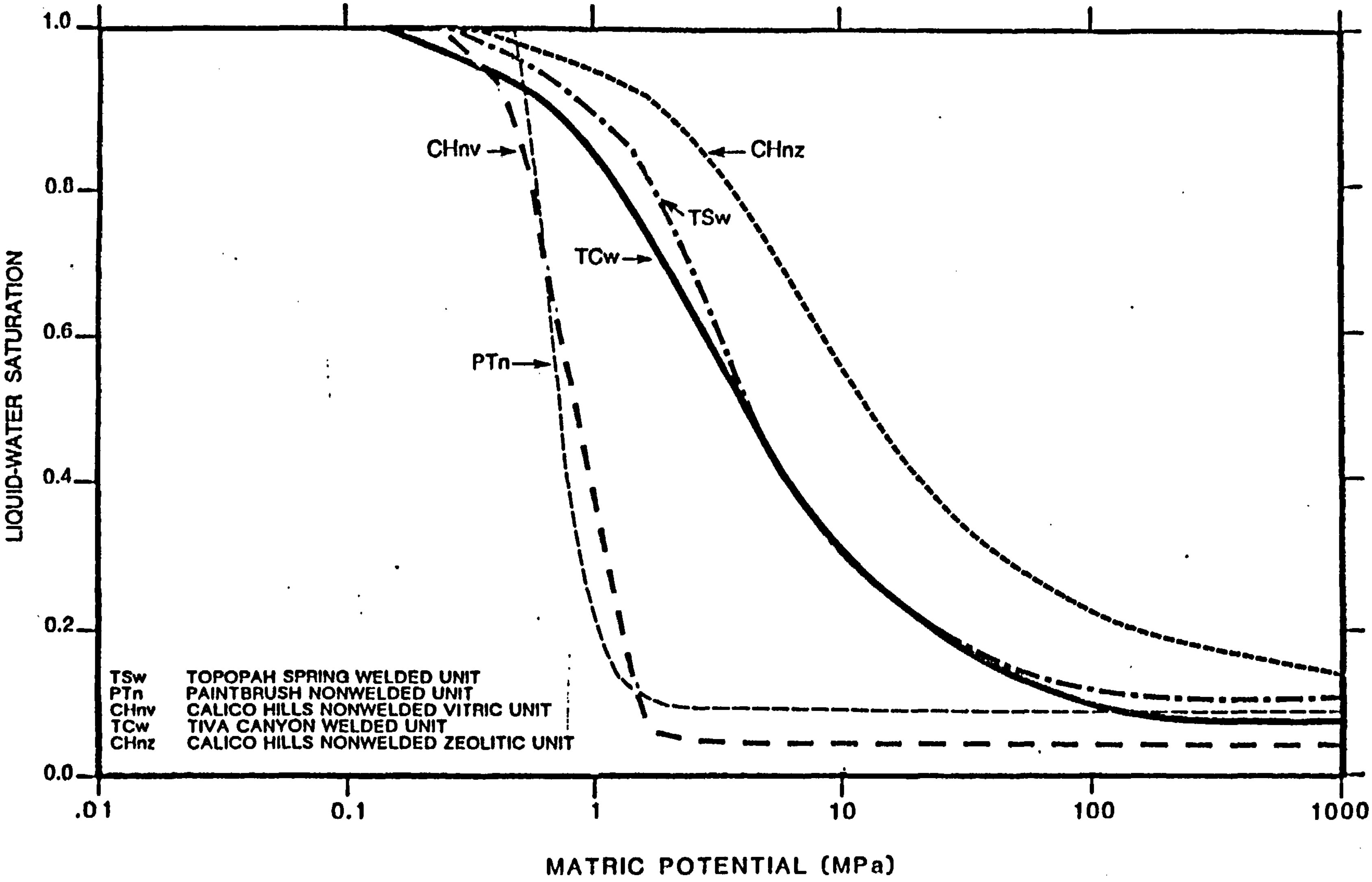
Peters et al. (1984) developed a set of matrix moisture-retention curves (under drainage conditions) relating matrix-potential and saturation. These curves were obtained by fitting the van Genuchten (1978) analytic representation to laboratory psychrometric data obtained for unfractured samples extracted from cores from test wells USW G-4 and USW GU-3. Because psychrometric techniques are appropriate only for matrix potentials less than about -3 bars (-0.3 MPa), the moisture retention curves reported by Peters et al. (1984) are not well determined for matrix potentials that exceed this value. In lieu of direct measurements, the van Genuchten representation can also be used to estimate matrix relative hydraulic conductivity of these units. The DOE believes that such estimates must be regarded as highly tentative.

The set of moisture-retention curves developed by Peters et al. (1984) is reproduced on Figure 3-8. The curves in this figure are based on laboratory determinations on small sample sets from only two locations, and therefore, the

TABLE 3-2

SUMMARY OF HYDROGEOLOGIC PROPERTIES OF HYDROGEOLOGIC UNITS WITHIN THE UNSATURATED ZONE, YUCCA MOUNTAIN

Hydrogeologic Unit	Range of Thickness (m)	Fracture Density (no./m^3)	Porosity	Saturated Matrix Conductivity (m/s)
TCw	0 - 150	10 - 20	.08 - .12	9.7×10^{-12} - 2×10^{-11}
PTn	20 - 100	1	.40 - .46	1×10^{-7} - 3.9×10^{-7}
TSw	290 - 360	8 - 40	.11 - .14	1.9×10^{-11} - 3.5×10^{-11}
CHnv	100 - 400	2 - 3	.37 - .46	5×10^{-8} - 2.7×10^{-7}
CHnz	100 - 400	2 - 3	.28 - .31	2.0×10^{-11} - 9×10^{-11}



SOURCE: PETERS et al (1984)

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FIGURE 3-8

MOISTURE RETENTION CURVES FOR THE HYDROGEOLOGIC UNITS WITHIN THE UNSATURATED ZONE AT YUCCA MOUNTAIN

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DOE considers that these curves may not be representative of the units at Yucca Mountain as a whole.

The DOE has acknowledged that standard laboratory methods are not yet available by which to determine the moisture-characteristic relations for fractures and fractured rocks. Therefore, reliance must be made on theoretically based models and approximations. Liquid-water storage within fractures probably is insignificant, but the flow of liquid water within and across fractures is not yet well understood. Theoretical models for liquid-water flow in single fractures have been developed but have not been field or laboratory tested.

Fractures may or may not impede liquid flow at low matrix saturations, but longitudinal flow within the fractures may dominate liquid-water flow above some critical matrix saturation. At high matrix saturations, the fracture systems within the densely welded, fractured hydrogeologic units and within the fault zones may become highly efficient pathways for liquid water flow. The potential in the fractures need not be equal to the matrix potential in the rock matrix, especially under highly transient conditions.

3.3 FLOW MECHANISMS IN THE UNSATURATED ZONE

Moisture flux, whether under saturated or unsaturated flow conditions, cannot be measured directly and must be calculated from measured values of hydraulic conductivity and total potential gradient along the path of flow. Fluid potentials that govern variably saturated two-phase (liquid and gas) flow are as follow: (1) matrix potential for the liquid phase: (2) gravitational potential; (3) gas-phase pressure, or pneumatic potential; (4) osmotic potential; and (5) thermal potential. Fluid potential measurements in the saturated zone can be made either by measuring water levels in piezometers or wells, or by measuring fluid pressures in wells using precise pressure gages. Fluid Potential measurements in the unsaturated zone can be made by tensiometers or thermocouple psychrometers, among other equipment.

The theory of moisture flow within variably saturated natural media has been developed for specific application to problems of soil physics. The conventional theory of moisture flow in variably saturated porous media may be applicable for several of the hydrogeologic units at Yucca Mountain. However, the resultant generally considered theory may not be applicable to indurated tuffs that have low matrix porosity and permeability and that also may be highly fractured. The following sections describe the flow mechanisms for the various hydrogeologic units and structural features at Yucca Mountain.

3.3.1 Single Porosity Partially Saturated Flow

Flow in partially saturated porous media can be described by the Richards (1931) equation

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) - \frac{\partial K}{\partial z} = - \frac{\partial \theta}{\partial t} \qquad (3\text{-}1)$$

where K is the hydraulic conductivity, h is the capillary pressure head, θ is the volumetric water content, t is time and x, y and z are space coordinates with z being the vertical coordinate with positive upward. Solution of the Richards equation requires the additional equations

$$\theta = \theta(h) \qquad (3\text{-}2)$$

$$K = K(h) \qquad (3\text{-}3)$$

so that the differential equation can be written in terms of one dependent variable. Equations 3-2 and 3-3 represent the functional forms of the hydraulic properties of a porous medium. If these equations are known, the medium is adequately characterized so that Equation 3-1 can be solved.

3.3.2 Double Porosity Partially Saturated Flow

As previously stated, the Richards equation may not be applicable to indurated tuffs that have low porosity and low permeability and that also may be highly fractured. Modeling of flow in an unsaturated fractured rock has followed two paths, composite continuum system (porous equivalency; see WWL, 1986a) and discrete fracture models. The simplest approach to modeling a flow system in fractured porous rock is to treat the entire flow region as an equivalent porous medium and adjust the flow and transport coefficients accordingly. The appropriateness of this approach depends upon the scale of the flow region relative to the fracture density. The alternative approaches are to regard the matrix and fractures as constituting either separate but overlapping continuum systems or as a single composite continuum system.

Peters and Klavetter (1988) define a composite continuum through their use of the macroscopic approach to defining flow. In their model, the fracture system is assumed to be one continuum with the matrix being a second continuum occupying the same space. Each continuum has distinct hydraulic properties. The two continuum are linked by fluid interchange between the two, with this interchange being handled mathematically by a source/sink term in the mass balance equations. This approach does not assume that the two continuum necessarily have the same pressure.[2]

The assumption of pressure head equilibrium between a matrix and a fracture system provides a simplified linkage between the general fluid continuity equations for a dual-porosity equivalent continuum. Other relationships are possible between the pressure head in the matrix and the pressure head in the fracture system. However, pressure head equilibrium between the two systems is the simplest assumption.[3]

Peters and Klavetter (1988) concluded that the use of the assumption of pressure head equality is appropriate for site scale modeling as making this assumption greatly simplifies the model required. Using this assumption means that the exchange of water between the matrix and the fracture system occurs so quickly that the pressure heads are always equal within the representative element volume. Peters and Klavetter (1988) stated that simulations of small-scale problems that explicitly incorporate the fractures and an analytical

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[2] WWL Comment - Validation of Composite Continuum Approach
The composite continuum approach has not yet been validated by field experiment. Therefore, it is as yet unknown if this modeling approach will be appropriate for the Yucca Mountain site.

[3] WWL Comment - Pressure Equilibrium at Steady State
It would seem that pressure equilibrium would only be reached between the fracture and the matrix once steady state for the entire system is realized. During a transient process, the pressure in the fracture system would probably be different than the pressure in the matrix system. Indeed, the only case when pressure equilibrium exists between the two systems would be for an idealized system of vertical fractures and steady state flow conditions. With a fracture orientation other than vertical, pressure differences are likely to exist between the fracture and matrix systems, even at steady state although the magnitude of pressure difference is probably small.

model of matrix recharge from partially saturated fractures indicate that this assumption is reasonable for the Yucca Mountain site.[4]

The hydrogeologic units at Yucca Mountain may be anisotropic with respect to intrinsic permeability and thus to hydraulic conductivity. Fracture and fault systems within the densely welded units probably introduce an inherent anisotropy wherever they are present. Two principal fracture sets have been identified within the Yucca Mountain block. One set strikes north-northwest and the other strikes north-northeast, and both fracture sets exhibit steep to vertical dips.[5]

3.3.3 Flow Through Hydrogeologic Units

The DOE considers the principal qualitative aspects of moisture flow within the unsaturated zone beneath Yucca Mountain to be summarized by the

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[4] WWL Comment - Transport Problems Using the Composite Continuum Approach
The problem of radionuclide transport through an unsaturated highly fractured welded tuff may not be adequately modeled by using the composite continuum approach. Transport modeling through this type of unit may require the use of a discrete fracture model.

[5] NRC Comment #29
Characterization of Site Structural Features (p.45)
The CDSCP's approach to characterizing the complex three-dimensional nature of fracture systems in the repository block relies too heavily on fractal analysis of outcrop exposures. Also, the CDSCP limits the objectives of fracture network studies to providing fracture parameters and analyses to supporting hydrologic modeling. Such a narrow approach and limited objective to characterization may not lead to adequate descriptions of the fracture networks. The SCP should integrate fracture studies proposed by various methods: fractal analysis, shaft/drift mapping, geologic mapping, systematic drilling and core analysis, hydrologic tracer testing and geophysical surveying including borehole geophysics.

following hypotheses.[6] A generalized east-west cross-section through Yucca Mountain showing the conceptual model of flow is shown on Figure 3-9.

1. Moisture enters the system as net infiltration below the plant-root zone principally as liquid-water flow into and within the fractures of the surficial TCw unit with subsequent uptake under capillary forces into the TCw matrix. It is expected that at sufficiently low rates of net infiltration, all the water entering the TCw unit may be drawn into the matrix before the full thickness of the TCw unit is traversed. (Further information on this phenomena can be found in WWL, 1986c).

2. Hydraulic gradients directed parallel to the dip may induce lateral flow either under saturated or unsaturated conditions at the contact between the TCw unit and the underlying PTn unit as a consequence of (1) efficient fracture dominated flow in the TCw unit at high infiltration rates or (2) capillary barrier effects. Capillary barriers may inhibit water movement from a unit of low matrix or fracture conductivity into a unit of higher conductivity by capillary forces in the low-conductivity unit.[7]

3. Both vertical and lateral flow may occur in the relatively high-conductivity PTn unit. Lateral flow may occur because of the intrinsic anisotropy of this unit as well as because the low matrix conductivity of the underlying TSw may impede the vertical movement of water from the PTn unit into the TSw unit.[8]

4. Flow in the TSw unit is expected to be essentially vertical and under steady-state conditions to occur as flow within the matrix for fluxes less than some critical value of flux related to the saturated matrix hydraulic

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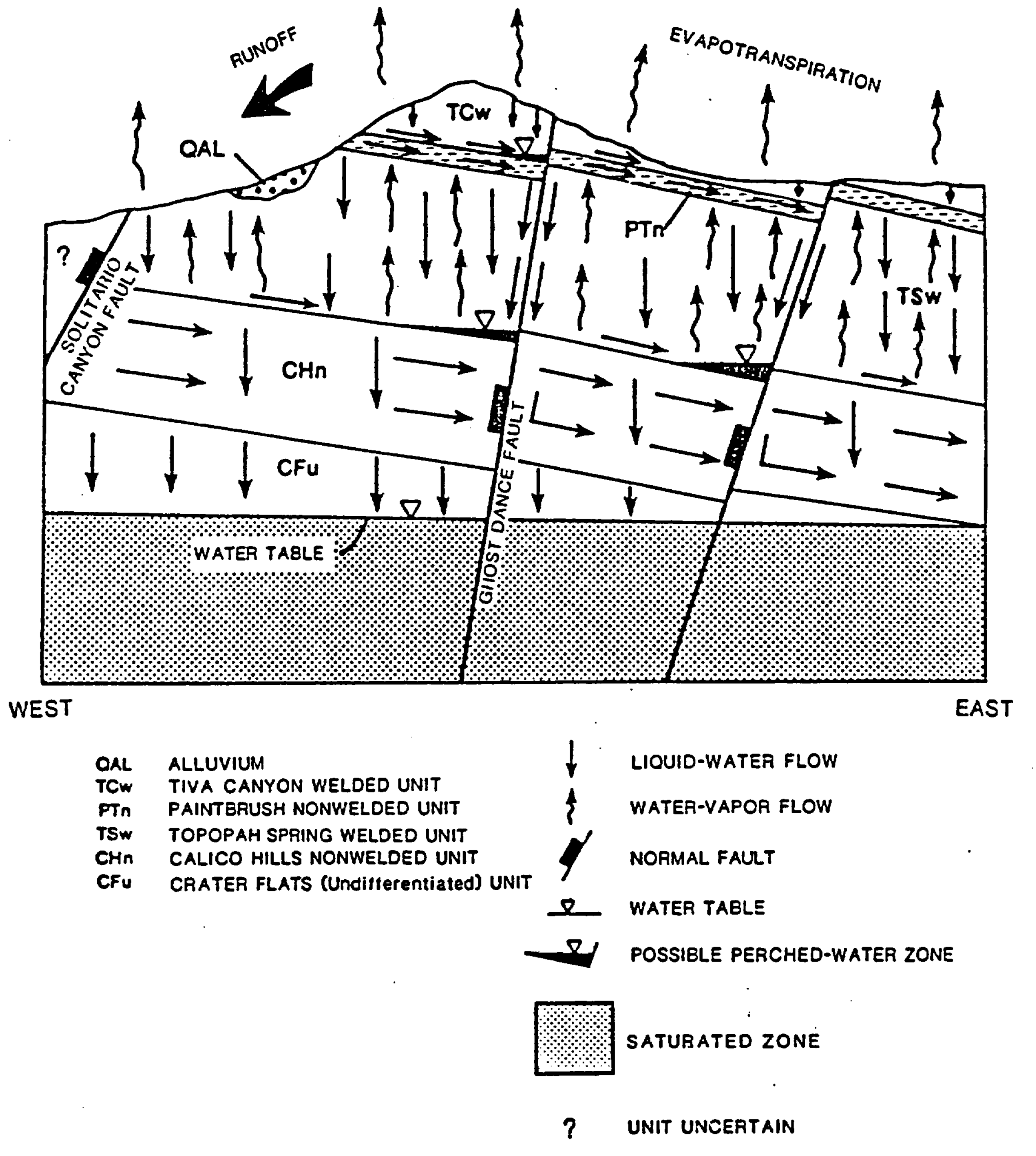
[6] WWL Comment - Characterization of Unsaturated Flow
The conceptual model of flow in the unsaturated zone at Yucca Mountain includes fracture flow, flow in the matrix, the effect of bedding and textural discontinuities (capillary barriers), and vapor flow. The presentation of these phenomena as generic principles appears accurate and correct. It is the degree to which these phenomena interact to effect the flow at Yucca Mountain that remains in question. since hard, reliable data on the flux and the hydraulic properties of the fractures are not yet available, it is hard to estimate the actual flow conditions which may be present in the unsaturated zone. The effectiveness of the textural discontinuities above the TSw unit in limiting flux into the repository horizon may be overstated.

[7] WWL Comment - Capillary Barriers
Capillary barriers do not exist under steady-state flow conditions.

[8] WWL Comment - Anisotropy in the Unsaturated Zone
The effect of intrinsic anisotropy on flow in the unsaturated zone is not well understood. It has not yet been shown by field investigations that lateral flow is occurring in some of the units at Yucca Mountain.



