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April 7, 1986

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RS-NMS-85-009
Communication No. 45

U.S. Nuclear Regulatory Commission
Division of Waste Management
Geotechnical Branch
MS-623-SS
Washington, DC 20555

Attention: **Mr. Jeff Pohle, Project Officer**
Technical Assistance in Hydrogeology - Project B (RS-NMS-85-009)

Re: **NNWSI Conceptual Model Evaluation Report - Subtask 1.4**

Dear Mr. Pohle:

This cover letter transmits to the NRC staff the Conceptual Model Evaluation Report for NNWSI, Subtask 1.4 of Contract No. RS-NMS-85-009. This report has been prepared by the Mssrs. Lyle Davis and Tom Snipp and Dr. David McWhorter (Water, Waste, and Land), all members of the site team for NNWSI. The report has received a management and technical review by Mark Logsdon of Nuclear Waste Consultants.

As anticipated in earlier communications with the NRC staff, WWL proposes in this report to pursue several topics arising from the current conceptual models using numerical modeling. To date, the NNWSI site team has begun scoping these problems, including some modest effort at fine-tuning their current versions of the codes that will be used. Mr. Davis will be in Silver Spring on April 14 - 15 and again on April 21 - 23, 1986 for meetings called by the NRC Project Officer. Nuclear Waste Consultants and WWL consider that either or both of these times would be appropriate times for Mr. Davis to meet with the NNWSI Site leads to discuss the proposed work plans, so that WWL may begin the proposed analytical work in a timely fashion.

WM-RES
WM ~~Record File~~ D1021
NWCI

WM Project 10, 11, 16
Docket No.
PDR ✓
LPDR ✓ (B, N, S)

Distribution:
Pohle

(Return to WM, 623-SS) sac

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The submission of this letter report meets the contractual deliverable for Subtask 1.4 of Contract Number RS-NMS-85-009 and completes the NNWSI Conceptual Model Evaluation subtask requirements at this time. Per the terms of the contract, WWL/NWC will submit regular updates of this report.

If you have any questions concerning this report or related matters, please contact me immediately.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS, INC.

Mark J. Logsdon

Mark J. Logsdon, Project Manager

Att: NNWSI Conceptual Model Evaluations Report - Subtask 1.4

cc: US NRC - Director, NMSS (ATTN: PSB)
DWM (ATTN: Division Director) - 2
Barry Bromberg, Contract Administrator
WMGT (ATTN: Branch Chief)

M. Galloway, TTI
R. Knowlton, DBS

bc: L. Davis, WWL

Water, Waste & Land, Inc.
CONSULTING ENGINEERS & SCIENTISTS

RECEIVED
APR 0 1 1986

March 31, 1986 WWL #4001

Nuclear Waste Consultants
ATTN: Mark Logsdon
8341 South Sangre de Cristo Road, Suite 6
Littleton, Colorado 80217

Re: Subtask 1.4, Conceptual Model Evaluation
Letter Report for Contract NRC-02-85-009 (WWL #4001)
Technical Assistance in Hydrogeology - Project B - Analysis

Dear Mark:

This letter serves as our report for Subtask 1.4, Conceptual Model Evaluation, as required by our subcontract with Nuclear Waste Consultants. After your review of this report please forward it to Jeff Pohle at the U.S. Nuclear Regulatory Commission.

The letter report has been divided into the following sections:

5.0 LOCAL NUMERICAL MODELING

6.0 FUTURE CONDITIONS

7.0 AREAS OF UNCERTAINTY AND ADDITIONAL DATA NEEDS
- 7.1 REGIONAL MODEL
  - 7.1.1 Areas of Uncertainty
  - 7.1.2 Additional Data Needs
- 7.2 LOCAL MODEL

8.0 DETAILED WORK PLAN FOR NUMERICAL EVALUATION
- 8.1 SATURATED (REGIONAL) ZONE MODELING
- 8.2 UNSATURATED (LOCAL ZONE MODELING
  - 8.2.1 Capillary Barrier Analyses
  - 8.2.2 Fracture/Matrix Flow Analysis
  - 8.2.3 Persistence of Water Flow in Fractures Affected by Air in the Matrix
  - 8.2.4 Vapor Transport

If you have questions or if we can in any way be of assistance to you during your review of this document, do not hesitate to contact us.

Sincerely,

WATER, WASTE & LAND, INC.

Lyle A Davis

Lyle A. Davis, P.E.
Project Manager

LAD:dml

1.0 INTRODUCTION

Conceptual models which have been presented for the Yucca Mountain site and the larger area surrounding Yucca Mountain are evaluated for proposed ground water flow systems and radionuclide transport pathways. The regional models which were evaluated encompass a large area surrounding the proposed repository site with some models including portions of Southern Nevada and adjacent parts of California. The conceptual models evaluated for the local (Yucca Mountain) scale are primarily concerned with the unsaturated zone above and below the repository.

A review of numerical modeling, both for the regional and local conceptual models is presented. The numerical models reviewed for the regional conceptual model consists of two-dimensional steady-state parameter estimation codes. These codes take given boundary conditions and head distributions and develop a set of physical parameters which gives a calculated head distribution such that the difference between the input head and calculated head distributions is minimized. Local numerical modeling is primarily concerned with the flow phenomena present in a fractured, highly complex, layered hydrogeologic section. Areas of uncertainty and additional data needs are described for both the regional and local models.

Work plans for future evaluation of the conceptual models by numerical methods are described. Because of the importance of the unsaturated zone for the retardation of radionuclides, initial numerical work will be primarily focused on developing a better understanding of the flow phenomena which may exist in this zone.

2.0 REGIONAL SITE DESCRIPTION

The regional hydrologic regime, including geology, hydrology, and climate, are described in this section. These descriptions are based on review of available literature. The regional geology is very complex and only an overview is presented herein. The description of the hydrologic setting is more thorough and, indeed, includes geologic discussions pertinent to the hydrology of the region. In the final subsection, the general climate of the region, as reported in the literature, is described.