SOURCE: MONTAZER AND WILSON (1984)

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FIGURE 3-9
GENERALIZED EAST-WEST SECTION THROUGH YUCCA MOUNTAIN SHOWING CONCEPTUAL MOISTURE-FLOW SYSTEM UNDER NATURAL CONDITIONS

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conductivity and predominantly as fracture flow at fluxes higher than the critical value.[9]

5. Lateral flow may be induced in the TSw unit at its contact with the underlying CHn unit. The circumstances under which this may occur depend on the magnitude of the flux in the TSw unit and whether this unit is underlain by the low-conductivity zeolitic facies (CHnz) or the relatively higher-conductivity vitric facies (CHnv) of the CHn unit. At low fluxes within the TSw unit, lateral flow may be produced by capillary-barrier effects within the matrix of the TSw unit where it overlies the CHnv unit. At high fluxes, efficient fracture flow in the TSw unit may produce lateral flow as well as vertical flow where the low-conductivity CHn unit underlies the TSw unit.

6. Flow in both the CHnv and CHnz units is predominantly vertical through the matrix (although a lateral component may occur parallel to the bedding within the vitric CHnv unit) and continues directly to the water table wherever the latter transects the CHn unit. Where the CHn unit lies above the water table, flow is presumed to proceed vertically downward to the water table through the Crater Flat undifferentiated unit.

7. Temperature-driven moisture transport may occur, especially within the highly fractured TSw unit. This could be expected to occur by molecular diffusion if local thermodynamic phase equilibrium is maintained between liquid water and water vapor within the system, which would produce a water-vapor concentration gradient along the natural geothermal gradient. Of greater importance may be the advective transport of water vapor accompanying thermally or barometrically driven upward bulk-gas flow within the fractures of the TSw unit. Under steady-state conditions, the upward movement of water vapor in the air-filled fracture openings would be compensated by downward return flow of liquid water within the rock matrix.

8. Moisture flow within the deep unsaturated zone at Yucca Mountain may be occurring under essentially steady-state conditions. The steady-state hypothesis implies that moisture flow within the natural system is occurring predominantly as vertically downward liquid-water flow within the rock matrix of the hydrogeologic units with possible water-vapor movement within the air-filled pore and fracture space. Significant liquid-water flow within the fractures may occur but only as near-surface, transient, nonequilibrium events that are followed by eventual uptake by the rock matrix of water descending through the fractures. Equilibrium

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[9] WWL Comment - Characterization of Unsaturated Flow
The DOE concluded that the host rock at Yucca Mountain is free draining. However, fracture flow has been documented in USW H-1 by television camera logs and a saturated zone which may be above the water table was observed at USW UZ-1. The water from USW UZ-1 contained chemicals which had migrated from USW G-1 located 305 meters to the southwest. This indicates significant lateral flow can occur in the unsaturated zone portion of the host rock. Again the potential for fracture flow or matrix flow and the conditions for which one flow phenomena dominates need to be resolved (WWL, 1986b).

> would prevail between the liquid-water matrix potentials in the fractures and the unsaturated rock matrix at depth. Liquid water movement could occur in fractures as well as the matrix. Although the amount of fracture flow probably would be small, additional understanding of the factors controlling fracture flow is needed to assess this phenomenon. Under these conditions, the liquid-water flux through the matrix of the TSw unit would be expected to be less than the mean matrix saturated hydraulic conductivity of about 1 mm/yr.

The water in the unsaturated zone of Yucca Mountain is derived from precipitation on the mountain. At Yucca Mountain, infiltration rate is both spatially and temporally variable. The spatial variations of infiltration are mostly dependent on the variations in properties of the surficial units and topography. Direct measurements of infiltration have not been made at Yucca Mountain. However, a number of estimates of the infiltration have been made Most of these estimates are based primarily on the total annual precipitation.

Measurements of precipitation at Yucca Mountain were initiated too recently to obtain reliable direct estimates of average annual precipitation at the mountain. However, estimates can be made based on the regional distribution of precipitation or on relationships established between altitude and precipitation. From a regional map of precipitation presented by Winograd and Thordarson (1975), precipitation at Yucca Mountain is estimated to be about 100 to 150 mm/yr. As discussed in Chapter 2, Quiring (1983) established local relationships between altitude and precipitation for 1964-81 at the NTS. Using Quiring's data, the DOE estimated the precipitation to be 138 to 166 mm/yr. The DOE has since used 150 mm/yr as the average yearly precipitation value.

After a precipitation event, a portion of the water infiltrates into the surface. Some of this water is stored in the soils and rocks and returns to the atmosphere by evapotranspiration. Interflow probably is of short duration and occurs only during intense storms. This conclusion is inferred from the lack of evidence for springs or seeps along the washes. The small quantity that is not evapotranspired or discharged as interflow percolates deep into the unsaturated zone and becomes net infiltration. The quantity of net infiltration that percolates through different paths is quite variable. Therefore, the average recharge does not represent percolation rates through specific flow paths.

3.3.4 Flow Through Structural Features

The geologic framework for the hydrologic system within the unsaturated zone is defined by a block of layered, east-dipping hydrogeologic units that is bounded above by land surface, below by the water table, laterally on the west by a west-dipping normal fault, and laterally on the east by one or more west-dipping normal faults. In addition, the interior of the block may be transected by one or more high-angle faults across which hydrologic properties may change abruptly. The DOE considers that the bounding and internal faults may act preferentially either as conduits for or as barriers against moisture flow.

The nearly vertically oriented fault zones and their associated fracturing may be highly effective pathways for vertical moisture flow, especially in the competent TCw and TSw units. Faults may also impede lateral flow and may thus produce perched-water bodies where the faults transect zones or horizons of significant lateral flow.

3.4 BOUNDARY AND INITIAL CONDITIONS

This section discusses the boundary and initial conditions present in the unsaturated zone at Yucca Mountain. Boundary conditions refer to the state of the hydrologic parameters at the outer boundary of the unsaturated zone. The important boundary parameters are the flux, saturation, and the potential field along the outer surface of the unsaturated zone. The initial conditions refer to the current state of the hydrologic system throughout the three-dimensional representation of the unsaturated zone.

3.4.1 Boundary Conditions

The surface of Yucca Mountain represents one boundary to the unsaturated zone. Therefore, the gas phase pneumatic potential at this boundary is simply the existing atmospheric pressure. Monitoring of pneumatic potentials (pore-gas pressures) by downhole pressure transducers has been accomplished in boreholes USW UZ-1 and UE-25a#4. Diurnal and barometrically induced fluctuation of gas pressure of about 0.25 kPa have been observed in these boreholes to depths of about 30 m. Seasonally induced pressure variations are observed to occur at greater depths.

One indication of the water potential from the matrix is the moisture content, however, available data on the moisture content of the surface units

(TCw and QAL) is scanty. Drill cuttings from test boreholes USW UZ-1 and USW UZ-6 were collected continually, and their gravimetric moisture contents measured, during drilling operations. Using the average moisture content along with the mean porosity and mean grain density, the DOE calculated a mean saturation for the TSw unit of 0.6. If this saturation is used in the moisture retention curve for the TSw unit as shown on Figure 3-8, the corresponding matrix potential would be about -5 MPa.

The other easily defined boundary of the unsaturated zone is the water table. The water table lies below the TSw unit (the potential repository horizon) at Yucca Mountain. With the number of wells which are planned to be drilled during the site characterization process, the configuration of the water table beneath Yucca Mountain should be adequately determined.

The difficult boundaries to define at Yucca Mountain are those that go from the water table to the surface. It is not clear as to where these boundaries will be located. However, for the purposes of this report it will be assumed that the boundaries extend vertically upward from the water table to the ground surface at the perimeter defined as the accessible environment. Currently, this accessible environment perimeter can extend no more than five kilometers from the repository.

Several possible boundary conditions could exist along this vertical boundary. If vertical flow is indeed the primary mechanism of flow through the unsaturated zone, then no flow boundary conditions may be appropriate. However, if lateral flow conditions are found to exist during the site characterization process, then constant flux, variable flux, or constant potential boundary conditions may be appropriate. Indeed, it may be that the actual vertical boundary has a combination of boundary conditions which must be considered for the numerical models.

3.4.2 Initial Conditions

Little direct information on matrix potentials is presently available for the unsaturated zone beneath Yucca Mountain. The hydrologic parameters relating to the existing potential field have only been monitored in one borehole at Yucca Mountain. This borehole, USW UZ-1, was completed in November, 1983 in the TSw unit. Air was used as the drilling fluid in a reverse air vacuum system to minimize disturbing local hydrologic conditions near the borehole. Thirty three instrument stations were installed within the borehole. These instrument stations contained thermocouple psychrometers and heat dissipation probes to measure matrix potential, and pressure transducers to measure pore-gas pressure.

Montazer et al. (1985) presented a preliminary analysis and interpretation of data collected in the drillhole over a two year period following completion of the borehole. If the conditions within the borehole have reached equilibrium with those in the surrounding host rock, then the matrix potentials within the PTn hydrogeologic unit at the borehole range from -10 to -1 bar (-1 to -.1 MPa). The matrix potentials within the TSw unit range from -10 to -1 bars with an approximately constant mean value of about -3 bars over the thickness of the unit. However, problems with the well's completion and instrument drift make some of this data questionable.[10]

Indirect evidence of the matrix potential come from the results of measuring ambient rock-matrix saturations on 19 samples from cores obtained in test well USW H-1. Mercury intrusion techniques were used to develop moisture retention curves for each of the samples from which ambient matrix potentials were inferred. The resulting set of moisture-retention curves differs considerably from the analytic representation of Peters et al. (1984) which were based on psychometric measurements made over a range of matrix potentials much less than the minimum value of about - 0.20 MPa that could be measured by Weeks and Wilson (1984).

As stated by the DOE in the CDSCP (p.3-192) "the actual rate and distribution of net infiltration over the surface of Yucca Mountain is not presently known, although likely upper bounds have been established." The DOE has hypothesized that moisture flow within the deep unsaturated zone at Yucca Mountain may be occurring under essentially steady-state conditions. This implies that moisture flow within the natural system is occurring predominantly as vertically downward liquid water flow within the rock matrix of the hydrogeologic units with possible water-vapor movement within the air filled

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[10] NRC Comment #7 - Site Vertical Borehole Studies (p. 19)
Alternative data collection techniques have not been considered should the planned instrumentation for the site vertical borehole studies (dur9ing site ;characterization) fail or prove infeasible. This could lead to a loss of data or information needed to characterize the site. There may to be enough time to complete long-term monitoring of the unsaturated zone and prototype testing of the instrumentation. Many of the instruments may fail or drift out of calibration during the long period of monitoring.

pore and fracture space. Under these conditions, the liquid-water flux through the matrix of the TSw unit would be expected to be less than the mean matrix saturated hydraulic conductivity of about 1 mm/yr, as determined for this unit by Peters et al. (1984).

3.5 FLOW AND TRANSPORT

This section describes the various numerical techniques which have been utilized to quantify the conceptual model of flow and transport at Yucca Mountain. A description of the model, the assumptions used in the model, and the pertinent results are presented. The groundwater travel time from the repository to the accessible environment is presented. In addition, the hydrochemistry and the problems associated with the modeling of radionuclide transport are discussed.

3.5.1 Numerical Models

Because of the lack of hydrologic data from the unsaturated zone, numerical models of the unsaturated flow regime are few. The model calculations which have been performed are based on highly idealized representations of the physical system, use a coarse grid size, and use hydrologic property data that are preliminary and with unknown limits of uncertainty. Therefore, the DOE states in the CDSCP that "the model results may not be quantitatively reliable."

As previously stated, no direct measurements of net infiltration have been made at Yucca Mountain and thus neither its magnitude nor its spatial and temporal distribution over the surface of Yucca Mountain are known. Therefore, the DOE has concluded that it will be necessary to rely on indirect methods, such as numerical flow and solute-transport modeling and geostatistical techniques, to infer the state of the presently existing natural hydrologic system by interpolation within and extrapolation from a somewhat incomplete set of field data.

This section describes the models which have been used by the DOE in the CDSCP to somewhat quantify the flow regime in the unsaturated zone at Yucca Mountain. These initial models have been directed in part towards examining some of the hypotheses underlying the DOE's conceptual model and contribute especially to identifying specific problems that will need to be resolved as part of the site characterization program.

The numerical models have assumed that natural moisture flow within the unsaturated zone at Yucca Mountain occurs solely as liquid-water movement through rock-matrix pores and fractures under isothermal, steady-state conditions. Because of their expected low magnitudes, fluxes at depth probably will not be directly measurable within the unsaturated zone but will have to be inferred from measured potential distributions and hydrologic properties. The DOE has stated that the analysis and interpretation of the Yucca Mountain hydrologic system will be complicated greatly if the steady-state approximation is invalid.

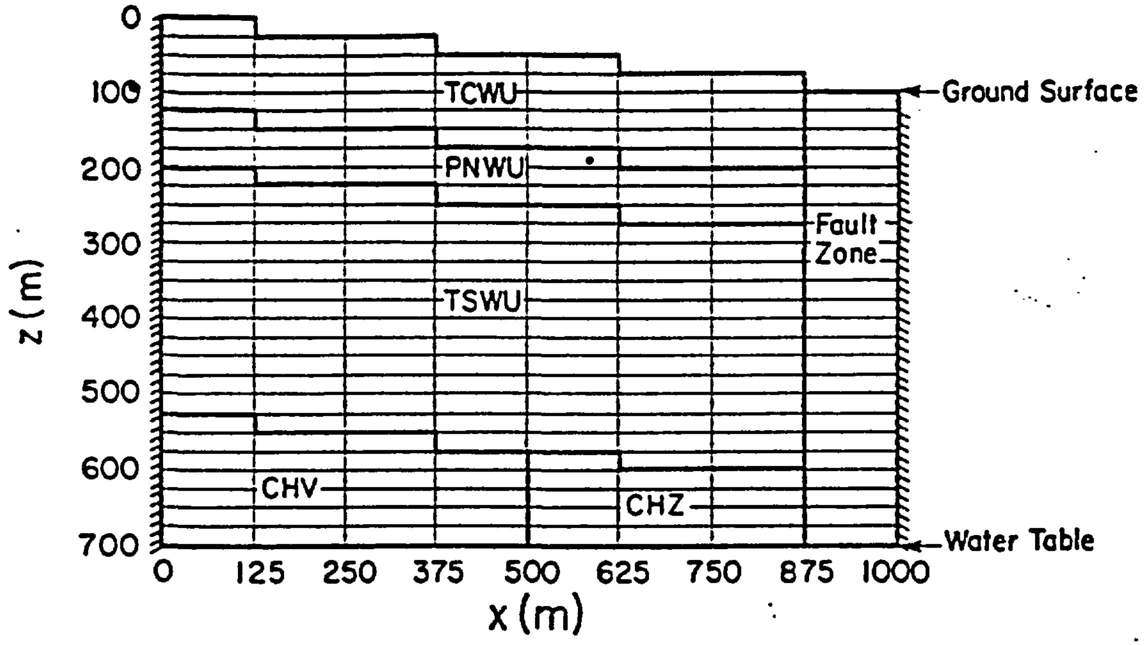
3.5.1.1 Rulon et al., 1986

Rulon et al. (1986) performed numerical simulations of the natural state of the unsaturated zone underlying Yucca Mountain. The model simulated two-dimensional liquid-water flow in a vertical cross section extending from the ground surface to the water table at a depth of about 650 m. The numerical model TOUGH (Transport Of Unsaturated Groundwater and Heat) was used in this investigation.

TOUGH was used to model the isothermal flow of liquid water for a system containing water and air. The primary variables used in the TOUGH simulator are pressure, temperature, and air mass fraction for elements in single-phase condition and pressure, gas saturation, and temperature for two-phase nodes. The numerical model uses the integral finite-difference method for formulation of the governing equations and discretizing the flow region. The equations are solved simultaneously using Newton-Raphson iteration, and the linearized equations are solved using a direct matrix solver.

Various fluxes representing the net infiltration were specified at the surface and the steady-state flux, liquid-saturation distribution, and matrix-potential distribution were computed. Various cases were considered to examine the liquid-water flux through the proposed repository unit. All of the results are controlled by poorly known hydraulic parameters such as the characteristic curves.

The discretized, two-dimensional flow region is shown on Figure 3-10. The mesh is coarse, containing 208 elements, each measuring 125 m by 25 m. The region is bounded below by the water table and above by the ground surface. The two vertical boundaries are considered to be impermeable. One boundary



TCWU = Tiva Canyon Welded Unit
PNWU = Paintbrush Nonwelded Unit
TSWU = Topopah Spring Welded Unit
CHV = Vitric Facies of Calico Hills Nonwelded Unit
CHZ = Zeolitzed Facies of Calico Hills Nonwelded Unit

XBL 852-10282

SOURCE: RULON et al (1986)

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FIGURE 3-10
DISCRETIZED FLOW REGION USED IN THE TWO-DIMENSIONAL FLOW SIMULATIONS

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corresponds to the western flank of Yucca Mountain and the other corresponds to the eastern extent of the Ghost Dance fault zone.

Rulon et al. (1986) considered that the conclusions from their study should be viewed as preliminary due to: (1) uncertainties in values used for the material properties of the units, (2) uncertainties in the estimates of net infiltration, and (3) the lack of field or laboratory experiments to verify that the numerical simulations produce results that are physically meaningful. The conclusions presented by Rulon et al. (1986) are as follows:

1. Lateral flow into the Fault Zone is an important feature of the modeled flow system.
2. A reduction in the infiltration rate leads to increased lateral flow above the TSw unit. This is due to the reduced permeability of the TSw unit for lower infiltration rates (See WWL Comment ??).
3. In the matrix-flow simulations, most of the lateral flow occurs within the PTn unit. In the fracture and fracture-matrix flow simulations, most of the lateral flow occurs within the welded units, just above the contact with the underlying nonwelded unit.
4. If fracture-flow conditions dominate in the welded units, then lateral flow occurs at the base of the TSw unit. This condition has important implications with regard to available pathways for solute transport from the potential repository horizon to the water table. Specifically, if lateral flow occurs at the base of the TSw unit, then flowpaths may be directed around the CHn unit and into the Fault Zone where water is quickly transmitted to the water table.

The DOE stated in the CDSCP that any correlation between this model and the system in place at Yucca Mountain may be premature. Further, any assumptions involving the effects of these faults on groundwater flow, and travel times should be considered preliminary.

3.5.1.2 Peters et al., 1986

Peters et al. (1986) used a one-dimensional model to simulate liquid-water flow in an idealized vertical column through the unsaturated zone at Yucca Mountain. They investigated the mode (fracture or matrix dominated) of liquid water flow for a set of prescribed percolation fluxes within the column. The column was simulated to be 530.2 m in height and consisted of a basal CHnz or CHnv unit overlain by an upward succession of the units TSw, PTn, and TCw. The mean hydrologic properties for these units were taken from Peters et al. (1984)

The mathematical model used by Peters et al. (1986) to determine the movement of water in the fractured, rock mass was based on these assumptions:

1. A unit change in the quantity total saturation times pressure head at a point causes a unit change in the local stress field.
2. Fluid flow can be calculated using Darcy's equation.
3. The pressure heads in the fractures and the matrix are identical in a direction perpendicular to the flow lines.