2.1 REGIONAL GEOLOGIC SETTING

The Yucca Mountain Site is located in the southern Great Basin, an arid region that is characterized by alluvial basins filled with sediment, lying between linear fault-bounded mountain ranges. The ranges are commonly faulted on both sides and are modified by erosion, giving deep canyons and ravines on steep range fronts. Yucca Mountain is an example of a range which is only faulted on one side, leaving the opposite side with a more gentle slope. The southern Great Basin is bordered on the east by the high Colorado Plateau and on the west by the Sierra Nevada, both of which are steep, fault controlled mountain fronts. Within the basin, erosion is basically caused by flash floods with few perennial streams existing. The intermontane basins are deep sediment-filled structural depressions with sediment thicknesses ranging from hundreds to thousands of meters. Fine grained deposits from playas cover parts of the basin floors.

The DOE (1984) has divided the rocks in the region around Yucca Mountain into four major groups. The oldest rocks are Precambrian crystalline rocks which are part of the crystalline shield of North America. These rocks are not exposed in the vicinity of Yucca Mountain. The second major group and the oldest rocks of hydrologic significance are Precambrian and Lower Cambrian quartzites and shales, Middle Cambrian to Late Devonian limestones and dolomites, and argillite, quartzite, and limestone of the Mississippian and Late Devonian age. Tertiary volcanic rocks, comprising the third group, were formed during a period of from about 40 million to ten million years ago. Volcanic activity produced thick deposits, at least 2000 m at Yucca Mountain, from eruptive centers of Silent Canyon, Claim Canyon, Black Mountain, Sleeping Butte, Oasis Valley, and Timber Mountain.

The large scale normal block faulting, which occurred during the Miocene and Quaternary ages, disrupted the Tertiary volcanic and sedimentary strata as well as previously deformed Precambrian and Paleozoic rocks. Strike-slip faulting may have occurred during Tertiary time after deposition of early Miocene tuff (Winograd and Thordarson, 1975). Thrust faulting has displaced the pre-tertiary rocks laterally upwards of several miles and some of the major thrust faults can be followed in outcrop or reconstructed for miles. At several places, strike-slip faults and shear zones cut and offset the thrust faults (e.g., the Las Vegas Valley shear zone).

During the last ten million years, erosional processes have partially filled the structurally created basins. These deposits compose the fourth group and are represented at Yucca Mountain by alluvium. Most of the basins contain playas with some badland development occurring on exhumed pluvial lakebeds. Pediments, where present, are disrupted by normal faults. The

Quaternary strata generally are less than 600 m in thickness and consist of valley fill deposits. In addition, basalt flows and cinder cones of Quaternary age are present at the surface in some locations.

2.2 REGIONAL HYDROLOGIC SETTING

2.2.1 Description of Hydrogeologic Units

Many reports on the geohydrology of the Nuclear Test Site (NTS) and surrounding area have been written. A summary of the information available in 1970 was provided in a report by Rush (1971). The project area considered in his report covered approximately 16,060 square kilometers as depicted on Figure 1 and 16 hydrographic areas. Rush identified three types of ground water aquifers:

1. Alluvium, which is usually only saturated at great depth beneath the valley floors.

2. Volcanic rock aquifers which locally transmit water downward to carbonate rock aquifers in the eastern study area, and which transmit a regional flow in the western study area.

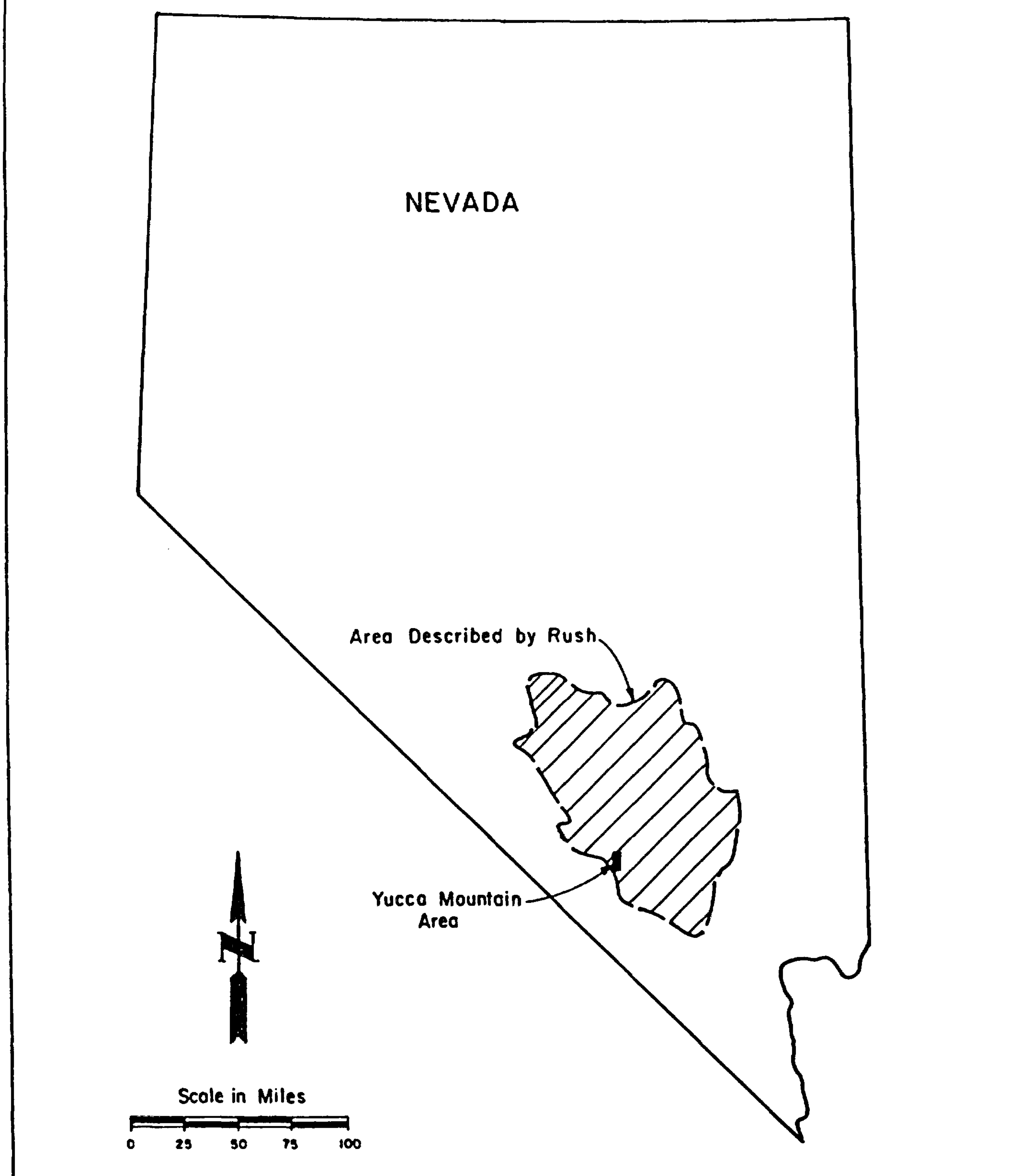
3. Carbonate rock aquifers underlying the eastern study area and which transmit ground water on a regional basis to form a large ground water system.