The total flux flowing through the mountain at any time is then the sum of the flux in the fractures and the flux in the matrix. The water velocity in either the fracture or the matrix is the Darcy flux divided by the area through which the water moves. Both saturation and permeability (and hence flux) are functions of the pressure head. The time required for water to travel across one of the hydrologic units is then the thickness of the unit divided by the velocity of the water in the unit. Two travel times are possible, matrix and fracture. The steady-state module of the TOSPAC computer code was used to determine the one-dimensional movement of water. Calculations were performed for six cases; three values of unsaturated flux, 0.1, 0.5, and 4.0 mm/yr for each of the Calico Hills subunits (CHnv and CHnz).

Peters et al. (1986) presented pressure head distributions, saturation, and water velocities as functions of distance above the water table for each of the six cases. The authors concluded:

1. Using current estimates of percolation rate, water movement is confined to the matrix and travel times are on the order of hundreds of thousands of years.
2. Travel times are very sensitive to percolation rate and an increase in percolation rate may initiate fracture flow and reduce travel times significantly. (This conclusion was also presented by WWL, 1986d).

3.5.1.3 Sinnock et al., 1986

Sinnock et al. (1986) used their model to obtain estimates of pre-waste emplacement groundwater travel times through the unsaturated zone. Their model makes the following assumptions:

1. Moisture flow in the unsaturated zone occurs under steady state conditions in which the vertical flux of moisture within the deep unsaturated zone is equal to the ambient hydraulic conductivity.
2. The unsaturated-zone flux below the disturbed zone is vertically downward and uniformly distributed in time and space.
3. The ambient (effective) hydraulic conductivity through the matrix varies spatially as a function of saturation. Under conditions of a unit vertical hydraulic gradient, the vertical volumetric flux through the matrix becomes numerically equivalent to the unsaturated matrix hydraulic conductivity at the existing saturation level. As the saturation reaches 100 percent, the matrix is assumed to conduct water at a rate numerically equivalent to the saturated conductivity. Any remaining flux is assumed to travel through fractures, even though fracture flow may be initiated at lower saturation values.
4. Water does not move rapidly through fractures that are not connected to the surface until fluxes approach the saturated matrix hydraulic conductivity. This is due to the strong negative capillary pressures exerted by the pores of the matrix, which draw water away from the fractures.

By varying flow-model parameters and using a Monte Carlo approach, probabilistic distributions for the groundwater travel time were developed. The DOE concluded that although these calculations demonstrate the utility of the methodology, the quantitative results were sensitive to hydrologic property input data that are as yet highly uncertain.[11]

Application of the Sinnock et al. (1986) model to a 963-column, rock-unit model of Yucca Mountain gives results that indicate that, for 0.5 mm/yr percolation flux, groundwater travel time has a mean of about 43,000 years and a standard deviation of about 12,000 years. Because 0.5 mm/yr is believed to be an upper limit on the percolation flux below repository level at Yucca Mountain, the results of this application suggest that less than 1 percent of the calculated groundwater travel times are less than 10,000 years. In an attempt to assess the sensitivity of the travel time to variations in flux, an

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[11] NRC Comment #86 - Issue Resolution Strategy - (p.118)
Procedures for calculating pathways and groundwater travel times presented in the strategy for Issue 1.6 may not be adequate for determining the groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment. The NRC staff presently has a concern that the use of cdf's (cumulative distribution function), as described in the CDSCP, will not fulfill the regulatory requirement.

initial flux of 1 mm/yr was used in the model. This analysis resulted in a minimum travel time of about 3,700 yr.

Sinnock et al. (1986) emphasize the need for obtaining reliable field and laboratory hydrologic-property data for all of the hydrogeologic units that affect the travel time calculations. In addition, they recommend that, to the extent that the sparse distribution of data-gathering sites will allow, geostatistical techniques be used to estimate the spatial correlation of hydrologic properties within and between hydrogeologic units.

3.5.2 Groundwater Travel Time

The DOE used the results of Sinnock et al. (1986) model to determine a probabilistic groundwater travel time for the unsaturated zone. The results of their model are shown on Table 3-3. Travel paths are from the repository horizon to the water table and are based on multiple modeling scenarios as discussed in Sinnock et al. (1986)

3.5.3 Hydrochemistry

No complete hydrochemical or isotopic analyses are available for water from the unsaturated zone at the site. Methods (triaxial compression, high-speed centrifuge and vacuum distillation) are currently under development for extracting uncontaminated samples upon which to perform these analyses. Yang (1986) has reported some preliminary calcium and sodium concentration data, showing that calcium is elevated in the pore water from the unsaturated zone relative to samples of groundwater collected from below the water table, to the extent that it dominates over sodium. Complete chemical and isotopic characterization of the infiltration pore water is needed (1) to develop an understanding of the hydrochemical nature of the water that may contact a waste package and (2) to isotopically trace the movement of these waters through the unsaturated zone. The plans for collecting these data as a function of depth are presented in the CDSCP.

The preliminary carbon-14 and carbon-13 composition of the unsaturated zone CO_2 gas phase has been determined by Yang et al. (1985) on samples obtained by the new methods developed by Haas et al. (1983). Radiocarbon from bomb-test fallout was observed to a depth of 12.2 m in borehole UZ-1 on the exploration block. Radiocarbon activity decreased to below 100 percent modern

TABLE 3.3

UNSATURATED ZONE TRAVEL TIME FOR VERTICAL FLUX OF 0.5 MM/YR

Travel Path	Travel Time (yr)
Minimum	9,345
Mean	43,265
Maximum	80,095

carbon below 18.3 m, which may indicate that downward gas-phase transport from the surface has not occurred beyond this depth since mid-1960's.

Improvements in the sample collection methods and the interpretation of these results with pore-water hydrochemical data as outlined in the CDSCP will enhance the understanding of two phase transport in the unsaturated zone at the site. The DOE has stated that when the exploratory shafts are constructed, water from the pores in unsaturated tuff, water flowing in fractures in unsaturated tuff, and water from any perched water zones in Yucca Mountain will be sampled, where possible, and analyzed. Some of the potential problems in interpreting hydrochemistry data from the unsaturated zone were reported by WWL (1988).

3.5.4 Transport Problems

The modeling of radionuclide transport requires that the reactions of radionuclides that occur between the solid phase and aqueous phase be coupled with the hydrologic flow and physical processes like diffusion and dispersion. The transport of radionuclides from a repository to the accessible environment could occur in the aqueous or vapor phase of the unsaturated zone.

The transport of contaminants by flow through either a porous matrix or a fracture system in a porous matrix will in each case be affected by geochemical and mechanical processes. Some of the geochemical processes are adsorption on mineral surfaces (both internal and external to the crystal structure) and precipitation. Mechanical processes include dispersive effects (hydrodynamic dispersion, channeling) and diffusion.

Vapor-phase transport is generally in the opposite direction from aqueous transport and may proceed more quickly since the pores that are not filled with water are the larger pores and have a higher permeability than the water-filled pores. In the unsaturated zone, volatile elements, such as iodine, can be transported in the vapor phase.

For radionuclide transport through fractures, the DOE has acknowledged that more information is needed on fracture flow in Yucca Mountain tuffs. Additional information is needed to establish whether the recharge water moves vertically through unfractured layers and then enters fractures, or if water moves through fractures as a film on the fracture surface or as a pulse fully saturating the fracture. If fractures are present but not connected or intersecting, their impact on flow and transport will be greatly diminished.

If fractures are a connected network, the path that a water slug will travel will probably be tortuous and might involve branching into cracks in other directions.

Given fracture flow, the contaminant will diffuse into the pore spaces of the rock. Because of this diffusion into the matrix, the effective flow rate for radionuclides must be modified. The modification introduces a retardation factor due to a matrix diffusion from fractures. One can then calculate an equivalent retardation value, applicable only when fracture flow is occurring, combining retardation through sorption with retardation through diffusion.

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4.0 SITE SATURATED HYDROGEOLOGIC SYSTEM

An understanding of the saturated zone hydrologic system is required for waste isolation as this zone contains some of the possible pathways for radionuclide travel from the repository to the accessible environment. An understanding of saturated zone hydrology is also needed in order to evaluate the hydrologic effects of future climate changes; these effects include potential rises in the water table and changes in gradients and paths of groundwater flow in the saturated zone.

The primary source of groundwater flow within the site saturated zone occurs as subsurface lateral inflow. This inflow ultimately originates from upland regional recharge areas to the north and west of Yucca Mountain. Some vertical recharge may also occur from the overlying unsaturated zone, however this component is believed to be small. Some upward flow from the underlying carbonate aquifer may also occur. Discharge from the site saturated zone occurs as subsurface lateral outflow to the southeast and the south beneath Fortymile Wash. Ultimately this discharge flows to the regional discharge areas (Alkali flat and Furnace Creek Ranch). Relatively large groundwater velocities may be possible in the area from beneath the repository to the accessible environment. This is the result of large bulk hydraulic conductivity but low effective porosity in welded, fractured units.

The site saturated hydrogeologic system has been divided into the following six components:

1) Hydrologic Setting
2) Hydraulic Characteristics
3) Groundwater Flow Mechanisms
4) Boundary Conditions
5) Groundwater Travel Time
6) Paleohydrology

Each of the above components is described in the following sections.

4.1 HYDROLOGIC SETTING

This section focuses on the site hydrogeologic system in the immediate vicinity of Yucca Mountain (generally within a few kilometers of the outer boundary of the repository). Because the areal extent of the Site Saturated Hydrogeologic System is similar to that of the Site Unsaturated System which was described in Chapter 3, extensive reference to the preceding chapter occurs in the following discussion.

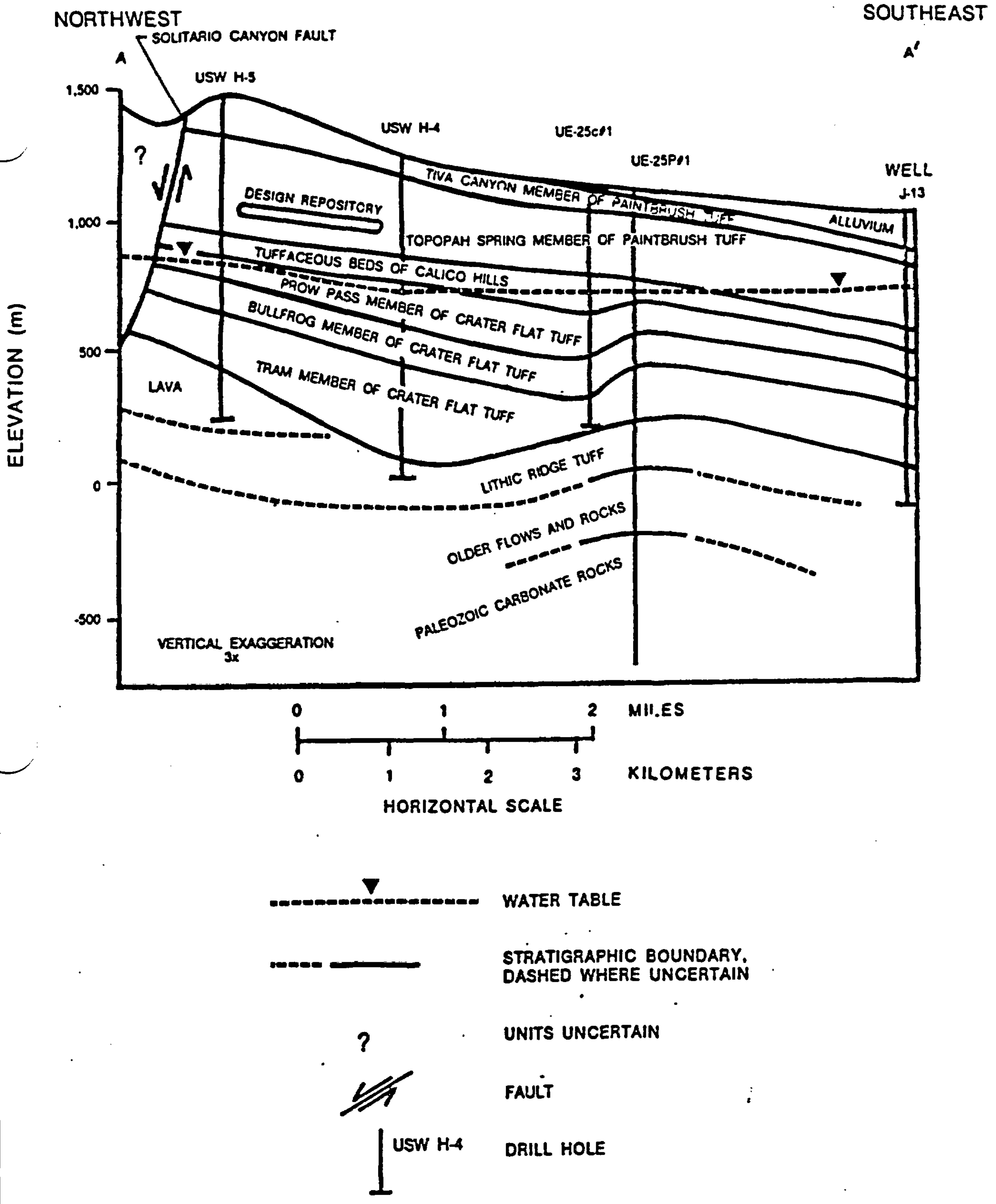
4.1.1 Geology

The stratigraphy and lithology for the site were described in detail in Section 3.2.1 and in general those descriptions apply to the Site Saturated System. Section 3.2.2 describes the site geologic structural features which are pertinent to the saturated system. The major geologic units in the site saturated zone are the Topopah Springs, the Calico Hills, the Crater Flat, the Lithic Ridge, the Older Flows and Rocks, and the Paleozoic Carbonates.

4.1.2 Hydrogeologic Units

Because physical properties of the rocks that are believed to control movement of groundwater in the unsaturated zone are not completely consistent with stratigraphic boundaries, the division of the hydrogeologic units and their relation to the stratigraphic units is shown on Table 3-1. The geologic units are divided into hydrogeologic units based primarily on the degree of welding. The nonwelded and bedded tuff units have a low fracture density and the primary mechanism of flow is through the matrix. The partially welded and densely welded tuff units have a much higher fracture density and fracture flow is the dominant flow mechanism. Additional units at the site which are not included in Table 3-1 are the Lithic Ridge Tuff, the Older Flows and Rocks, and the Paleozoic Carbonate Rocks. These stratigraphic and hydrogeologic units are considered to be equivalent due to lack of information.

The Paintbrush Tuff is mostly unsaturated in the near vicinity of Yucca Mountain. The Topopah Spring Member, which is unsaturated in the repository block, but saturated east of Yucca Mountain as shown on Figure 4-1, consists mostly of moderately to densely welded tuffs. The Crater Flat Tuff (Prow Pass, Bullfrog, and Tram members) consists of partially to moderately welded tuffs. The tuffaceous beds of Calico Hills and Lithic Ridge Tuff are predominantly nonwelded and bedded tuffs. In addition, bedded tuffs commonly separate the major ash-flow tuff units. Partial alteration of vitric tuffs to zeolites or clays reduces their permeability substantially. As shown on Figure 4-2, the thickness of the zeolitic facies of the tuffaceous beds of Calico Hills



SEE FIGURE 4-1 FOR LOCATION OF CROSS-SECTION

SOURCE: DOE, 1988

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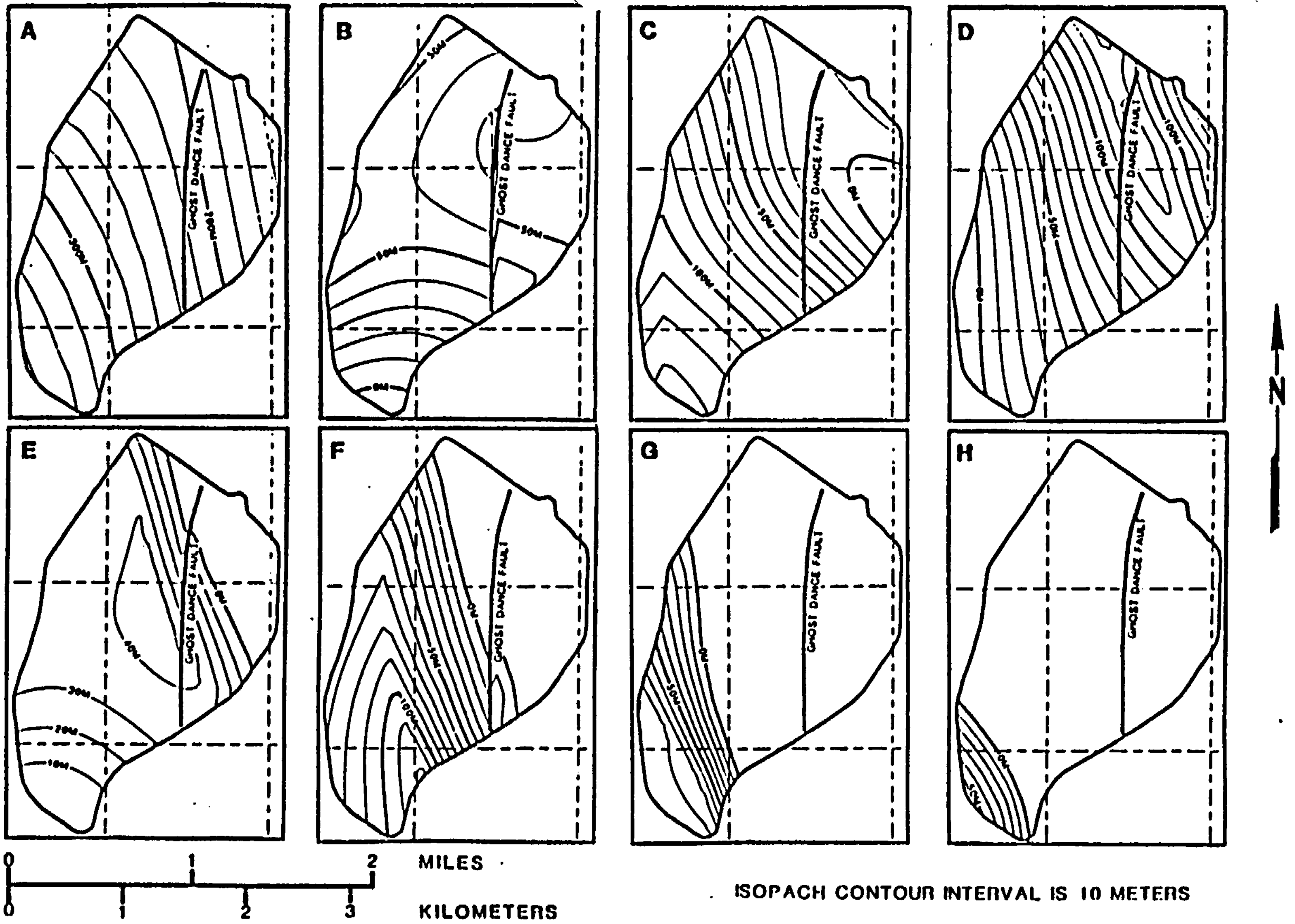
FIGURE 4-1
STRATIGRAPHIC RELATIONSHIPS
THROUGH YUCCA MOUNTAIN

Date: SEPT 1988

Project: 4001



ISOPACH CONTOUR INTERVAL IS 10 METERS

(A) TOTAL THICKNESS FROM DISTURBED ZONE TO THE WATER TABLE: (B) THICKNESS OF UNDISTURBED TOPOPAH SPRING WELDED UNIT TSw: (C) THICKNESS OF THE CALICO HILLS NONWELDED VITRIC UNIT. CHnv: (D) THICKNESS OF THE CALICO HILLS NONWELDED ZEOLITIC UNIT CHnz: (E) THICKNESS OF THE PROW PASS WELDED UNIT PPw (F) THICKNESS OF THE PROW PASS NONWELDED UNIT PPn: (G) THICKNESS OF THE BULLFROG WELDED UNIT

SOURCE: SINNOCK et al (1986)

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FIGURE 4-2

ISOPACH CONTOUR MAPS WITHIN THE REPOSITORY BLOCK

Date: SEPT 1988

Project: 4001

increases from southwest to northeast, and the entire unit is altered beneath the northern and northeastern parts of the Yucca Mountain repository block (Montazer and Wilson, 1984).

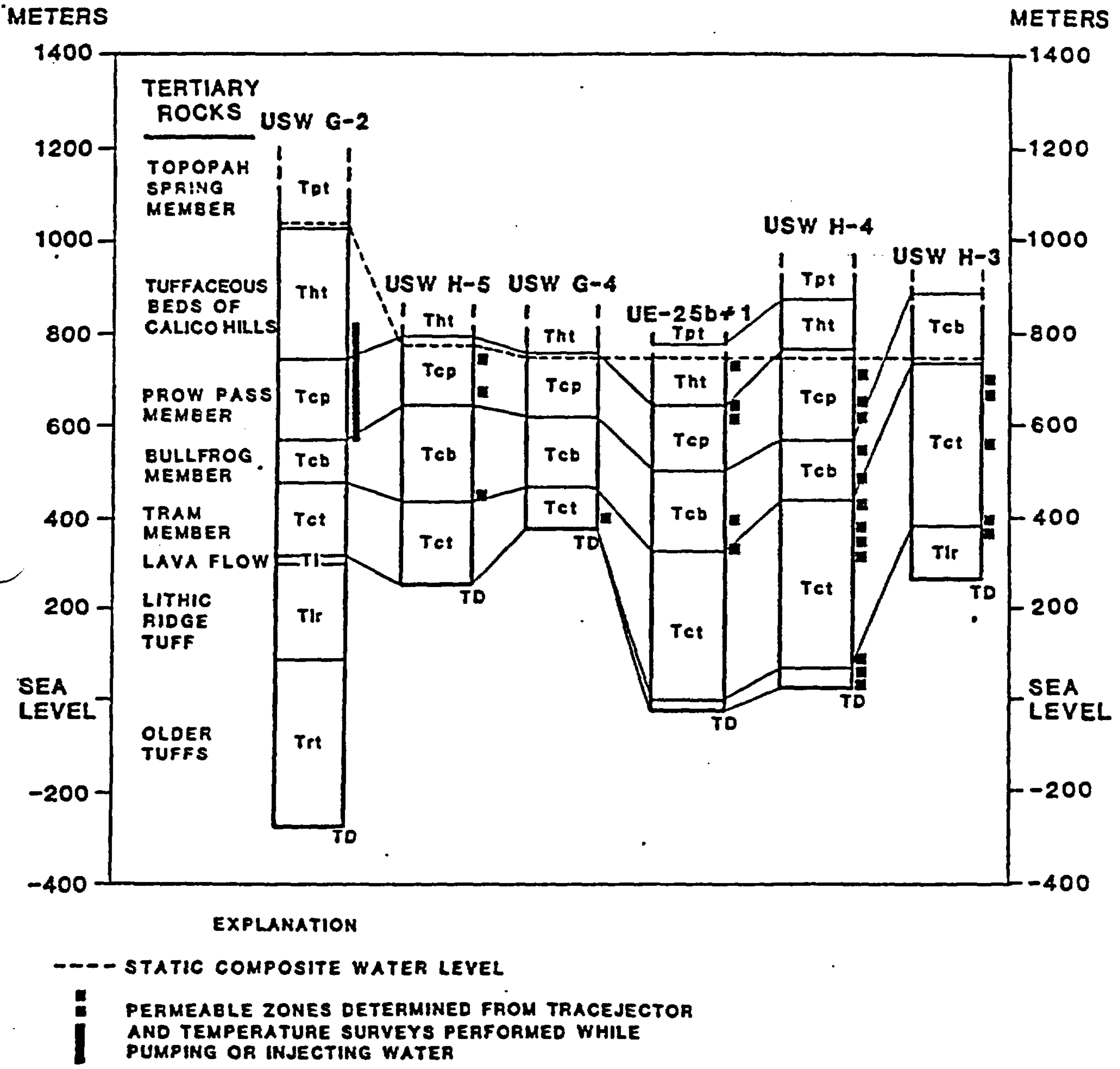
The Tiva Canyon and the Topopah Springs members are part of the welded tuff aquifer described by Winograd and Thordarson (1975). The Calico Hills, the Crater Flat Tuff, the Lithic Ridge Tuff, and the Older Flows and Rocks are part of Winograd and Thordarson's (1975) tuff aquitard. Also, beneath Yucca Mountain are Paleozoic carbonate rocks, equivalent to the regional "lower carbonate aquifer" of Winograd and Thordarson (1975). These rocks occur at a depth of 1,200 m in drill hole UE-25p#1 and probably much deeper elsewhere (Craig and Robison, 1984). These carbonate rocks are permeable, but at Yucca Mountain the potentiometric head, as measured at drill hole UE-25p#1 (which is the only drillhole penetrating the Paleozoic rocks), is greater in the Paleozoic rocks than in overlying rocks. Therefore, the DOE believes that groundwater moving through the shallow part of the saturated zone in the vicinity of the Yucca Mountain repository block probably does not have significant local interaction with water from the Paleozoic rocks.

4.2 HYDRAULIC CHARACTERISTICS

This section presents information on the hydraulic characteristics of the saturated zone in and around Yucca Mountain. Values for parameters such as hydraulic conductivity, transmissivity, porosity, and storage coefficients for each hydrogeologic unit are presented and discussed. The effect of fractures on the hydraulic conductivity and effective flow porosity of the units is also described.

4.2.1 Transmissivity and Hydraulic Conductivity Values of Stratigraphic Units

Much of the information on the hydraulic characteristics of the site saturated zone has come from analysis of well tests. These tests have included pump (drawdown and recovery), injection, and tracer surveys. As a result of these tests, the DOE has concluded that stratigraphic controls on the distribution of permeability cannot be readily established or predicted with confidence for untested areas. The heterogeneity of the permeable zones can be seen in Figures 4-3 and 4-4, which show the distribution of permeable zones within the wellbores for selected wells near Yucca Mountain. The productive intervals are determined by the depths at which holes intercept transmissive



SOURCE: WADDELL et al (1984)

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FIGURE 4-3
DISTRIBUTION OF PERMEABLE ZONES IN TEST HOLES NEAR YUCCA MOUNTAIN

Date: SEPT 1988

Project: 4001

FORMATION	WELL NUMBER						
	USW H-6	USW H-5	USW H-1	USW G-4	USW H-4	UE-25b#1	J-13
TOPOPAH SPRING MEMBER OF PAINTBRUSH TUFF							WT ▨
TUFFACEOUS BEDS OF CALICO HILLS			WT	WT		WT ▨	
PROW PASS MEMBER OF CRATER FLAT TUFF	WT	WT	▨		WT ▨		
BULLFROG MEMBER OF CRATER FLAT TUFF	▨	▨	▨		▨	▨	
TRAM MEMBER OF CRATER FLAT TUFF	▨	▨		▨ TD		TD	
LAVA	TD	TD					
TUFF OF LITHIC RIDGE			TD ↓		▨ TD		TD

WT = WATER TABLE   TD = TOTAL DEPTH   ▨ PERMEABLE ZONE

SOURCE: BENSON et al (1983)

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FIGURE 4-4
VERTICAL DISTRIBUTION OF PERMEABLE ZONES
IN THE YUCCA MOUNTAIN AREA

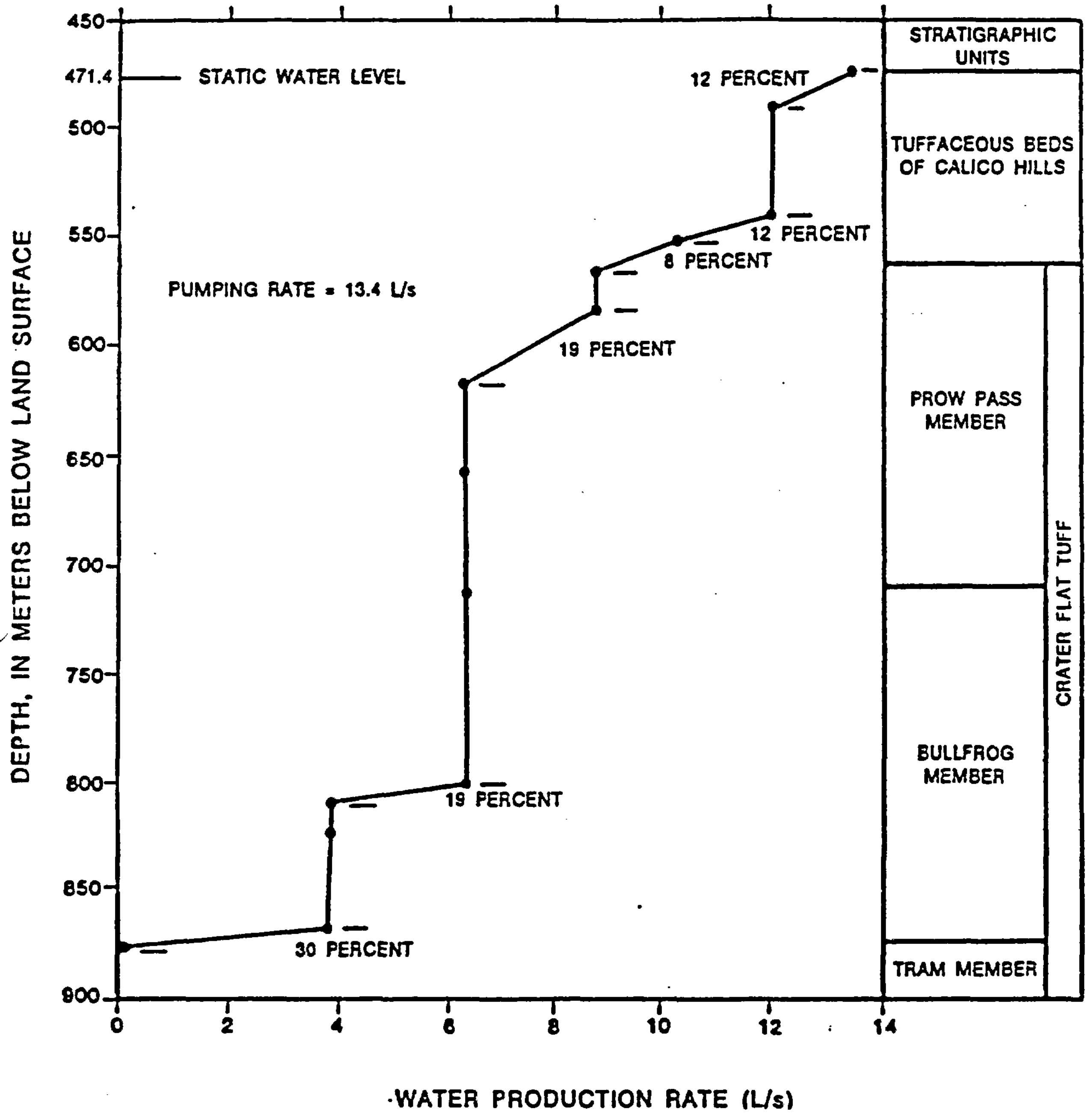
Date: SEPT 1988
Project: 4001

fractures. In the following several paragraphs, the saturated hydraulic characteristics (as presented by the DOE) of each major stratigraphic unit beneath the Yucca Mountain site is discussed.

The Topopah Spring Member of the Paintbrush Tuff, which lies below the water table east of the repository block (see Figure 4-1), has a relatively high bulk hydraulic conductivity. The matrix hydraulic conductivity, however, is extremely low. Again, the productive zones appear to be controlled by fractures; many of which have been observed in cores and in television surveys. Another indication of high bulk conductivity are the problems related to loss of drilling fluids while penetrating this unit. Thordarson (1983) reported hydraulic conductivities from cores at well J-13 that range from 2×10^{-4} to 8×10^{-7} m/d. The average in situ hydraulic conductivity is about 0.7 m/d and the Topopah Spring Member is the most productive unit penetrated by the well.

The tuffaceous beds of Calico Hills are above the water table in most hydrologic test holes near Yucca Mountain. In drillhole UE-25p#1 the unit is mostly saturated but poorly permeable. The DOE (CDSCP,1988) reported that during a pumping test, a borehole-flow survey indicated the unit yielded less than 2 percent of the total amount pumped. Craig and Robison (1984) concluded that the 41 m of saturated Calico Hills penetrated by UE-25p#1 has a transmissivity of about 0.5 m^2/day. In contrast, Figure 4-5 illustrates that in drillhole UE-25b#1 the tuffaceous beds of Calico Hills yielded 32 percent of the production during pumping of the entire hole (Lahoud et al., 1984). In the vicinity of UE-25b#1, the unit is zeolitized which would indicate low matrix hydraulic conductivity. Therefore, the relatively high values of hydraulic conductivity as determined from in situ tests and reported in Table 4-1 probably are due to nearby normal faults or shear fractures (Waddell et al., 1984).

The Prow Pass and Bullfrog Members of the Crater Flat Tuff are generally considered to be similar in hydrologic properties. As shown on Figures 4-3 and 4-4, these units are commonly the most productive units penetrated by drillholes in the vicinity of Yucca Mountain with their in situ bulk hydraulic conductivity being largely controlled by fractures (Waddell et al., 1984). In addition, Figure 4-5 illustrates that nearby 68% of the total production from drillhole UE-25b#1 originated in these two units.



(TEST HOLE WAS AT A TOTAL DEPTH OF 1,220 M)

SOURCE: LAHOUD et al (1984)

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FIGURE 4-5
BOREHOLE-FLOW SURVEY OF
DRILLHOLE UE- 25 b #1

Date: SEPT 1988

Project: 4001

T[illegible] 4-1

PRELIMINARY[a] SUMMARY OF HYDROLOGIC CH[illegible]CTERISTICS OF MAJOR STRATIGRAPHIC UNITS IN THE VICINITY OF YUCCA MOUNTAIN

(PAGE 1 OF 2)

		In situ (field) analyses					Laboratory analyses (cores)					
							Saturated matrix hydraulic conductivity		Matrix porosity[e]			
Stratigraphic unit	Typical character	Saturated thickness (m)	Transmissivity[b] (m^2/d)	Average hydraulic conductivity[c] (m/d)	Well or hole tested	Reference[d]	m/d	No. of samples	%	No. of samples	Well or hole analysed	Reference[d]
Topopah Spring Member	Moderately to densely welded tuff	167	120	0.7	J-13	7	$3x10^{-7}$ to $2x10^{-4}$	5	4 - 33	5	J-13	7
							$7x10^{-7}$ to $5x10^{-4}$	18	6 - 30	24	UE-25a#1	1
							$8x10^{-7}$	1	12	1	UE-25b#1	4
Tuffaceous beds of Calico Hills	Zeolitized, nonwelded tuff, vitric tuff	148	(82)	0.5	UE-25b#1	4	$4x10^{-6}$ to $3x10^{-4}$	6	20 - 34	7	UE-25a#1	1
Prow Pass Member of Crater Flat Tuff	Nonwelded to moderately welded tuff	116	167	1.44	USW H-1	2	$6x10^{-5}$ to $1x10^{-4}$	3	28 - 29	3	USW H-1	6
		135	150	1.1	USW H-1	6	$2x10^{-5}$ to $1x10^{-2}$	8	10 - 25	12	UE-25a#1	1
		174	36 - 142[f]	0.2-0.8[f]	USW H-4	9	$6x10^{-7}$ to $1x10^{-3}$	5	17 - 30	18	USW G-4	5
		150	(65)	0.4	UE-25b#1	4						
		111	14	0.1	UE-25p#1	3						
Bullfrog Member of Crater Flat Tuff	Nonwelded to densely welded tuff	125	0.8	0.006	USW H-1	6	$3x10^{-5}$ to $1x10^{-3}$	10	19 - 34	9	USW H-1	6
		119	70 - 276[f]	0.6-2.3[f]	USW H-4	9	$2x10^{-4}$ to $1x10^{-3}$	3	17 - 34	3	UE-25a#1	1
		159	(65)	0.4	UE-25b#1	4	$2x10^{-4}$ to $5x10^{-4}$	2	24 - 27	6	USW G-4	5
		132	(7)	0.05	UE-25p#1	3						
Tram Member of Crater Flat Tuff	Nonwelded to moderately welded ash-flow and bedded tuffs	284	$2x10^{-3}$	$7x10^{-6}$	USW H-1	6	$4x10^{-6}$ to $4x10^{-4}$	9	18 - 26	9	USW H-1	6
		354	0.7	0.002	USW H-3	8						
		352	70 - 276[f]	0.2-0.8[f]	USW H-4	9						
		183	(3.3)	0.02	UE-25p#1	3						
Lithic Ridge Tuff and older tuffs	Partially welded ash-fall tuffs	594	0.001	$2x10^{-6}$	USW H-1	6	$6x10^{-5}$ to $3x10^{-4}$	2	9 - 17	2	USW H-1	6
		110	0.1	$1x10^{-3}$	USW H-3	8						
		371	>10	>0.03	UE-25p#1	3						

TABLE 4-1

PRELIMINARY[a] SUMMARY OF HYDROLOGIC C TERISTICS OF MAJOR STRATIGRAPHIC UNITS IN THE VICINIT F YUCCA MOUNTAIN

(PAGE 2 OF 2)

		In situ (field) analyses					Laboratory analyses (cores)					
							Saturated matrix hydraulic conductivity		Matrix porosity[e]			
Stratigraphic unit	Typical character	Saturated thickness (m)	Transmissivity[b] (m^2/d)	Average hydraulic conductivity[c] (m/d)	Well or hole tested	Reference[d]	m/d	No. of samples	%	No. of samples	Well or hole analysed	Reference[d]
Lone Mountain Dolomite and Roberts Mountain Formation	Carbonate rocks Paleozoic age (lower) carbonate aquifer of Winograd and Thordarson, 1975)	>561	108	0.2	UE-25p#1	3						

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[a] Interpretive analyses from in situ testing at some drillholes are not completed yet, including those from drillholes USW C-4, USW H-6, and UE-25c#1,2,3.