Unsaturated alluvium, in topographically closed hydrographic areas, transmits water vertically downward to volcanic rock or carbonate rock aquifers. Rush (1971) reported that the downward leakage to the carbonate rock aquifers beneath Yucca and Frenchmen Flats is less than 100 acre-feet per year in each valley. Except for a few springs, very little of the ground water in the valleys is discharged into the atmosphere.

In the western third of the project area, the volcanic rock aquifers transmit ground water beneath topographic divides. Flow is through fractures and the transmissivity of the volcanic rock aquifers was estimated to range between 17 m^2/day to more than 1,240 m^2/day with a mean of about 124 m^2/day (Rush, 1971). The volcanic rock aquifers unite the project area into a regional ground water flow system. In the eastern two-thirds of the project area, the volcanic rock aquifers locally transmit water through fractures to the underlying carbonate aquifers.

The carbonate aquifers are believed to be thick, highly fractured limestone and dolomite, with transmissivities ranging from 0.075 to 74,500 m^2/day (Rush, 1971). A large ground water system with a small gradient to the piezometric surface (commonly only a few feet per mile) is formed by the carbonate rock aquifers on a regional basis. Major faults can cause large differences in water level altitudes within and between valleys.

Winograd and Thordarson (1975), expanded on the definitions by Rush (1970) and reported on a hydrogeologic investigation at the NTS. Their report significantly increased the resolution of the ground water systems in the South Central Great Basin. The purposes of their investigation were to:



From: Rush (1970)

Water, Waste & Land Inc.	Figure 1 Hydrogeologic Area Described by Rush	Date: 3/28/86 Project: 4001

1. Define the hydraulic character and subsurface distribution of major aquifers and aquitards.

2. Identify and describe the principle areas of aquifer recharge and discharge.

3. Determine the rate and direction of ground water movement within the major aquifers.

Winograd and Thordarson (1975) defined ten hydrogeologic units as outlined in Table 1 to describe the groundwater hydrology of the region. The units, in order of increasing age are as follows: valley-fill aquifer, lava-flow aquifer, welded-tuff aquifer, bedded-tuff aquifer, lava-flow aquitard, tuff aquitard, upper carbonate aquifer, upper clastic aquitard, lower carbonate aquifer, and lower clastic aquitard. The lower carbonate and the valley-fill aquifers have the widest areal distribution as shown on Figures 2 and 3. The upper carbonate, bedded tuff, welded tuff, and lava flow aquifers have a limited occurrence within the zone of saturation. Hydraulic properties of the aquifers vary widely, with the lower and the upper carbonate aquifers and the welded-tuff aquifer storing and transmitting ground water chiefly along fractures. The valley fill and bedded tuff aquifers store and transmit water primarily in interstitial openings.

The four aquitards (the lower clastic, upper clastic, tuff, and lava flow) were classified based on the definition that a reservoir with a specific capacity of less than about 0.012 m^3/min per m of drawdown for 305 m of saturated rock constitutes an aquitard. Both the lower clastic and tuff aquitards play a key role in the regional movement of ground water. The lower clastic aquitard is believed to be the hydraulic basement for ground water movement throughout the study area. All of the aquitards have low fracture transmissibility and negligible interstitial permeability. A description of the aquifers and aquitards in order of increasing age is given in the following paragraphs.

The valley fill aquifer constitutes the major water supply aquifer in Frenchman Flat, western Emigrant Valley, and Amargosa Desert. The valley fill consists of sediments in depressions created by post Pliocene block faulting. The valley fill is either unsaturated or only locally saturated in Yucca Flat, western Jackass Flats, and Mercury Valley. Pumping tests from six wells at NTS indicated transmissibility ranges from about 9.9 to 420 m^2/day. Saturated thickness data suggested average interstitial permeabilities of 0.2 to 2.8 m/day.

The lava flow aquifer is restricted to the Jackass Flats area and consists of the Basalt of Skull Mountain, the Rhyolite of Shoshone Mountain, and the Basalt of Kiwi Mesa. Transmissivities of about 25 m^2/day would be likely for the Basalt flows and Rhyolite.

The welded-tuff aquifer includes the Topopah Spring and Tiva Canyon Members of the Paintbrush Tuff and members of the Timber Mountain Tuff. This aquifer occurs throughout much of the NTS, but is saturated only in the structurally deepest part of the intermontane basins. Winograd and Thordarson (1975) reported that well tests indicated negative hydraulic barriers and

TABLE 1. Stratigraphic and Hydrogeologic Units at Nevada Test Site and Vicinity (Page 1)