[b] Determined from pumping tests, borehole-flow surveys, and slug-injection tests; parentheses indicate approximate value because reported values reflect more than one stratigraphic unit. See references cited for details of individual drillholes tested.

[c] Obtained by dividing transmissivity be saturated thickness, which in some cases may not agree with values reported in the cited reference. Productive zones are typically thin, fractured intervals rather than a generally-uniform rock matrix; therefore, the porous-media concept of hydraulic conductivity is not necessarily appropriate.

[d] 1, Anderson (1981); 2, Barr (1985); 3, Craig and Robison (1984); 4, Lahoud et al. (1984); 5, Peters et al. (1984); 6, Rush et al. (9184); 7, Thordarson (1983); 8, Thordarson et al. (1984); 9, Whitfield et al. (1985).

[e] Chapter 2 - of the CDSCP Geoengineering.

[f] Lower value based on straight-line method of pumping-test analysis; higher value based on Theis-recovery method (see Whitfield et al. (1985).

The DOE considers the Tram Member of the Crater Flat Tuff generally to be much less permeable than any of the overlying saturated units. As an example, at drill hole UE-25b#1, the Tram yielded no measurable production during pumping of the entire hole (see Figure 4-5; Lahoud et al., 1984). (The deepest productive zone included the zeolitized bedded and reworked unit at the base of the Bullfrog Member and produced 30 percent of the water from UE-256#1). In addition, the total transmissivity at drillhole USW H-3 is only about 1 m^2/d, virtually all of it from the Tram Member (Thordarson et al., 1985). Drillhole USW H-3 is located on the western edge of the repository block in an area relatively undisturbed by fracturing and faulting and where the Topopah Spring Member, tuffaceous beds of Calico Hills, Prow Pass Member, and most of the Bullfrog Member are unsaturated. However, an exception occurs at drillhole USW G-4, where about 98 percent of the water production was from the Tram Member. Table 4-1 shows that hydraulic conductivity for the Tram Member is as low as 7 x 10^{-6} m/d (drillhole USW H-1) and as high as 0.2 to 0.8 m/d (drillhole USW H-4).[1]

Hydraulic conductivity of Tertiary rocks older than the Crater Flat Tuff ranges from about 2 x 10^{-6} to 3 x 10^{-2} m/d (Table 4-1). Pre-Tertiary age rocks have been penetrated in only one drillhole in the vicinity of Yucca Mountain, at drillhole UE-25p#1 (see Figure 4-1), where Paleozoic carbonate rocks of the Lone Mountain Dolomite and Roberts Mountains Formation were observed (Craig and Robison, 1984). They reported an average hydraulic conductivity value of 0.2 m/day.

Porous-media solutions were used in calculations of bulk values of in situ transmissivity and hydraulic conductivity shown in Table 4-1 (in which transmissivity for individual stratigraphic units ranges from 0.001 to 276 m^2/day and hydraulic conductivity ranges from 2 x 10^{-6} to 2.3 m/day). Where appropriate, data will be reevaluated by the DOE as outlined in the CDSCP using alternative approaches, such as those based on fracture-flow concepts.

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[1] WWL Comment - Transmissivity Differences
The DOE has pointed out that there are significant differences in the transmissivity within the same units between different wellbores. The reason presented for these differences are (1) the fractures become "closed" at greater stratigraphic depth, and (2) the units at some drillholes are not as fractured. Further work is needed to understand the mechanisms which cause the transmissivity differences. In addition, the implications (if any) this phenomena has on the unsaturated units should be investigated.

In situ values of parameters such as transmissivity or hydraulic conductivity were determined from single-hole tests, the limitations of which are recognized by the DOE. Observations holes were not used because none were close enough to show responses that would be separable from normal background variations due to earth tides and barometric affects. However, Moench (1984) evaluated responses from an observation hole, 100 m from UE-25b#1 with a double-porosity conceptual model. Moench (1984) concluded that fracture skin may be important and calculated fracture system hydraulic conductivity to be about 10^{-5} m/s and block system hydraulic conductivity to be about 2 x 10^{-6} m/s. As the precision of water-level measurements is increased, aquifer tests that include responses in observation holes at substantial distances from the pumped well may be feasible. Plans for these tests are outlined in the CDSCP.

4.2.2 Hydraulic Conductivity with Respect to Fractures

The importance of flow in fractures is indicated by two lines of evidence:

(1) Hydraulic conductivity of the matrix, as measured on cores and by packer tests of nonproductive parts of drill holes, is much lower than in situ conductivity measurements in productive parts of the drill holes.

(2) Productive zones, as determined by borehole-flow and temperature surveys performed during pumping tests, correlate with fracture zones determined from televiewer and caliper logs.

Preliminary interpretations indicate that conductivities of fractures are several orders of magnitude greater than matrix conductivities. In addition, fractures at Yucca Mountain have preferred orientations (Scott et al., 1983). Therefore, a high degree of anisotropy, with respect to hydraulic conductivity, probably also exists.

Two sets of faults and fractures are currently believed to be present at Yucca Mountain (Scott et al., 1983). The first set strikes north-northwest and the second strikes north-northeast. Both sets dip steeply to the west. The minimum compressive stress is coincident with the regional direction of tectonic extension (Carr, 1974) which is oriented N. 50 to 60 degrees W. Therefore, fractures with these orientations may tend to be closed by tectonic stresses and fractures with orientations of N. 30 to 40 degrees E. may tend to be more open. The DOE recognizes that this may cause the system to be hydraulically anisotropic because the north-northeast-striking fracture set may be more transmissive. Multiple well hydraulic tests in the vicinity of drillhole UE-25c#1 are planned by the DOE in the site characterization process to test the hypothesis that fracture orientation may tend to control the direction or rate of ground-water flow.[2]

Preliminary interpretation of the anisotropy has been performed by Erickson and Waddell (1985) using fracture frequency and orientation data from drillhole USW H-4. They calculated the probable shape and orientation of the hydraulic-conductivity ellipsoid at that site and determined that the plane containing the two larger principal axes strikes northeast and is nearly vertical. They concluded that the hydraulic conductivity in this plane is 5 to 7 times that of the smallest principal hydraulic conductivity.

Other controls on fracture density are not clear. Besides being a function of rock type, fracture density is a function of structural setting. A zone of increased fracturing and faulting on the southeastern and eastern sides of Yucca Mountain has been mapped (Scott and Bonk, 1984). Another feature evident from surface mapping is that fracture density decreases in the northern part of Yucca Mountain, where displacement and number of faults are less than in the southern part. Fracture density is presumed to increase near faults of large displacement and a corresponding increase in local bulk hydraulic conductivity could be expected. Plans to examine this hypothesis are presented in the CDSCP.

Analogies to the flow regime at Yucca Mountain have been investigated at other locations at the NTS as part of the nuclear bomb testing program. Claassen and White (1979) studied the possible extent of fracture control on the Rainier Mesa groundwater system and concluded that the hydraulic characteristics of the Paintbrush Tuff are controlled by secondary (fracture) porosity. Blankennagel and Weir (1973) observed that welded tuff and rhyolite

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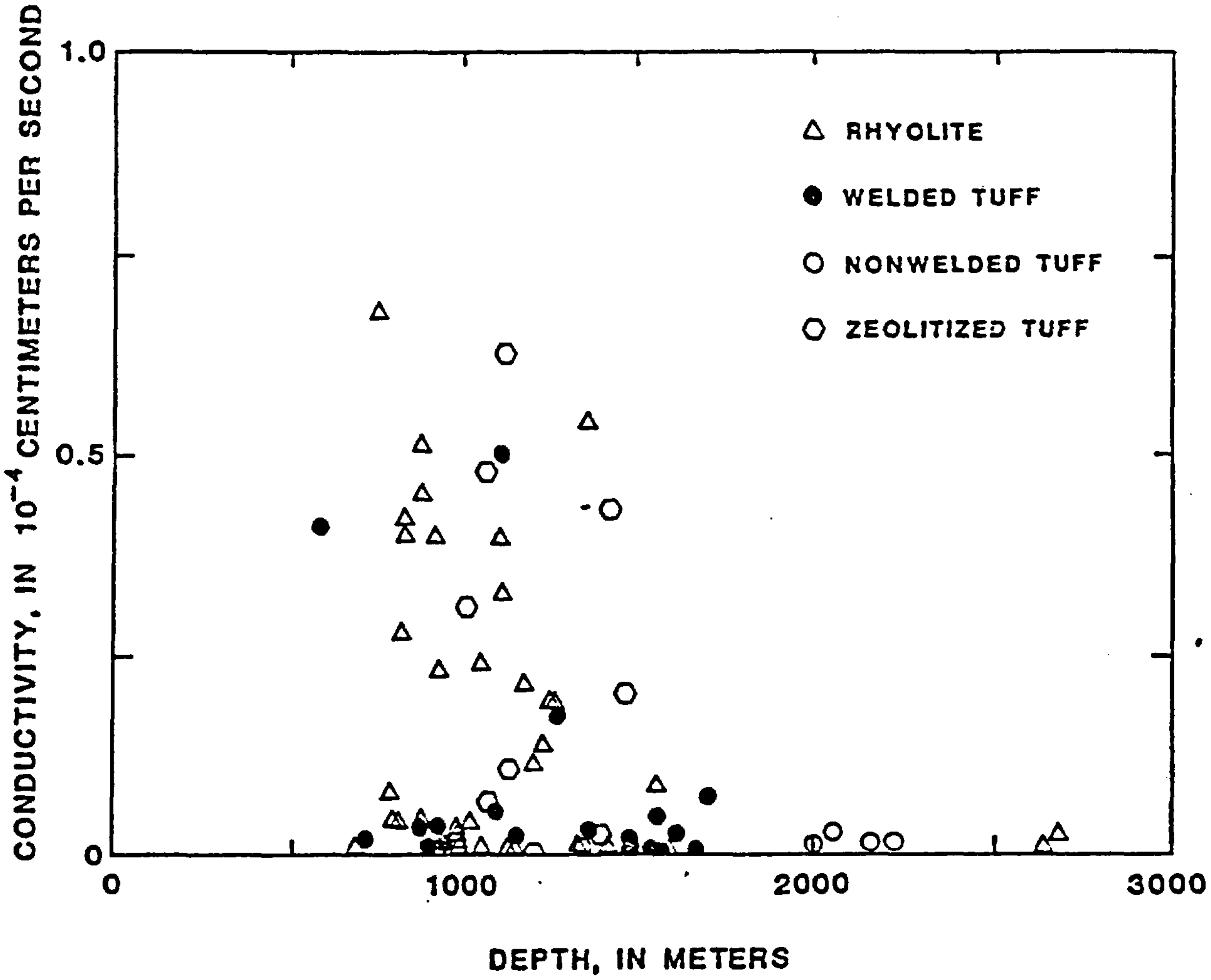
[2] USGS Comment - Multiple Well Tests (p. 180).

The DOE states on page 8.3.1.2-295 of the CDSCP that although single well tests are useful for determining aquifer properties on a local scale, multiple well test will be required to understand the nature and areal distribution of bulk aquifer properties. However, even the proposed multiwell tests are at a scale which is minute compared with the travel distance form the repository to the 'accessible environment'. Thus multiple well testing may shed little light on the large-scale flow and transport of which understanding is required to satisfy design criteria. In particular, measurement of local dispersion coefficients with tracer tests will likely give values unrelated to dispersion at the large scale of the design criteria.

have higher permeabilities than nonwelded or bedded tuffs through extensive hydrologic testing of rocks beneath Pahute Mesa. Hydraulic conductivity measurements in test holes beneath Pahute Mesa are shown on Figure 4-6. Welded tuffs and rhyolite lavas are brittle and fracture readily. Nonwelded and bedded tuffs commonly contain fractures, but the fracture systems generally are less extensive. Interconnection of some fractures in welded tuffs, both beneath Pahute Mesa and Yucca Mountain, was demonstrated by hydrologic tests in holes that included slug-injection or withdrawals of water of isolated depth intervals, pumping tests, and borehole-flow surveys to determine intervals that yield water. These tests indicated that the volumes of water removed during pumping tests are many times the volumes of the fractures near the drill holes (Blankennagel and Weir, 1973; Rush et al., 1984), which may indicate that these fractures are connected to more distant ones, although there may also be some contribution from the rock matrix.

Hydraulic conductivity of tuffs may decrease with increasing depth. However, welded tuffs are generally less conductive than rhyolites at the same depth (Waddell et al., 1984). At greater depths, formation of minerals in fractures (commonly clays, silica, calcite, zeolites, or iron and manganese oxides) or closing of fractures because of greater lithostatic stresses tend to decrease the aperture of fractures. Rush et al. (1984) show that, in drillhole USW H-1, bulk hydraulic conductivity (determined from pumping tests) is substantially greater than matrix hydraulic conductivity (determined from cores) for the shallower rocks, but at greater depths the bulk and matrix hydraulic conductivity are approximately equivalent. They concluded that there may be no fracture flow below a depth of 790 m in rocks penetrated by drillhole USW H-1 because the greater overburden pressure decreases fracture porosity. However, the DOE does not know if these conditions prevail throughout the Yucca Mountain area.

The DOE concluded that vertical and horizontal interconnectivity of fractures was demonstrated by a pumping test of drillhole UE-25b#1, which was pumped for 29 days at about 12 L/s from the interval 853 to 914 m (lower Bullfrog to upper Tram Member). A sodium bromide tracer was placed in drillhole UE-25a#1, which is 107 m away from drillhole UE-25b#1 and is open to the formation from the water level (470 m) to total depth of 762 m (tuffaceous beds of Calico Hills to upper Bullfrog Member). Breakthrough of the tracer in UE-25b#1 occurred in two days, and above-background concentrations continued



SOURCE: BLANKENNAGEL AND WEIR (1973)

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FIGURE 4-6
HYDRAULIC CONDUCTIVITY MEASUREMENTS
IN TEST HOLES BENEATH PAHUTE MESA

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for the next 26 days of pumping (Waddell, 1984; Waddell et al., 1984) (see footnote number 1).

The DOE has concluded that knowledge of the role of fractures in controlling paths and velocities of groundwater flow at Yucca Mountain is as yet insufficient to characterize the flow system adequately. A further understanding is also needed of the applicability of the concepts of porous-media equivalents for describing the flow system. Improved understanding of these factors is expected to come from planned tracer tests at Yucca Mountain, as presented in the CDSCP.

The dip of most fractures is very steep, and drillholes are nearly vertical. Therefore, a statistically significant number of fractures are not likely to be intercepted by a vertical drilling program of reasonable design. The DOE believes that this bias will be better understood through data gathered from horizontal boreholes extending off the exploratory shaft.[3]

4.2.3 Porosity and Storage Coefficients

Laboratory results of porosity testing on cores are shown in Table 4-1. Porosities reported by Anderson (1981) and by Thordarson (1983) were determined by water-saturation techniques while the values reported by Lahoud et al. (1984) and Rush et al. (1984) were estimated with helium pycnometer methods. Lahoud et al. (1984) and Rush et al. (1985) reported generally similar values for porosity calculated from dry-bulk and grain densities.

Erickson and Waddell (1985) determined that fracture porosity at drillhole USW H-4 is 10^{-4} to 1×10^{-3} by using a method that involves calculating equivalent fracture apertures. They concluded that, if most water moves through fracture rather than the rock matrix, fracture porosity approximates effective porosity. Although results from single-hole tests are not necessarily reliable, Rush et al. (1984) used slug-injection tests to estimate storage coefficients that range from 2×10^{-3} to 6×10^{-6} among the stratigraphic units penetrated at drillhole USW H-1. Using the same data from

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[3] WWL Comment - Fracture Frequency and Orientation
It should be pointed out that the horizontal boreholes and the shafts will be in the unsaturated zone. In addition, these holes and shaft will primarily be in the Topopah Springs unit. The units below the Topopah Springs therefore may not be adequately sampled as to the fracture frequency and orientation.

drillhole USW H-1, Barr (1985) calculated values for storativity (storage coefficient) that are about an order of magnitude lower.

Based on breakthrough of a tracer placed in drillhole UE-25a#1 while drillhole UE-25b#1 was being pumped, Waddell (1984) estimated effective porosity between two drill sites to be on the order of 1×10^{-4} to 1×10^{-3}. Various hydraulic tests are planned by the DOE in the vicinity of drillholes UE-25c#1, UE-25c#2, and UE-25c#3 to obtain more values for effective porosity and storage coefficients that will give a range of values that may be expected in the vicinity of the Yucca Mountain site.

4.3 GROUNDWATER FLOW MECHANISMS

The proposed repository horizon at Yucca Mountain is within the unsaturated Topopah Springs unit about 250 meters above the water table and ranging from about 80 meters to 140 meters above the underlying Calico Hills unit. The DOE states that the most credible pathway for liquid-water movement (and hence, radionuclide movement) from the repository horizon enroute to the accessible environment (located beyond 5 km from the outer boundary of the repository underground facility) depends to a large extent on the flow mechanisms within the Topopah Spring unit. The DOE currently believes liquid-water movement to be restricted to the matrix of the TSw unit and therefore will tend to be directed vertically downward. This vertical flow would then continue through the CHn unit to the water table. If this scenario is correct, then the likely path of a radionuclide entering the site saturated zone begins at the vertical footprint of the repository horizon on the underlying phreatic surface.

In the saturated zone, differences in potentiometric levels indicate general directions of groundwater flow. In general, groundwater flow beneath Yucca Mountain probably is southward through the site and then southeastward away from the site into the Fortymile Wash area. Because of the nearly flat potentiometric surface under parts of Yucca Mountain, and the uncertainty about the degree of anisotropy, specific flowpath directions are currently difficult to define. Therefore, the DOE has planned additional water-table holes and extensive multiple-well and single-well tracer tests to help define anisotropy, hydraulic connections, and probable flow paths in the saturated zone. Plans for these tests are outlined in the CDSCP.