System	Stratigraphic Unit			Major Lithology	Maximum Thickness (feet)	Hydro-geologic Unit
Quaternary and Tertiary	Valley fill			Alluvial fan, fluvial, fanglomerate, lakebed, and mudflow deposits	2,000	Valley-fill aquifer
Tertiary	Basalt of Kiwi Mesa			Basalt flows, dense and vesicular.	250	Lava-flow aquifer
Tertiary	Rhyolite of Shoshone Mountain			Rhyolite flows.	2,000	Lava-flow aquifer
Tertiary	Basalt of Skull Mountain			Basalt flows	250	Lava-flow aquifer
Tertiary	Piapi Canyon Group	Timber Mountain Tuff	Ammonia Tanks Member	Ash-flow tuff, moderately to densely welded; thin ash-fall tuff at base.	250	Welded-tuff aquifer
Tertiary	Piapi Canyon Group	Timber Mountain Tuff	Rainier Mesa Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff at base.	600	Welded-tuff aquifer
Tertiary	Piapi Canyon Group	Paintbrush Tuff	Tiva Canyon Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff near base.	300 -350	Welded-tuff aquifer
Tertiary	Piapi Canyon Group	Paintbrush Tuff	Topopah Spring Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff near base.	890	Welded-tuff aquifer
Tertiary	Piapi Canyon Group	Paintbrush Tuff	Bedded tuff (informal unit)	Ash-fall tuff and fluvially reworked tuff.	1,000	Bedded-tuff aquifer
Tertiary	Wahmonie Formation			Lava-flow and interflow tuff and breccia; locally hydrothermally altered.	4,000	Lava-flow aquitard

From Winograd and Thordarson (1975)

TABLE 1. Stratigraphic and Hydrogeologic Units at Nevada Test Site and Vicinity (Page 2)

System	Stratigraphic Unit		Major Lithology	Maximum Thickness (feet)	Hydro-geologic Unit
Tertiary (cont.)	Wahmonie Formation (cont.)		Ash-fall tuff, tuffaceous sandstone, and tuff breccia, all interbedded; matrix commonly clayey or zeolitic.	1,700	Tuff aquitard
	Salyer Formation		Breccia flow, lithic breccia, and tuff breccia, interbedded with ash-fall tuff, sandstone, siltstone, claystone, matrix commonly clayey or calcerous.	2,000	
	Indian Trail Formation	Grouse Canyon Member	Ash-flow tuff, densely welded.	200	
		Tub Spring Member	Ash-flow tuff, nonwelded to welded.	300	
		Local informal units	Ash-fall 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.	2,000	
	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 zeolitic.	>2,000	

TABLE 1. Stratigraphic and Hydrogeologic Units at Nevada Test Site and Vicinity (Page 3)

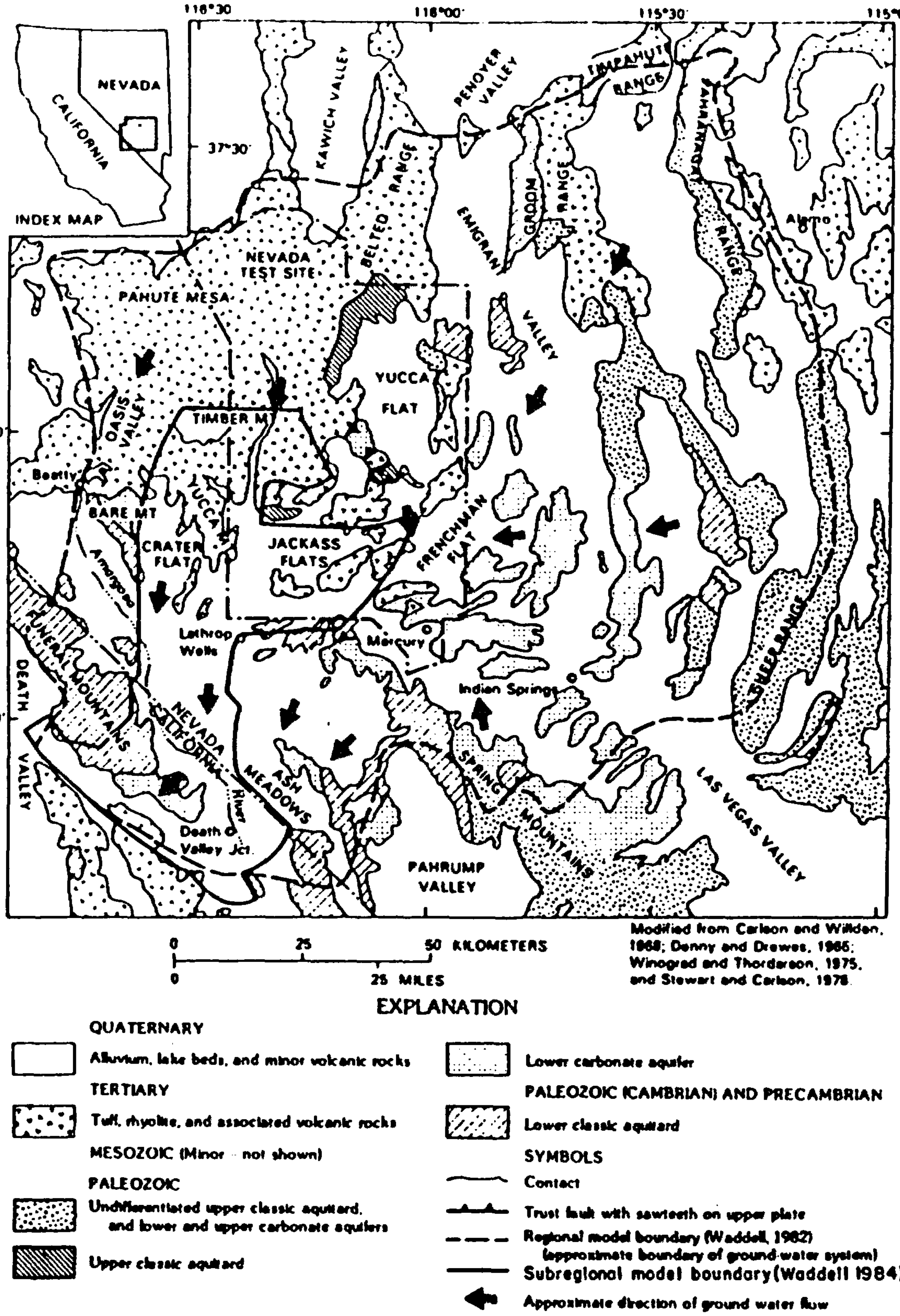
System	Stratigraphic Unit	Major Lithology	Maximum Thickness (feet)	Hydro-geologic Unit
Tertiary (cont.)	Tuff of Crater Flat	Ash-flow tuff, nonwelded to partly welded, interbedded with ash-fall tuff; matrix commonly clayey or zeolitic.	300	Tuff aquitard (cont.)
	Rocks of Pavits Spring	Tuffaceous sandstone and siltstone, claystone; fresh-water limestone and conglomerate; minor gypsum; matrix commonly clayey, zeolitic, or calcareous.	1,400	
	Horse Spring Formation	Fresh-water limestone, conglomerate, tuff.	1,000	
Cretaceous to Permian	Granitic stocks	Grandodiorite and quartz monzonite in stocks, dikes, and sills.		(A minor aquitard)
Permian and Pennsylvanian	Tippipah Limestone	Limestone.	3,600	Upper carbonate aquifer
Mississip-pian and Devonian	Eleana Formation	Argillite, quartzite, conglomerate, conglo-merite, limestone.	7,900	Upper clastic aquitard
Devonian	Devils Gate Limestone	Limestone, dolomite, minor quartzite.	>1,380	Lower carbonate aquifer
	Nevada Formation	Dolomite	<1,525	
Devonian and Silurian	Undifferentiated	Dolomite	1,415	

TABLE 1. Stratigraphic and Hydrogeologic Units at Nevada Test Site and Vicinity (Page 4)

System	Stratigraphic Unit		Major Lithology	Maximum Thickness (feet)	Hydrogeologic Unit
Ordovician	Ely Springs Dolomite		Dolomite	305	Lower carbonate aquifer (cont.)
Ordovician	Eureka Quartzite		Quartzite, minor limestone.	340	Lower carbonate aquifer (cont.)
Ordovician	Pogonip Group	Antelope Valley Limestone	Limestone and silty limestone.	1,530	Lower carbonate aquifer (cont.)
Ordovician	Pogonip Group	Ninemile Formation	Claystone and limestone, interbedded.	335	Lower carbonate aquifer (cont.)
Ordovician	Pogonip Group	Goodwin Limestone	Limestone	>900	Lower carbonate aquifer (cont.)
Cambrian	Nopah Formation Smoky Member		Dolomite, limestone	1,070	Lower carbonate aquifer (cont.)
Cambrian	Halfpint Member		Limestone, dolomite, silty limestone.	715	Lower carbonate aquifer (cont.)
Cambrian	Dunderberg Shale Member		Shale, minor limestone	225	Lower carbonate aquifer (cont.)
Cambrian	Bonanza King Formation, Banded Mountain Member		Limestone, dolomite, minor siltstone.	2,440	Lower carbonate aquifer (cont.)
Cambrian	Papoose Lake Member		Limestone, dolomite, minor siltstone.	2,160	Lower carbonate aquifer (cont.)
Cambrian	Carrarra Formation		Siltstone, limestone, interbedded. Upper 1,050 feet predominantly limestone, lower 950 feet predominantly siltstone.	1,050	Lower carbonate aquifer (cont.)
				950	Lower clastic aquitard
Cambrian	Zabriskie Quartzite		Quartzite.	220	Lower clastic aquitard

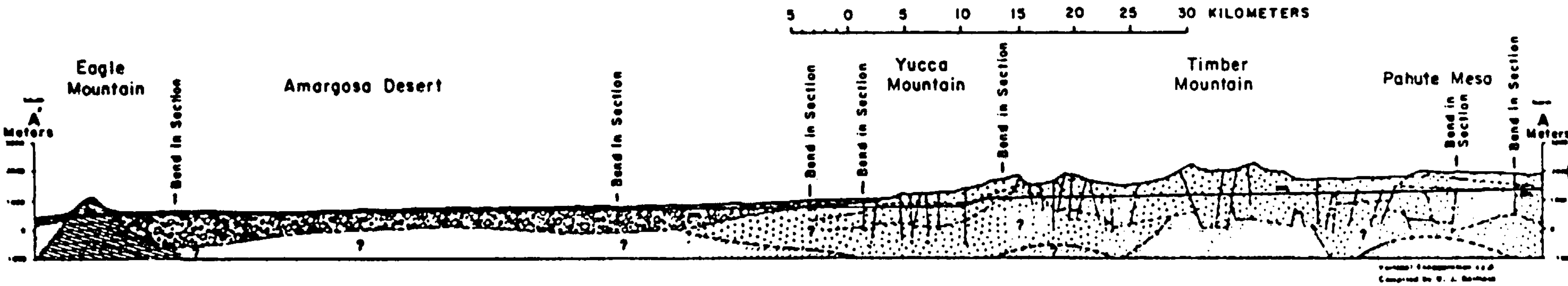
TABLE 1. Stratigraphic and Hydrogeologic Units at Nevada Test Site and Vicinity (Page 5)

System	Stratigraphic Unit	Major Lithology	Maximum Thickness (feet)	Hydro-geologic Unit
Cambrian (cont.)	Wood Canyon Formation	Quartzite, siltstone, shale, minor dolomite.	2,285	Lower clastic aquitard (cont.)
Precambrian	Stirling Quartzite	Quartzite, siltstone.	3,400	
	Johnnie Formation	Quartzite, sandstone, siltstone, minor limestone and dolomite.	3,200	



From: Czarnecki and Waddell (1984)

Water, Waste & Land Inc.	Figure 2 Regional Hydrologic Model	Date: 3/28/86 Project: 4001



LEGEND

Aquitards and Barriers

- Upper Clastic Aquitard
- Lower Clastic Aquitard
- Intrusive Rocks
- Other Hydrologic Barriers

Transmissive Rocks

- Alluvium
- Volcanic Rock
- Carbonate Rocks

From: Waddell (1982)

Water, Waste & Land Inc.

Figure 3

Hydrologic Cross-Section of Nevada Test Site and Vicinity

Date: 3/28/86

Project: 4001

suggest that the welded-tuff aquifer is locally compartmentalized, as is the lower carbonate aquifer. In general, both interstitial porosity and interstitial permeability vary inversely with degree of welding. Thordarson (1983) reanalyzed the data which were obtained from ten test holes previously reported by Winograd and Thordarson (1975). He reported that the welded tuff aquifer at well J-13 has an estimated transmissivity of 120 m^2/d and a hydraulic conductivity of 1.0 m/d. The tests also showed the welded tuffs and bedded or reworked tuffs beneath the Topopah Spring Member (the predominant aquifer of the welded tuff) are confining beds with transmissivities of 0.088 to 4.5 m^2/d, and hydraulic conductivities of 0.0026 to 0.15 m/d. The welding process which occurs after emplacement of an ash flow apparently causes a porosity reduction of the tuff. Lithophysae can form from the gases initially present in the densely and partially welded zone and may be as much as one inch in diameter. Lithophysae are usually unconnected or poorly connected. However, the welded tuff can be highly fractured.