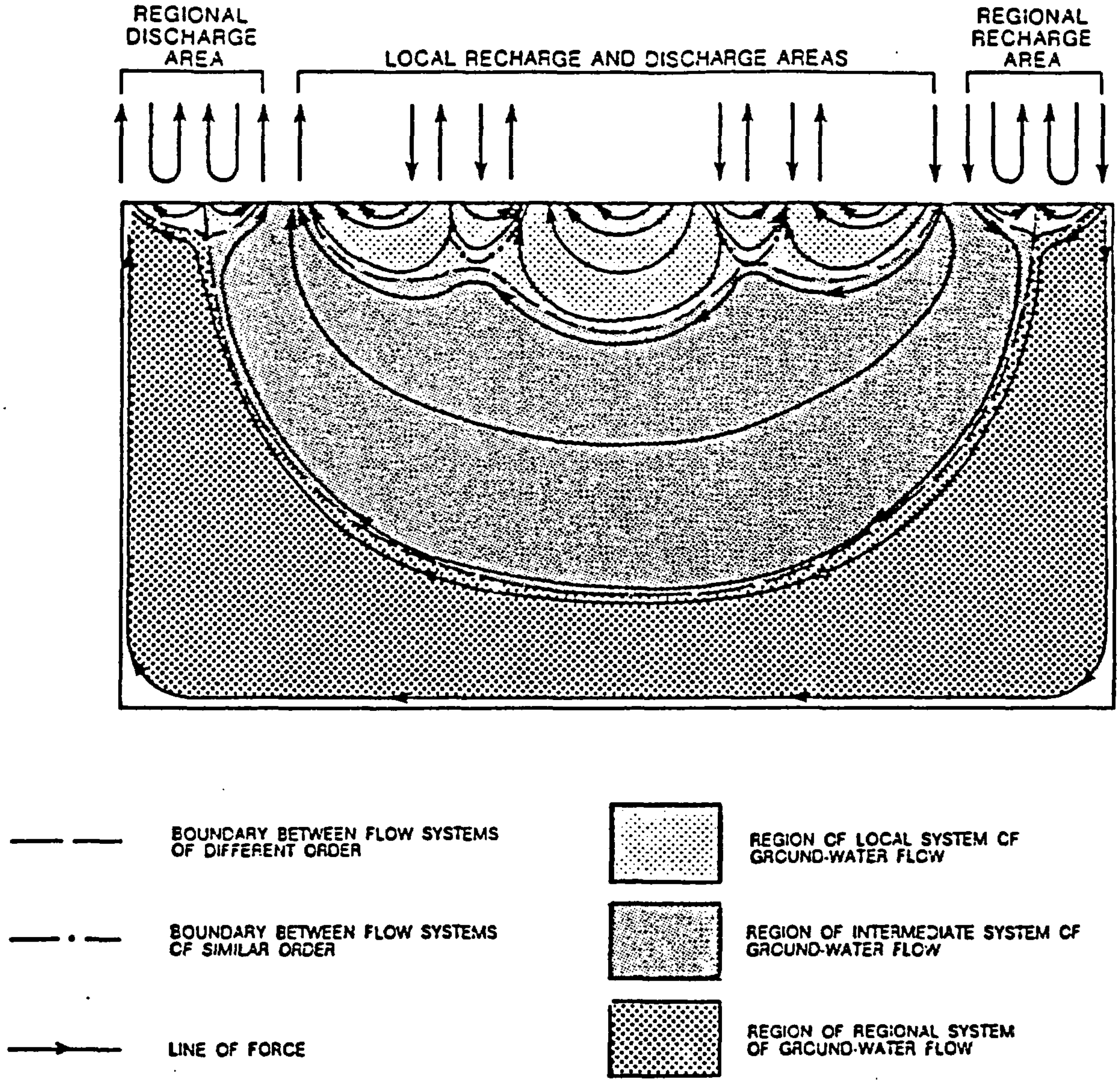
The upward component of groundwater flow that is indicated by higher heads in the deeper part of the saturated zone may be the result of the position of Yucca Mountain within the regional groundwater flow system. Simple models of groundwater basins consist of an area where recharge occurs (vertical flow is downward) and where discharge occurs (vertical flow is upward). Figure 4-7 illustrates that higher head can be observed at depth at Yucca Mountain, as indicated by the lines of force. In intermediate areas, flow is transitional from downward, to strictly horizontal, to upward (Figure 4-7). Although the Alkali Flat-Furnace Creek Ranch subbasin (of which Yucca Mountain is a part) is not simple, these concepts generally apply. Thus, Yucca Mountain may be in an area where local vertical flow can be either up or down (Waddell et al., 1984). Erickson and Waddell (1985) observed slight upward and downward movement among different intervals of the same drillhole (USW H-4). This upward and downward movement may also be due to differences in horizontal and vertical hydraulic conductivity beneath Yucca Mountain.

4.4 BOUNDARY CONDITIONS

4.4.1 Potentiometric Levels

A network of 27 test holes from which water level measurements of the saturated zone are obtained currently exists in the vicinity of Yucca Mountain as shown on Figure 4-8. Ten of the holes are monitored continuously and the remainder are measured periodically. Those being measured periodically are being converted to continuous monitoring. At least eight additional water table drill holes are planned by the DOE for future drilling to further define the gradient of the potentiometric surface. Based on available data, the DOE concludes that seasonal variations in water levels probably are a fraction of a meter, and no long-term trends have been discerned yet.

The monitored sites (most of those shown on Figure 4-8 are part of the monitoring program) include two geologic test holes, which were drilled as deep as 1,800 m to obtain data on lithology and stratigraphy; seven hydrologic test holes, in which pumping and other tests were performed to determine hydraulic characteristics of the formations, and 14 water-table holes, which were planned to penetrate the water table only a minimum amount. The water-table holes are aerially distributed to enable definition of the potentiometric surface at Yucca Mountain so that gradients and probable flow paths can be determined. The DOE has pointed out that the planned principal purpose of the drillholes



SOURCE: TOTH (1963)

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FIGURE 4-7
STANDARD THEORETICAL FLOW PATTERN AND BOUNDARIES BETWEEN DIFFERENT FLOW SYSTEMS

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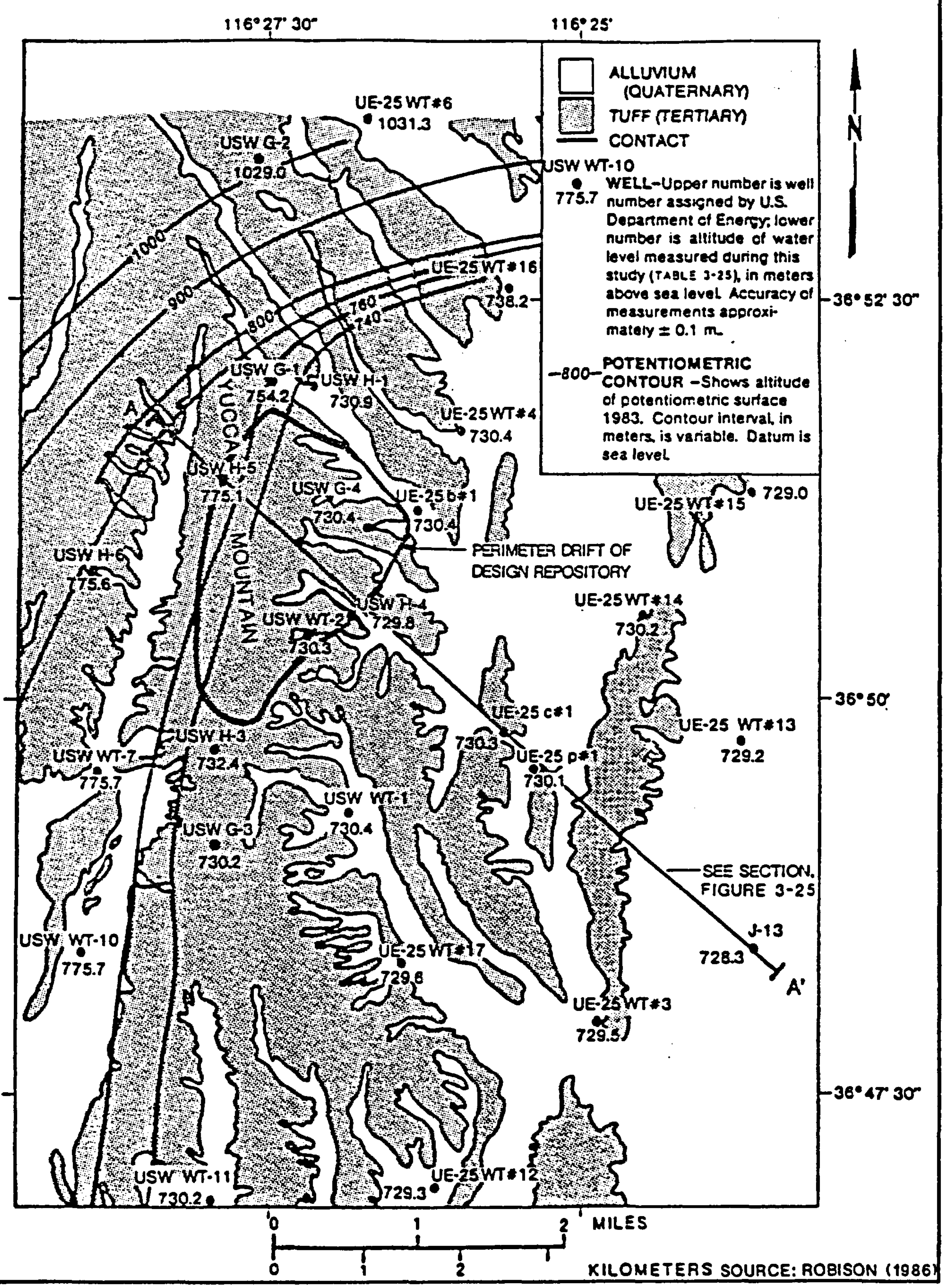

SOURCE: ROBISON (1986)

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FIGURE 4-8
PRELIMINARY COMPOSITE POTENTIOMETRIC-SURFACE MAP OF THE SATURATED ZONE

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now being observed was not for baseline monitoring and there was no formal selection process for their locations or depths. However, they are situated for general coverage of the upper part of the saturated zone. The construction of the geologic and hydrologic series of test holes was such that the first early measurements of head were composites. These composite heads reflect averages of all the members of the Paintbrush and Crater Flat Tuffs that were penetrated below the water table.

At Yucca Mountain, high accuracy and precision are needed in the measurement of water levels in wells. This accuracy and precision are required as in parts of the area the water table is nearly flat and calculation of the gradient is sensitive to small errors in water-level measurements. The DOE states that for comparison of levels among wells, true depths must be calculated, which involves a correction for hole deviation from vertical.

Measured head values used to construct the saturated zone potentiometric map (Figure 4-8) are mostly composite heads, reflecting heads similar to those in the zones of higher transmissivity. The figure was modified from Robison (1986), the most recent source of published data. However, the figure contains revisions based on resurveying in 1984 of land-surface altitudes at most of the well sites. The water levels range in altitude from about 1,030 to 730 m above sea level and generally represent water-table or unconfined conditions.

The potentiometric surface in the Yucca Mountain area occurs principally in members of the Paintbrush Tuff and underlying Crater Flat Tuff (the geologic units, not the hydrostratigraphic units defined for the unsaturated hydrologic zone). The slope of the potentiometric surface at Yucca Mountain, based on gradients indicated by the contours, is south to southeast, similar to the regional topographic slope.

The gradient in the north is relatively steep compared with that in the south. Water-level altitudes in Figure 4-8 are highest to the north at drillholes USW G-2 and UE-25 WT#6. It is not known whether the southward slope toward drillhole USW H-1 is uniform, or if there are abrupt flections. The cause for this steep slope is not yet known by the DOE. One possibilities that the southward movement of groundwater is inhibited in this area by a low-permeability formation, such as the tuffaceous beds of Calico Hills, or by a fault or other unknown structural control. Test drilling to resolve these and possible alternate hypotheses is presented in the CDSCP.

West of the crest of Yucca Mountain, in drillholes USW H-6, USW WT-7, and USW WT-10 and also in USW H-5 on the crest, the water levels are about 775 m above sea level. Water levels are as much as 45 m lower at drillholes USW G-3 and USW H-3, just east of drillhole USW WT-7. A fault in Solitario Canyon may itself be poorly permeable and restrict eastward movement of groundwater, or the fault may juxtapose permeable zones against less permeable zones and thereby restrict movement. Pumping tests in existing or proposed drillholes are expected to be used by the DOE to determine the hydraulic effects of the fault.[4]

From the eastern edge and southern end of Yucca Mountain to western Jackass Flats, the potentiometric surface ranges from about 728 to 720 m in altitude with a general southeastward slope (Figure 4-8 and Robison, 1986). As previously stated, significant vertical hydraulic gradients have been observed by the DOE in only a few drillholes. In drillhole UE-25p#1, the head in Paleozoic carbonate rocks that occur below a depth of 1.2 km is about 19 m higher than that observed in the shallow zone. In drillhole USW H-1 the head is about 54 m higher in the older tuffs of Tertiary age, at a depth of 1.8 km. Preliminary data from drillhole USW H-3 suggest that the head below 0.8 km (Tram Member of Crater Flat Tuff) is about 40 m higher. These higher heads occur only within or below intervals of low permeability. Semipermanent packers are installed in lower sections of several drillholes (UE-25b#1, USW H-3, USW H-4, USW H-5, and USW H-6) to enable comparison of water levels above and below the packers. Except in drillhole USW H-3, vertical differences of head within the Paintbrush and Crater Flat tuffs have been less than a meter.

Hydrographs of water-level data have not been presented by the DOE. The DOE states that groundwater levels are not expected to show short-term or seasonal fluctuations that can be correlated with precipitation. The DOE believes there will be no fluctuations because of extremely low rates of net

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[4] NRC Comment #13 - Site Saturated Zone Groundwater Flow System - (p. 25)
Activities presented for the study - Characterization of the Site Saturated Zone Groundwater Flow System - do not appear to be adequate for characterizing saturated zone hydrologic boundary conditions, flow directions and magnitudes. The study to characterize the saturated zone should contain activities for addressing the influence of faults within and east of the repository block on flow directions and magnitudes. In addition, the study should be integrated with the geophysical program and the systematic drilling program for geologic characterization.

infiltration and recharge attributable to local precipitation, the great depths to the water table, and groundwater travel times through the unsaturated zone that may be many thousands of years.

4.4.2 Recharge, Discharge, and Leakage

The DOE has estimated recharge to the saturated zone and the deep aquifers within the region surrounding Yucca Mountain. As at all sites, the actual value of recharge at Yucca Mountain depends on site-specific, local microclimatic, soil, vegetative, topographic, and hydrogeologic conditions. Wilson (1985) reviewed available site and regional hydrogeologic data in order to set conservative upper limits on the present, net vertically downward moisture flux below the repository horizon at Yucca Mountain and on the present rate of net recharge to the saturated zone in the vicinity of Yucca Mountain. Wilson (1985) concluded (1) that the liquid-water percolation flux, directed vertically downward in the matrix of the TSw unit below the repository horizon, probably is less than 0.2 mm/yr and (2) that the aerially averaged rate of net recharge to the saturated zone in the vicinity of Yucca Mountain probably is less than 0.5 mm/yr. Wilson (1985) considered a number of processes, such as upward water-vapor flow in the fractures of the TSw unit at the repository horizon. However, the DOE has concluded that these upper bounds on percolation and recharge fluxes must be regarded as preliminary estimates which have as-yet-unknown limits of uncertainty. These estimates are expected to be refined using data obtained from borehole monitoring of ambient hydrologic conditions within the unsaturated zone, from the surface-based infiltration experiments, and from the in situ measurements and experiments within the exploratory shaft, as described in the CDSCP.

4.5 GROUNDWATER TRAVEL TIME

Issue 1.6 of the issues hierarchy addresses the performance objective defined in 10 CFR 60.113(a)(2): "The geologic repository shall be located so 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...". Based on the proposed amendments (NRC, 1986a) to 10 CFR Part 60, the accessible environment is located beyond 5 km from the outer boundary of the repository underground facility. The following discussion addresses this issue, focusing on that portion of the hydrogeologic system extending from the surface of the water table beneath the repository to the accessible environment. The pre-waste-emplacement groundwater travel time from the disturbed zone to the water table was discussed in Chapter 3.

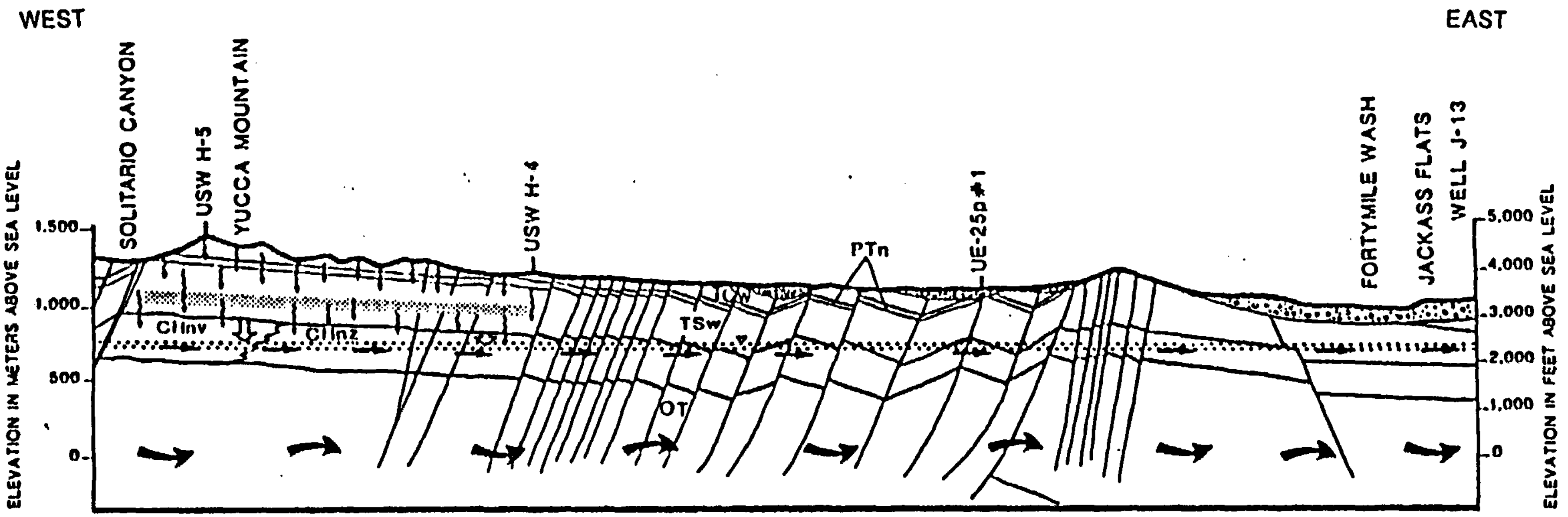
The components of the saturated pathway which must be considered include: (1) the hydraulic properties of the formations through which the water will flow; (2) the present hydrologic conditions in the vicinity of the proposed repository; and (3) the locations and lengths of the flow paths between the disturbed zone and the accessible environment. The DOE states that the data and information required to assess the influences of these components on groundwater velocity and travel times are presently limited and will be supplemented by hydrologic investigations discussed in the CDSCP. Therefore, these are preliminary estimates of groundwater velocities and travel times.