The bedded-tuff aquifer comprises ash-fall tuff interbedded with Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff and the Grouse Canyon Member of the Indian Trail Formation. These tuffs could be classified as tuffaceous sandstones, siltstone, and mudstones. Open joints or faults are not seen, even in tunnels through these rocks at Rainier Mesa, due to highly friable nature of the rocks.

All of the tuffs and associated sedimentary rocks older than the Paintbrush Tuff comprise the tuff aquitard. The strata usually have matrices consisting of zeolite or clay minerals. Zeolitic bedded tuff was extensively studied in the five miles of tunnels, shafts, and drifts beneath Rainier Mesa. The average interstitial permeability ranged from 1.63 x 10^{-5} to 1.22 x 10^{-3} m/day and interstitial porosity ranged from 25 to 38 percent. Interstitial saturation (100%) was found to occur as much as 120 m above the top of the zone of saturation within open fractures. The water bearing fractures were poorly connected or unconnected. Based upon these and other observations, the aquitard was classified as a fractured aquitard with high interstitial porosity but very low interstitial permeability. Again, regional ground water movement is controlled by matrix properties rather than fracture transmissibility.

The upper carbonate aquifer has been eroded from most of the study area, is saturated only beneath the western one-third of Yucca Flat, and is separated from the lower carbonate aquifer by the upper clastic aquitard. Based on these considerations, the upper carbonate reservoir does not play a significant role in the regional movement of ground water in the study area (see Figure 2).

The upper clastic aquitard probably also controls regional ground water movement by interstitial permeability rather than fracture transmissibility. The aquitard consists primarily of argillite, quartzite, and conglomerate, and is of hydrologic importance only beneath western Yucca Flat and northern Jackass Flats.

The lower carbonate aquifer has a saturated thickness ranging from 100 to 1,000 meters and comprises the carbonate rocks of middle Cambrian through Devonian age. In general, hundreds of meters of the aquifer occur within the zone of saturation throughout the study area. The inter-crystalline, or matrix, permeability and porosity of the lower carbonate aquifer are extremely low. Where exposed, the carbonate rocks are shown to be highly fractured and locally are brecciated, usually along faults exhibiting only a few feet of displacement. Mapping of the strike and frequency of the faults and joints show considerable variation from area to area.

Winograd and Thordarson (1975) present the following information for the matrix physical properties of lower carbonate aquifer materials based on core sample analyses:

	Number of Samples	Range	Median	Mean
Total Porosity	16	0.4 to 12.4	5.5	5.4
Effective Porosity	25	0.0 to 9.0	1.1	2.3
Permeability (m/day)	13	8.15×10^{-7} to 4.07×10^{-3}	3.26×10^{-6}	4.07×10^{-3}

Fractures found in the cores were divided into the following four types:

1. Fractures filled with breccia or clayey gouge.
2. Slickensides.
3. Fractures sealed with calcite, dolomite, or other minerals.
4. Fractures partly filled with calcite or dolomite.

The last type were the most abundant type of fractures observed in the core samples with upwards of 95 percent of all fractures found being of this type. Winograd and Thordarson (1975) estimated the average total porosity of the partly filled fractures at 0.1 percent with a range of from 0 to 1 percent of the volume of the core sample. Drilling records indicated that lost circulation commonly occurred with the rate of fluid loss changing abruptly with depth. In holes drilled with air, sudden entry of water into the well bore was occasionally noted, which probably indicated the penetration of the first major water-bearing fracture. Hydraulic properties of the lower carbonate aquifer were measured by drill-stem and pumping tests at ten wells, with depths ranging from 400 to 1,280 m. The tests yielded the following information on the lower carbonate aquifer:

1. Water-bearing fractures are sparse, but they are open to depths of at least 450 m beneath the top of the aquifer and up to 1,280 m below land surface. There is no apparent decrease in fracture yield to this depth.
2. The coefficient of transmissibility for the aquifer ranges from about 12 to 11,200 m^2/day.

As reported by Winograd and Thordarson (1975), the drill stem tests showed that the fracture transmissibility of the carbonate aquifer varied greatly with depth with some intervals yielding only a negligible discharge with a drawdown of tens of meters while other intervals in the same hole yielded up to 0.19 m^3/min without lowering the water level more than a meter.

The lower clastic aquitard comprises the clastic rocks of Precambrian through Early Cambrian age. Pump tests conducted in the lower clastic aquitard indicate specific capacities range from 8.3×10^{-6} to 2.1×10^{-5} m^3/s per meter of drawdown. Interstitial permeability may be the governing mechanism for regional flow through the aquitard, because of a lack of evidence for interconnected fracture porosity.

Winograd and Thordarson (1975) made the following generalizations about the regional disposition of the hydrogeologic units:

1. The lower carbonate aquifer occurs alternately under confined and unconfined conditions. Beneath the deepest parts of most intermontane basins, this aquifer is confined by the saturated tuff aquitard, whereas beneath ridges it is unconfined.

2. The lower carbonate aquifer is saturated throughout the study area except beneath or in the vicinity of outcrops or buried structural highs of the lower clastic aquitard.