Figure 4-9 presents the current conceptual model of the groundwater flow system at Yucca Mountain. This model considers water moving downward beneath the repository in the unsaturated zone until it reaches the water table. Once it reaches the water table, the flow in the saturated zone is generally horizontal to the accessible environment in a direction controlled by both the hydraulic gradient and the properties of the fractured medium. The DOE expects that some directional variability of groundwater flow may be induced by the anisotropy of the fractured rock matrix. The travel time estimates presented below are based on these concepts. As more data becomes available to the DOE and understanding of the system improves, the model will be modified, and the resulting travel time estimates adjusted accordingly.

4.5.1 Travel Time Estimates in the Saturated Zone

For the saturated zone, the DOE assumes that the flow path extends from the eastern edge of the primary repository area southeastward for 5 km to the accessible environment (see Figures 4-8 and 4-9) through the tuffaceous beds of Calico Hills and the welded Topopah Spring Member or the welded Crater Flat Tuff (Prow Pass or Bullfrog Member). Estimates for groundwater travel times along this travel path have been made using the following assumptions (DOE, 1986):

1. Darcian flow applies;
2. Flow paths are parallel to the hydraulic gradient and are nearly horizontal;



▨	ALLUVIUM & TIMBER MOUNTAIN TUFF
▨	DESIGN REPOSITORY (THICKNESS EXAGGERATED)
∵▽∵	WATER TABLE
⌇⌇⌇⌇	FLUX THROUGH THE UNSATURATED ZONE
⇩	UNSATURATED-ZONE FLOW PATHS USED FOR TRAVEL TIME CALCULATIONS
→	SATURATED-ZONE FLOW PATH FOR WATER THAT HAS PASSED THROUGH THE REPOSITORY LEVEL
➔	DEEP SATURATED-ZONE FLOW PATHS FOR WATER THAT HAS NOT PASSED THROUGH THE REPOSITORY LEVEL

TCw	TIVA CANYON WELDED UNIT
PTn	PAINTBRUSH NONWELDED UNIT
TSw	TOPOPAH SPRING WELDED UNIT
CHnv	CALICO HILLS NONWELDED VITRIC UNIT
CHnz	CALICO HILL NONWELDED ZEOLITIC UNIT
OT	OLDER TUFF UNIT

0 0.5 1 MILES
0 0.5 1 KILOMETERS

DIAGRAM IS FROM SOLITARIO CANYON NORTHWEST OF THE SITE, TO WELL J-13 IN JACKASS FLATS

SOURCE: SCOTT AND BONK (1984)

Water, Waste & Land, Inc.

FIGURE 4-9
CONCEPTUAL HYDROGEOLOGIC FLOW MODEL

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3. The water-level measurements shown in Figure 4-8 (Robison, 1986) provide a reasonable estimate for the hydraulic gradient along the flow path;
4. The system is isotropic within each unit, and hydraulic conductivity values obtained from hydraulic tests of wells in the southeastern part of the Yucca Mountain area are representative of the values along the flow path; and
5. Calculated effective porosities from Sinnock et al. (1984) are of a magnitude that will tend to result in minimum travel times calculated for flow in the saturated tuffaceous beds of Calico Hills.

The hydraulic gradient has been estimated using water-level altitudes of 730.4 m at drillhole UE-25b#1 and 728.3 m at well J-13. An examination of the data for well UE-25p#1 (Craig and Robison, 1984) suggests that the water table is located approximately at the interface between the Calico Hills and the Topopah Spring units at this point (approximately 3,000 m from both the edge of the repository and well J-13). Using the principle of conservation of mass, hydraulic gradients have been estimated for each of the units as shown in Table 4-2. The DOE considers that uncertainties in these estimates include the following components:

(1) With very low gradients, small errors in the measurements of water levels can have significant effects on the value of the gradient;

(2) The measured water level at well J-13 could be expected to be lower than the static water level because of pumping, thereby resulting in a steeper estimated gradient; and

(3) Vertical components of flow may be present.

Because vertical flow would have the effect of lengthening the flow path, the assumption of horizontal flow probably is conservative, although Waddell et al. (1984) indicate the controls on vertical and horizontal flow at Yucca Mountain are variable and generally unknown.

Table 4-2 shows these values and provides estimates for travel times through the Calico Hills and the Topopah Springs units. On the basis of these estimates, the cumulative travel time through the saturated zone is about 172 yr. This value is different from that presented in DOE (1986), due to the use of well UE-25b#1 instead of USW H-4; the former was chosen in this analysis as

TABLE 4-2

ESTIMATES FOR GROUNDWATER TRAVEL TIMES THROUGH THE SATURATED ZONE

Parameter	Unit	
	Tuffaceous beds of Calico Hills	Topopah Spring Member
Length of path (m)	3,000	2,000
Hydraulic conductivity (m/hr)[a]	69	365
Hydraulic gradient[b]	5.9×10^{-4}	1.1×10^{-4}
Darcy velocity (m/yr)[c]	4.1×10^{-2}	4.0×10^{-2}
Calculated bulk effective fracture porosity[d]	4×10^{-4}	2.8×10^{-3}
Particle velocity (m/yr)[e]	103	14
Travel time (yr)[f]	29	143

[a] Hydraulic conductivity for Calico Hills from Lahoud et al. (1984) and Thordarson (1983); Topopah Spring from Thordarson (1983).

[b] Based on water levels at drillhole UE-25 b#1 and at well J-13 (see Figure 4-8). The estimates for the hydraulic gradient for each of the units has been based on conservation of mass between drillhole UE-25b#1 and well J-13.

[c] Darcy velocity = (hydraulic conductivity) x (hydraulic gradient).

[d] Data from Sinnock et al. (1984).

[e] Particle velocity = (Darcy velocity)/(bulk effective porosity).

[f] Travel time = (length of path)/(particle velocity).

being more representative of regional trends in the hydraulic gradient (Figure 4-8).

The DOE believes this estimate of travel time to be conservative, based on the assumptions mentioned above and on the fracture effective porosities reported by Sinnock et al. (1984). These effective porosities were calculated by multiplying the fracture density from Scott et al. (1983) by the effective aperture calculated from a relationship provided by Freeze and Cherry (1979). The resulting effective porosities are considered to be reasonable estimates for fracture flow in the saturated zone. However, empirical estimates of saturated effective porosity for both matrix and fracture flow range from 8 to 12 percent for the Topopah Spring welded unit (Sinnock et al., 1984); 2.7 to 8.7 percent for Topopah Spring Member (Thordarson, 1983); and 20 to 30 percent for the Calico Hills vitric unit (Sinnock et al., 1984). Use of more realistic (less conservative) values of effective porosity would be likely to lead to a saturated groundwater travel time at least ten times greater (i.e., approximately 1,700 yr) than that indicated by Table 4-2.

4.5.2 Factors Affecting Travel Times and Flow Paths

The groundwater travel times estimated for the saturated and unsaturated zones at Yucca Mountain are presently based on Darcy's law and Richards' equation, respectively. However, the DOE believes that groundwater flow through fractured unsaturated media is in fact dominated by the matrix hydraulic conductivity. Water moving through a fractured system may travel into and out of the matrix from the fractures as it moves down gradient (DOE, 1986). This is due to the differences in matrix, osmotic, thermal, and pressure potentials across the fracture-matrix interface. This leads to a lengthening of the groundwater travel path for individual groundwater molecules, thereby increasing groundwater travel times.

Other factors may affect groundwater travel time, including the existence of faults or impermeable zones along the travel path, the vertical movement of water in the saturated zone, and the upward movement of moisture in the unsaturated zone. The DOE is uncertain whether some or all of these mechanisms exist along the travel path at this time. Efforts will be made during site characterization to determine the existence of these and other features and also to estimate the effect of these on pre-waste-emplacement groundwater travel times.[5]

The possible effects of thermal gradients on the groundwater flow system at Yucca Mountain are also unknown to the DOE at this time. However, as described in Chapter 2, little information exists on thermal gradients in the saturated zone. The information available is from isolated locations that give little indication of the thermal gradient in the vicinity of Yucca Mountain. Such information will be collected during site characterization, and its effect on the groundwater flow system will be evaluated at that time.

4.5.3 Groundwater Flow Modeling Results

Groundwater flow modeling studies of the saturated zone at Yucca Mountain and vicinity have been conducted by Waddell (1982), Czarnecki and Waddell (1984), Rice (1984), and Czarnecki (1985). These two-dimensional models have considerable areal variation in hydrologic properties, but vertically combine the properties of hydrogeologic units. Results from a three-dimensional steady-state groundwater flow model as outlined in the CDSCP will be used to gain a better understanding of the flow system. The groundwater flow modeling performed thus far has been only for regional and subregional saturated systems.

The subregional model of Czarnecki and Waddell (1984) describes groundwater flux through Yucca Mountain as part of the overall subregional flow. At this level of discretization, adequate resolution of the flow beneath Yucca Mountain is uncertain. However, results of this model showed that vectors of simulated vertically-integrated groundwater flux vary in direction from southeast to south, through and away from the Yucca Mountain repository

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[5] USGS Comment - Overview of the Geohydrology Program (p. 178)
The DOE states within the CDSCP that "Hydrologic modeling produces the velocity field essential for defining flow paths and computing ground water travel time. Such modeling requires sufficiently detailed knowledge of the hydrologic framework and the three-dimensional distribution of potential values and conductivity properties." A velocity field defined in this way only give some mean picture of actual flow paths and values. Water seeks to flow in the path where it loses least energy. Thus, a single preferred large scale flow path from the repository to the accessible environment may be made up of a series of connected and non-connected fractures and permeable zones with internal velocities orders of magnitude greater than a local modeled average of the area. Therefore, hydrologic modeling probably does not define velocities and flow paths accurately enough to satisfy the design criteria.

block, and have a magnitude of about 2 to 3 m^2/d. As stated in Chapter 2, this is a unit flux. These model-derived fluxes result from a parameter-estimation approach, in which an estimated transmissivity of 3,340 m^2/d was applied. This value of transmissivity is somewhat greater than obtained from pumping tests, however, it is not outside the expected range of agreement.

4.5.4 Hydrochemistry of the Saturated Zone

Analyses of groundwater from drillholes that penetrate the host rock where it is below the water table and surrounding units in the area of the exploration block indicate that they are principally sodium bicarbonate water (Benson et al., 1983; Ogard and Kerrisk, 1984) with low contents of total dissolved solids (200 to 400 mg/L). However, water from the carbonate aquifer (drillhole UE-25p#1) contains over 1000 mg/L total dissolved solids. These results indicate that principle water chemistry is derived by reaction with tuffaceous rocks (Waddell et al., 1984).

Tables 4-3 and 4-4 summarize the geochemical data reported on groundwater samples from Yucca Mountain and its vicinity.[6] The analytical techniques and sampling procedures by which these data were obtained are reported by Ogard and Kerrisk (1984). The locations of these wells are shown on Figure 4-10.

Figure 4-11 presents stiff diagrams of the major-ion data from six wells on or immediately adjacent to the site, which sample water from the tuff formations. The stiff diagrams illustrate that sodium bicarbonate water prevails throughout the area.

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[6] USGS Comment - Sampling of Water Table Wells (p. 118)
Activities delineated within the CDSCP propose drilling additional water table (WT) holes and sampling existing WT boreholes. Chemical and isotopic analyses are proposed for new holes after geophysical logging. These wells (both existing and new) should be sampled for complete chemical and isotopic analyses. This is an item that should be given extremely high priority, since they provide the only presently available access to the unsaturated-saturated zone boundary. In addition, the holes should be packed off a short distance above the water table and pumped for gas sample collection. The gas samples should be analyzed for composition and for C-13, C-14, deuterium, and O-18. The information gained would appear to be critical to establishing boundary conditions for both unsaturated and saturated zone hydrochemical modeling.

TABLE 4-3

ELEMENT CONCENTRATIONS IN GROUNDWATER FROM THE VICINITY OF YUCCA MOUNTAIN

Well[b]	Field pH	concentrations (mg/L)								
		Ca	Mg	Na	K	Li	Fe	Mn	Al	Si
USW VH-1[c]	7.5	10	1.5	80	1.9	0.090	--[d]	--	--	23
USW H-6	7.4	5.5	0.22	74	2.1	0.10	0.12	0.04	0.12	20.0
USW H-3	9.4	0.8	0.01	124	1.5	0.22	0.13	0.01	0.51	16.9
USW H-5	7.1	1.1	0.03	54	2.3	0.04	0.01	--	0.17	17.4
USW G-4	7.1	9.2	0.15	56	2.5	0.08	0.04	0.02	0.02	19.6
USW H-1[c]	7.5	6.2	<0.1	51	1.6	0.04	--	--	--	19
USW H-4	7.4	10.8	0.19	84	2.6	0.16	0.03	0.005	0.04	25.9
UE-25b#1	7.7	19.7	0.68	56	3.3	0.28	0.04	0.004	0.03	31.5
UE-25b#1[e]	7.2	18.4	0.68	46	2.5	0.30	0.69	0.36	0.04	28.7
UE-25b#1[f]	7.3	17.9	0.66	37	3.0	0.17	0.08	0.07	0.06	28.8
J-13	6.9	11.5	1.76	45	5.3	0.06	0.04	0.001	0.03	30.0
UE-29a#2	7.0	11.1	0.34	51	1.2	0.10	0.05	0.03	0.04	25.8
J-12[c]	7.1	14	2.1	38	5.1	-	-	-	-	25
UE-25p#1[g]	6.7	87.8	31.9	171	13.4	0.32	<0.1	<0.01	0.1	30

[a] Concentrations from Ogard and Kerrisk (1984) unless otherwise noted. All samples are integral water samples unless otherwise noted.
[b] See Figure 4-10 for locations.
[c] Data from Benson et al. (1983).
[d] --indicates the element was not detected.
[e] Bullfrog zone, 4th day of pumping.
[f] Bullfrog zone, 28th day of pumping.
[g] From dolomite aquifer.

TABLE 4-4

ANION CONCENTRATIONS AND OTHER MEASUREMENTS FOR GROUNDWATER FROM THE VICINITY OF YUCCA MOUNTAIN

	Concentration[a] (mg/L)								
Well[b]	F^-	Cl^-	SO_4^{2-}	HCO_3^-	NO_2^-	NO_3^-	O_2	Detergent	Eh[c]
USW VH-1[d]	2.7	11	44	167	--	--	--	--	--
USW H-6	4.1	7.7	27.5	--	--[e]	5.3	5.6	--	395
USW H-3	5.4	8.3	31.2	245	<0.10	0.2	<0.1	<0.02	-123
USW H-5	1.3	5.7	14.6	--	--	8.6	6.3	<0.005	353
USW G-4	2.4	5.5	15.7	--	--	5.5	6.4	--	402
USW H-1[d]	1.0	5.8	19	122	--	--	--	--	--
USW H-4	4.5	6.2	23.9	--	--	4.7	5.8	>2	216
UE-25b#1	1.2	7.1	20.6	--	--	0.6	1.8	--	220
UE-25b#1[f]	1.5	9.8	21.0	--	0.5	2.2	<0.1	2.7	-18
UE-25b#1[g]	1.2	6.6	20.3	--	--	4.5	1.8	0.02	160
J-13	2.1	6.4	18.1	143	--	10.1	5.7	--	--
UE-29a#2	0.56	8.3	22.7	--	--	18.7	5.7	--	305
J-12[d]	2.1	7.3	22	119	--	--	--	--	--
UE-25p#1[h]	3.5	37	129	698	--	<0.1	--	<0.2	360

[a] Concentrations from Ogard and Kerrisk (1984) unless otherwise noted. All samples are integral water samples unless otherwise noted.

[b] See Figure 4-10 for locations.

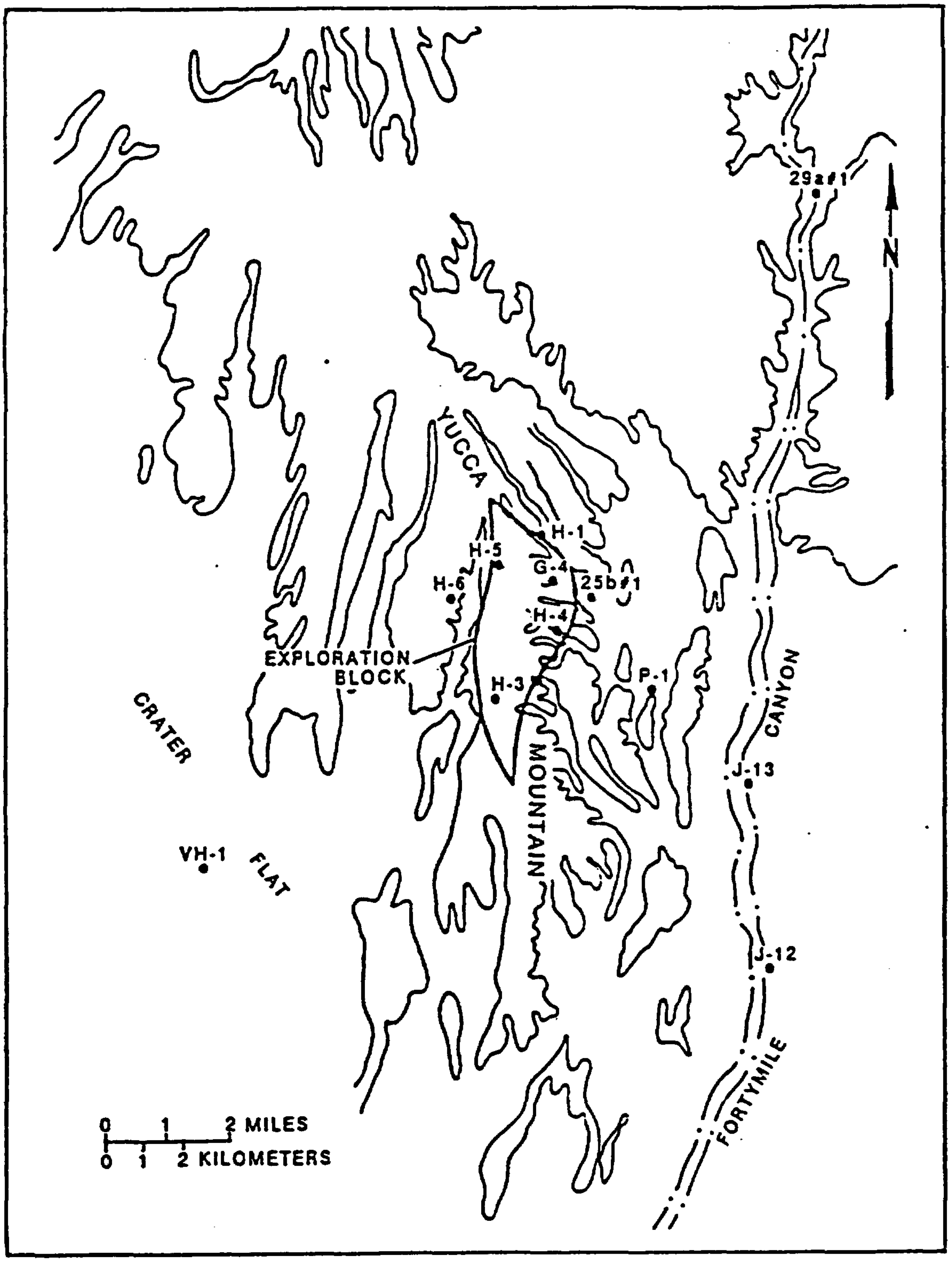
[c] Data from Benson et al. (1983).

[d] --indicates the element was not detected.

[e] Bullfrog zone, 4th day of pumping.

[f] Bullfrog zone, 28th day of pumping.

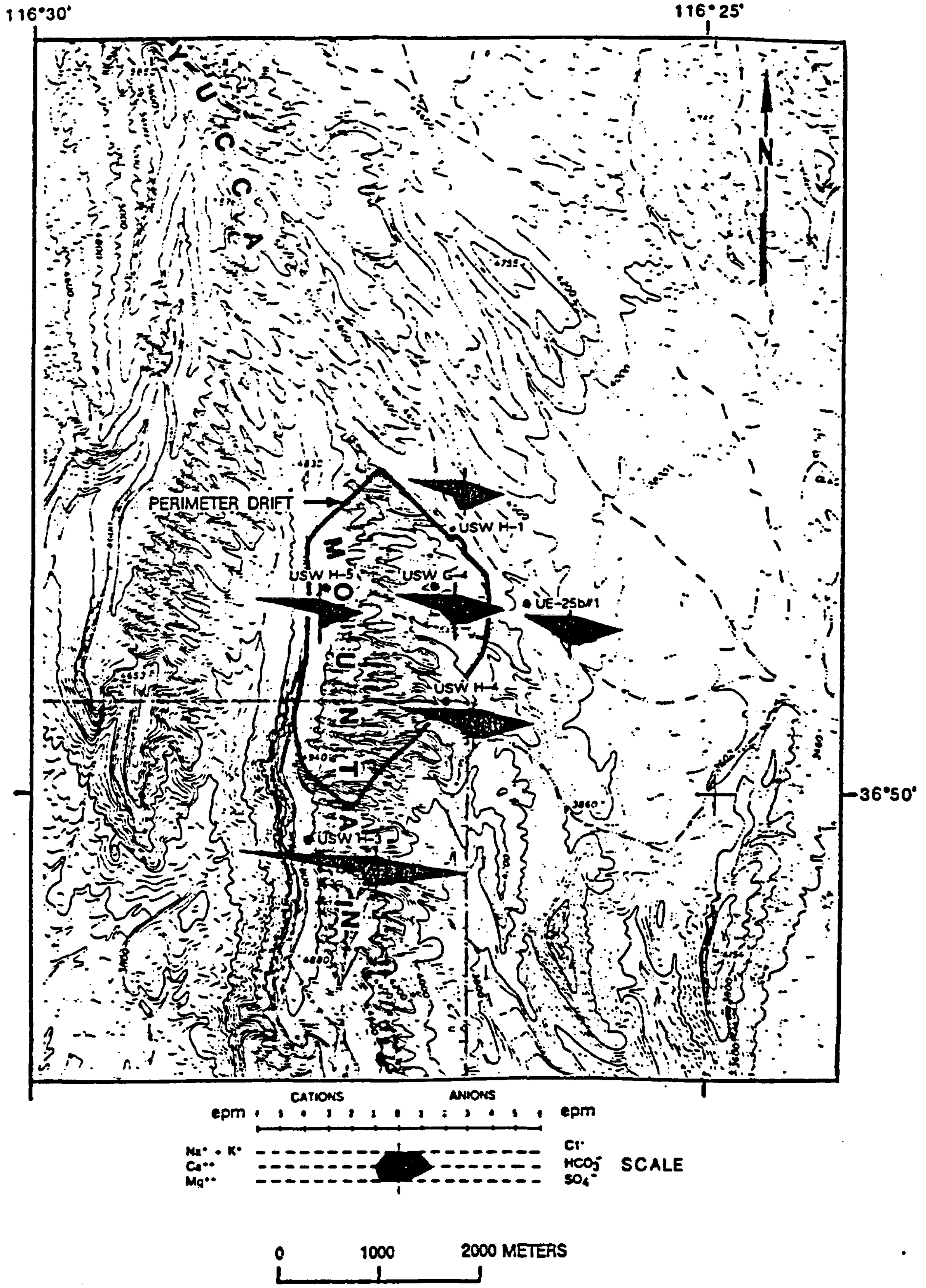
[g] From dolomite aquifer.



(THE NAMES OF DRILLHOLES HAVE BEEN SHORTENED FOR CLARITY: FOR EXAMPLE DRILLHOLE USW H-6 IS LISTED AS H-6 AND DRILLHOLE UE-25P#1 AS P-1, ETC.)

SOURCE: OGARD AND KERRISK (1984)

Water, Waste & Land, Inc.	FIGURE 4-10 SELECTED DRILLHOLE AND WELL LOCATIONS ON AND NEAR YUCCA MOUNTAIN EXPLORATION BLOCK	Date: SEPT 1988 Project: 4001



NOTE: STIFF DIAGRAMS INDICATE THE COMPOSITION OF SIX SAMPLES

SOURCE: DOE (1988)

Water, Waste & Land, Inc.

FIGURE 4-11

GEOCHEMICAL FACIES IN THE TUFF FORMATION AROUND YUCCA MOUNTAIN

Date: SEPT 1988

Project: 4001

4.5.4.1 Isotopic Data of the Saturated Zone

Environmental isotopic data are available for groundwater samples from wells in the tuff aquifers beneath Yucca Mountain (Benson et al., 1983; Benson and Mckinley, 1985). Both carbon-14 activity and "uncorrected, apparent radiocarbon age" of the samples were reported. In areas where carbonate minerals may contribute significant amounts of carbon, the DOE has stated that it can be misleading to use these apparent ages in interpreting a flow system. Therefore, such apparent ages, which can be off by more than a factor of two, have been omitted in Table 4-5. Since corrected ages (determined by modeling the initial radiocarbon activity of the water; e.g., IAEA, 1983) are not available, only the sample activity measurements were used. The DOE considers measured carbon-14 activities to be relatively homogeneous for an area this size, particularly when accounting for sampling, sample preparation, and analytical uncertainties. Table 4-5 presents results from samples obtained from the two southernmost drillholes (USW H-3 and USW H-4). These have lower carbon-14 content (mean value 11.1 percent modern carbon) than samples from the other, more northerly drillhole (mean value 20.1 percent modern carbon). The DOE believes that the significance of this difference cannot be fully assessed without carbon-14 modeling. Nevertheless, groundwater residence times of the southern samples may be on the order of 5,000 yr greater than the northern samples. The DOE states that because significant amounts of carbonate minerals do not occur in the tuff or in tuffaceous valley fill with which these groundwaters have come into contact, minimal radiocarbon dilution may have occurred from such contact and apparent ages may be more realistic than at other sites.

The δ carbon-13 ($\delta^{13}C$) values may show a spatial variability similar to those of the carbon-14. The values are consistent with recharge under very poorly vegetated conditions. The $\delta^{13}C$ value reported for sample USW H-3 is above the mean atmospheric value for carbon dioxide. The explanation of this unusual phenomenon could shed light on the differences in radiocarbon content between this sample and the northern ones. The $\delta^{13}C$ values below about -10 parts per thousand in dilute waters suggest that little carbonate rock/water and soil gas/water exchange has occurred.

The DOE states that the three tritium values of <62 TU in Table 4-5 serve only to indicate that no large amounts of bomb-test tritium have reached the aquifer at those points. The other samples, which were analyzed by a more

TABLE 4-5

ENVIRONMENTAL ISOTOPE DATA FOR GROUNDWATER SAMPLES FROM THE TUFF AQUIFERS UNDER THE EXPLORATORY BLOCK AND ITS IMMEDIATE AREA[a]

Well designation[b]	Collection date	δD (o/oo SMOW)[c]	$\delta^{18}O$ (o/oo SMOW)[c]	$\delta^{13}C$ (o/oo PDB)[d]	^{14}C (pmc)[e]	HTO (TU)[f]
UE-25b#1	08/07/81	-99.5	-13.4	-10.7	--[g]	--
UE-25b#1	09/09/81	-101.0	-13.4	-10.7	16.7	<62.0
UE-25b#1	07/20/82	-99.5	-13.5	-8.6	18.9	0.6
USW G-4	12/09/82	-103.0	-13.8	-9.1	22.0	--
USW H-1	10/20/80	-103.0	-13.4	--	19.9	<6.0
USW H-1	12/08/80	-101.0	-13.5	-11.4	23.9	<6.0
USW H-3	03/14/84	-101.0	-13.9	-4.9	10.5	0.6
USW H-4	05/17/82	-104.0	-14.0	-7.4	11.8	<3.0
USW H-5	07/03/82	-102.0	-13.6	-10.3	18.2	<62.0
USW H-5	07/26/82	-102.0	-13.6	-10.3	21.4	<62.0

[a] Source: Benson and McKinley (1985).

[b] Well locations indicated in Figure 4-10.

[c] δD_3 and $\delta^{18}O$ are reported in parts per thousand relative to Standard Mean Ocean Water (SMOW) standard.

[d] $\delta^{13}C$ is reported in parts per thousand relative to Peedee belemnite carbonate (PDB) standard.

[e] ^{14}C activity is reported as a percent of the modern carbon (pmc) standard.

[f] T is reported in tritium units (TU).

[g] --Indicates no data.

sensitive method to give a more precise result, are consistent with trace tritium contamination of samples of very old water (very old, in the context of tritium dating implies several hundred years or more). Such contamination is common and not unexpected at Yucca Mountain.

The deuterium and oxygen-18 data in Table 4-5 plot on and below the meteoric line of Craig (1961), occurring between a deuterium excess of +10 (mean continental meteoric water) to +5. Such a small deviation from the world-wide average meteoric deuterium excess is within expected local continental variation. The water is extremely depleted in heavy isotopes of both oxygen and hydrogen, consistent with high altitude, cold (winter) continental recharge or snow-melt. No evaporative enrichment or thermal alteration is observed.

4.5.4.2 Hydrochemical Confirmation of Groundwater Behavior

This section presents information concerning hydrochemical evaluation of the groundwater system and the question of whether the site will meet the performance objective for pre-waste emplacement groundwater travel time as required by 10 CFR 60.113(a)(2) (Issue 1.6). Summaries of the hydrochemical characteristics of the water in the saturated zone in the Yucca Mountain area, of the hydrochemical mechanisms controlling these characteristics, and of the hydrochemical evidence for groundwater origin, aquifer mixing and groundwater residence time are presented in Section 2.8 for the regional hydrogeologic study area and in this section for the site saturated system. Only limited data exist in the immediate vicinity of Yucca Mountain, and those data tend to be mainly radiocarbon data.

Kerrisk (1987) has pointed out that at Yucca Mountain, gaseous CO_2 from the unsaturated zone may be added to or exchanged with the carbonate of the saturated zone water. This process could lead to apparent ages that are younger than the true ages of the water in the saturated zone.

An accurate knowledge of initial carbon-14 activity is less important in calculating relative groundwater ages or velocities than it is in determining absolute chronologies. Groundwater velocities can be estimated by dividing the distance between two points along a hydrologic flow line by the carbon-14 age difference of the water at the two points. Consistent errors in estimating initial activity tend to cancel, resulting in relative ages which are more accurate than are the individual absolute ages. This is not the case when calculating the velocity of water to a point where the carbon-14 age is known from the assumed point of present day recharge (absolute age zero). Mixing (i.e., the two points are not actually on the same hydrodynamic flow line or the line has moved during the transit of the parcel of water) is also not considered in this calculation. These two difficulties apply to the results of Claassen (1985) who states, "For example, assume recharge near the head of Fortymile Canyon occurred 17,000 years ago and flowed to the lower end of the Canyon, where it is sampled. The velocity that is calculated, 7 m/yr, must be a maximum. Because recharge may occur anywhere but not necessarily everywhere along surface drainageways, no probably minimum velocity can be calculated. The absence of water older than about (apparent age) 10,000 yr. B.P. even near the head of Fortymile Canyon, would favor velocities slower than 4 m/yr." The planned use of initial carbon-14 modeling and relative dating along flow paths to resolve apparent difficulties of interpretation is described by the DOE in the CDSCP.

4.6 PALEOHYDROLOGY

A summary of the paleohydrology of the south-central Great Basin, including Yucca Mountain, is presented in Section 2.9. In this section, the discussion is limited to those past and probably future hydrologic conditions that may directly affect a repository at Yucca Mountain.

Bish and Vaniman (1985) noted that nonwelded glass occurs both above and below the welded zone in the Topopah Spring Member of the Paintbrush Tuff. Bish and Vaniman (1985) state "the lower nonwelded vitric zone thins and disappears to the east where stratigraphic dip and structural displacements bring the basal Topopah Spring glassy zone closer to the static-water level. The vitric nonwelded material may have important paleohydrologic significance because the preservation of open shards and pumice made of nonwelded glass is rare below past water levels (Hoover, 1968)." Where present, the base of the lower nonwelded vitric tuff occurs about 80 to 100 m above the present water table. On the basis of mineralogy, Bish and Vaniman (1985) concluded, "The only apparent change in phase assemblage near the water table in Yucca Mountain is the alteration of vitric tuff of Calico Hills and lower Topopah Spring Member." The observations by Bish and Vaniman (1985) suggest that past water levels beneath Yucca Mountain may never have been more than 100 m higher than the modern water levels.

To help assess the implication in Bish and Vaniman (1985) that the lowest position of vitric nonwelded tuff might be related to a stand of a paleo-water table, the DOE has stated that a contour map of the base of the lower vitric nonwelded tuff (in both the Topopah Spring Member and in the tuffaceous beds of the Calico Hills) will be prepared and contrasted with the modern water table. If such a contour map indicates (1) a relatively smooth surface at the base of the vitric nonwelded tuff, (2) a surface that locally cross-cuts stratigraphic horizons in the tuffs, and (3) a surface that climbs sharply to the north as does the modern water table beneath Yucca Mountain[7], then it is possible that the porous nonwelded vitric tuffs have indeed been altered below a paleo-water table, as suggested by Bish and Vaniman (1985). Such a contour map would then presumably mark the stand of water table at the time or times of alteration of the tuffs. The occurrence of such a stand probably could not be dated, but might have occurred several million years ago. Even in the absence of a date for the alteration, the case of the nonwelded vitric tuff shown on Bish and Vaniman's (1985) cross sections is tens of meters to more than 100 m below the base of the proposed repository horizon. Thus, if the previously discussed work demonstrates the likelihood of a relationship of the paleo-water table to the lowest occurrence of vitric tuff, a possible maximum (though undated) water table stand would have been identified that is significantly lower than the repository horizon under consideration.

Czarnecki (1985) addressed the issue of possible past, and by implication, future pluvial-related water table rises beneath Yucca Mountain with a two-dimensional finite element groundwater flow model of the region. Czarnecki (1985) calculated a maximum increase in water table altitude of about 130 m beneath the site of the proposed repository. Inundation of any part of the planned repository would require a water table rise of more than 200 m. His analysis also suggests a past shortening by two-thirds of groundwater flow paths from Yucca Mountain to discharge areas in the southern Amargosa Desert. These discharge areas are still beyond the boundary of the accessible environment.

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[7] WWL Comment - Paleo-water Table
The DOE states that a contour map will be prepared to show the lower vitric nonwelded tuff. This contour map will be used to determine possible paleo-water table configurations. The surface defined in this contour map does not necessarily need to mimic the present water table beneath Yucca Mountain.

The DOE considers that the analysis by Czarnecki (1985) may be conservative for several reasons. A 100-percent increase in precipitation during pluvial periods was assumed. This resulted in a 15-fold increase in recharge from the modern rate (0.5 mm/yr) to about 8 mm/yr at Yucca Mountain. Czarnecki (1985) acknowledges that this recharge value, which was derived from the empirical Maxey-Eakin water-budget method, probably is high. Half of the calculated recharge flux in the model was applied directly east of the proposed repository site, along a segment of Fortymile Wash. This flux causes about three-quarters of the computed water table rise of 130 m. Czarnecki (1985) notes, however, that under a 100-percent increase in precipitation, large quantities of runoff might flow away from the area down Fortymile Wash and other drainageways. This would have the effect of decreasing the effective groundwater recharge to much less than the calculated values (Czarnecki, 1985).

Other considerations were noted by Czarnecki (1985) that might have resulted in a greater simulated water table rise. Recharge into Fortymile Wash was limited to the main stream channel near Yucca Mountain. If recharge had been included along the full length of Fortymile Wash and its distributors, then a greater water table rise would have been simulated.

Simulated development of discharge areas southeast of the town of Amargosa Valley helped to limit the water table rise beneath the primary repository area. If this discharge were decreased because of the possible existence of marsh deposits or eolian silts or because of a greatly decreased ratio of vertical hydraulic conductivity to horizontal hydraulic conductivity, then the simulated water table rise might be greater.

The model used by Czarnecki (1985) derived its parameters from a model presented in Czarnecki and Waddell (1984), which assumed that the groundwater system was in steady-state conditions. If the groundwater system was still equilibrating to recharge that may have occurred 10,000 to 20,000 years before present, then the values of transmissivity used in the model in Czarnecki (1985) might be too high. Large transmissivities used in recharge simulations would produce less water table rise than if smaller transmissivities were used. The DOE is planning extensive investigation to better quantify the parameters of the hydrologic system in the Yucca Mountain area. These parameters will be used to model the hydrologic system more effectively and any variations induced by climatic or tectonic changes. Plans for these studies are outlined in the CDSCP.

During pluvial periods of the Pleistocene, perched springs and seeps could have occurred along the flanks of Yucca Mountain and these might have resulted from recharge along the exposed up-dip portion of tuff units, with water moving down-dip to discharge sites along the flank of the mountain. No conclusive evidence for former springs has been observed, but additional investigations are planned by the DOE in the CDSCP.

Deposits along fault zones may provide additional evidence for changed hydrologic conditions. Along portions of the Bow Ridge fault, 1 km east of the eastern boundary of the proposed repository, Trench 14 has exposed deposits of carbonate, opal, and minor amounts of sepiolite (Vaniman et al., 1985; Taylor and Huckins, 1986; Veogele, 1986a,b). The origin of these deposits is under study, and the following hypotheses are being considered:

1. The deposits are the result of groundwater discharge along the fault, from the deep regional flow system and reflect former higher water levels, tectonic uplift of the deposits, or a combination of both.
2. The deposits are the result of discharge along the fault zone from a shallow groundwater flow system along the flank of Yucca Mountain.
3. The deposits are shallow soil features that resulted from rain water that moved downslope from the top of a nearby low hill, along the contact between the soil zone and bedrock and accumulated at the fault zone. The water would have evaporated slowly, leaving precipitates of the minerals that were dissolved in the water.

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