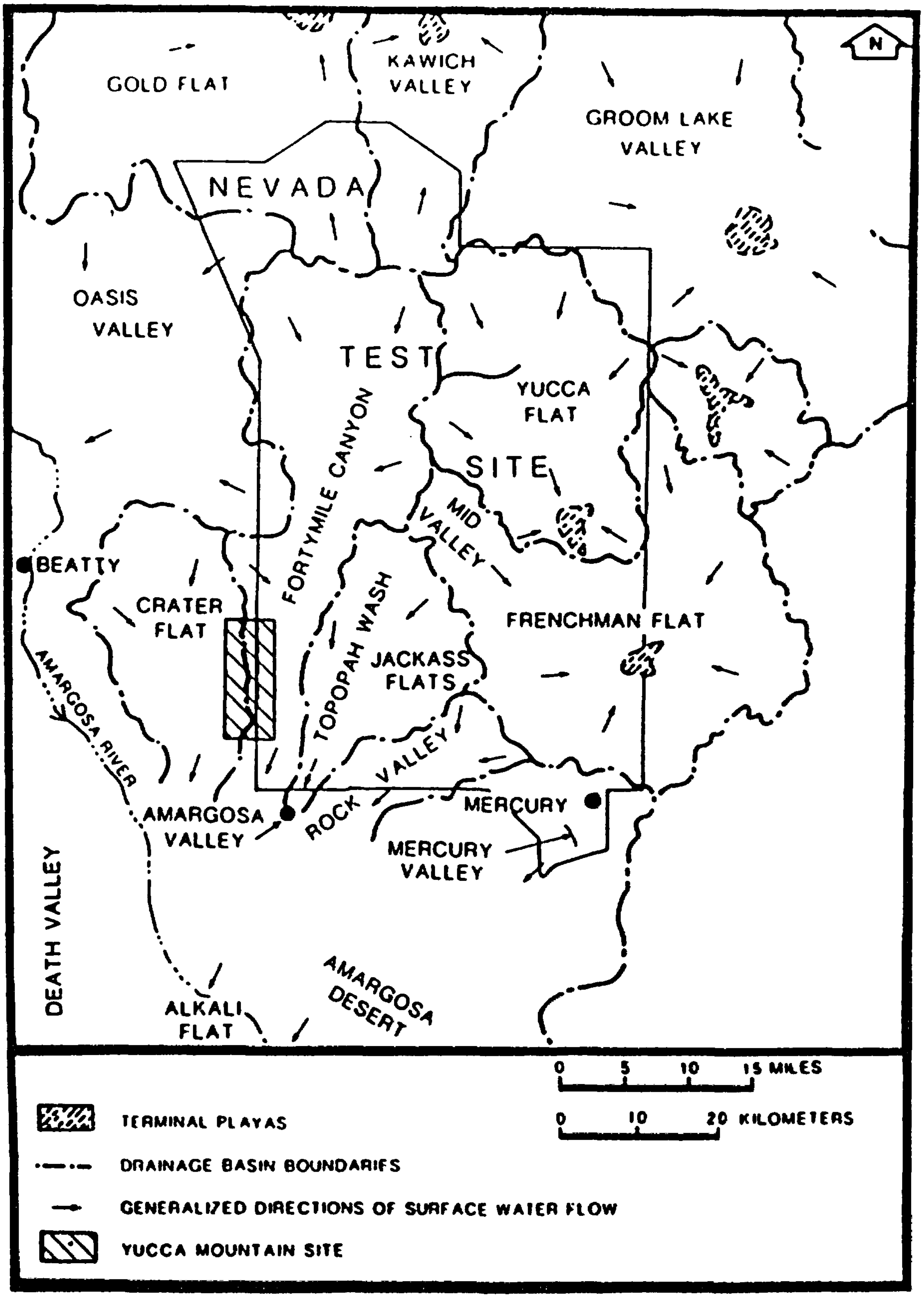
3. The tuff aquitard generally separates the welded-tuff and valley-fill aquifers from the lower carbonate aquifer, particularly in the structurally deep parts of the intermontane basins.

4. In valleys with deep water tables (150 to 610 m) the tuff aquitard may surround, as well as underlie, the Cenozoic aquifers at the altitude of the water table.

2.2.2 Ground Water Basins

A conceptual model of NTS was presented by Waddell (1982). and is based largely on the model proposed by Winograd and Thordarson (1975). Waddell's conceptual model considers three ground water basins: Ash Meadows, Oasis Valley, and Alkali Flat-Furnace Creek Ranch. The model proposed by Winograd and Thordarson (1975) proposed two ground water basins, the Ash Meadows ground-water basin and the Oasis Valley-Fortymile Canyon ground water basin.

The Nevada Department of Conservation and Natural Resources calculated recharge versus discharge estimates for the local sub-basins (See Figure 4) in the 1960's and 1970's (Rice, 1984). Because the accountable discharges were several times less than the recharge estimates, it was concluded that while the valleys are topographically separated, ground-water flow is significant between the sub-basins in the region. The lower carbonate aquifer appeared to be primarily responsible for interbasin or regional ground-water flow. Ground water moves laterally in this unit toward discharge areas occurring primarily in the valleys in the form of springs, evapotanspiration, and pumping (Rice, 1984).



From: ERDA (1977)

Water, Waste & Land Inc.	**Figure 4** Boundaries of Basins and Directions of Surface Drainage	**Date:** 3/28/86 **Project:** 4001

The Ash Meadows ground water basin, as defined by Winograd and Thordarson (1975) is the area contributing ground water to the springs at Ash Meadows (see Figure 2). Aquifer discharge due to the springs was estimated to be about 57,800 m^3/day. The underflow and evapotranspiration discharge components were not estimated by Thordarson and Winograd. However, they theorized that water from the spring pools originates from the underlying and flanking lower carbonate aquifer, based on head differentials, water temperature, and water chemistry. The lower carbonate aquifer crops in the southwestern and southern parts of the Amargosa Desert at altitudes approximately 37 to 49 meters lower than the water level in Devils Hole, yet spring discharge does not occur. Winograd and Thordarson theorize that a ground water barrier is formed by normal faulting of the low permeability Cenozoic rocks against the lower carbonate aquifer, thus forming the spring line at Ash Meadows. Some upward leakage from the lower carbonate aquifer north of the spring line occurs into an alluvial valley and playa. The upward leakage in this area is believed to be less than 3,380 m^3/day. Since no reliable estimate of underflow at Ash Meadows is available, the measured spring discharge of about 57,800 m^3/day must be considered the minimum quantity of ground water in transit through the lower carbonate aquifer at Ash Meadows.

The Ash Meadows ground water basin encompasses approximately 11,650 square kilometers and contains ten intermontane valleys: Desert Valley, Three Lakes Valley, Indian Springs Valley, Emigrant Valley, Yucca Flat, Frenchman Flat, eastern Jackass Flats, Mercury Valley, Rock Valley, and an unnamed valley in the east-central Amargosa Desert. Winograd and Thordarson could not define a northeast boundary to the Ash Meadows ground water basin. Intrabasin movement of ground water occurs in the region from the welded-tuff and valley-fill aquifers to the lower carbonate aquifer beneath several of the intermontane valleys. However, the volume of flow is believed to be small. Geologic structure significantly controls interbasin movement through the carbonate rocks and causes the lower carbonate aquifer to be compartmentalized.

Winograd and Thordarson (1975) used chemical variations in ground water sources to deduce regional ground water movement. Some of their conclusions are:

1. Ground water beneath the Nevada Test Site moves towards the Ash Meadows area.

2. Ground water may move into the Ash Meadows basin from Pahranagat Valley and if so, may constitute as much as 35 percent of the spring discharge at Ash Meadows.

3. Ground water movement from Pahrump or Stewart Valleys into the Ash Meadows area is minor.

4. Ground water within the central Amargosa Desert comes from the east, north, and the northwest.

5. Flow from the central Amargosa Desert into Death Valley is the most likely source of the major spring discharge in east-central Death Valley.

The Oasis valley ground water basin consists of those areas which contribute to discharge in Oasis Valley. As defined by Waddell, the Oasis Valley basin does not include all the area included in Winograd and Thordarson's (1975) Oasis Valley-Forty mile Canyon ground water basin. The Fortymile Canyon part of Winograd and Thordarson's basins is included as part of the Alkali Flat - Furnace Creek Ranch basin of Waddell's conceptual model. Discharge into Oasis Valley has been estimated to be 0.078 m^3/s, with the water flowing from western and central Pahute Mesa.

Waddell (1982) considers the Ash Meadows and Oasis Valley ground water basins to be sub-basins within the Alkali Flat - Furnace Creek Ranch basin. However, the contributions of the Oasis Valley and Ash Meadows ground water basins to the Alkali Flat - Furnace Creek Ranch basin are unknown, but probably small due to the arid environment and low conductivity rocks. The Yucca Mountain site is located in Waddells Alkali Flat - Furnace Creek Ranch ground water basin.

The boundaries of the Alkali Flat - Furnace Creek Ranch ground water basin are not well known. Czarnecki and Waddell (1984) estimated the boundaries from hydraulic head data, geology, location of discharge areas, and hydrochemistry. The basin was named after Alkali Flat and the Furnace Creek Ranch, which are the two major discharge areas near its southern end. Discharge in the Alkali Flat area is estimated at 0.39 m^3/S and is almost entirely through evapotranspiration, the principle component of which is bare-soil evaporation. Origin of the water from the other major discharge, the springs near Furnace Creek Ranch in Death Valley is not completely known. Alluvium and the carbonate rocks that probably underlie that alluvium in the Amargosa Desert immediately northeast of the Funeral Mountains are the two most likely sources of water. Ground water from the Ash Meadows basin probably provides some lateral recharge, but the rate is unknown.

Winograd and Thordarson (1975) defined five hydrochemical facies of ground water in their study area:

1. Calcium magnesium bicarbonate type - water that has moved only through the lower carbonate aquifer or through valley fill rich in carbonate detritus.

2. Sodium potassium bicarbonate type - water that has moved only through rhyolitic tuff or lava-flow terrain, or through valley fill deposits rich in volcanic detritus.

3. Calcium magnesium sodium bicarbonate type - water in the lower carbonate aquifer, in areas of downward crossflow from the Cenozoic aquifers and aquitards.

4. Sodium sulfate bicarbonate type - water in east-central Death Valley.

5. Playa type - shallow ground water, such as that beneath saturated playas.

2.3 CLIMATE

The Yucca Mountain site is located within the most arid part of Nevada, the most arid State in the United States (Winograd and Thordarson, 1975). The average annual precipitation ranges from 76 to 254 mm, with most of the precipitation falling during winter and summer. The winter precipitation is usually associated with large low pressure systems originating from the west. The summer precipitation is usually associated with intense, but of small area, convective storms.

Winograd and Thordarson (1975) reported that precipitation within the study area is a function of altitude and of longitudinal position. Generally, stations east of longitude 115 degrees, 45 minutes receive up to 2.5 times more precipitation than stations at similar altitudes but west of longitude 116 degrees 15 minutes. As reported by ERDA (1977), the precipitation can range from 102 mm at Frenchman Flat (elevation-910 meters) to about 305 mm on Pahute Mesa (elevation-2150 meters) with the primary maximum occurring in the winter and a secondary maximum occurring in the summer. Average temperatures in Frenchman Flat can range from minus 3 degrees C in January to 36 degrees C in July. Higher altitudes such as at Rainer Mesa have an average temperature of minus 3 degrees C in January to 25 degrees C in July. Nighttime temperatures can be strongly influenced by nocturnal air drainage. In the past 70,000 years, several pluvials occurred which gave the entire region a much wetter climate, with the last major pluvial probably occurring around 9,000 years ago.

3.0 REGIONAL NUMERICAL MODELING

Because of the highly complex geology and hydrogeology of the area around and in the NTS, a number of simplifications for numerical modeling were made. At a particular location in the modeled site, the model uses the most transmissive hydrostratigraphic unit at that location. The use of transmissivity eliminates the need for structural surfaces, which allows a flux to be determined without knowledge of saturated thickness.

3.1 TWO-DIMENSIONAL MODEL - 1982

A regional two-dimensional steady-state ground water flow model was developed by Waddell (1982) using parameter estimation techniques. Waddell's major assumptions and simplifications regarding geology and hydrology for the model are:

1. Ground water flow is strictly horizontal. Even though evidence indicates upward and downward flow exists in the study area, the areas where vertical flow is significant make up a small fraction of the flow system.

2. Hydraulic heads are at steady-state conditions and hydrological parameters do not change with time. This steady-state assumption is known to be violated by the natural system, however, available data did not allow development of a model for transient flow.

3. The rocks are isotropic with respect to hydraulic conductivity.

4. Homogeneity exists within zones. The effects of this assumption are that the simulated heads may not agree with measured values.

Model variables include transmissivities, distributed and point fluxes, and constant hydraulic-head values. Model parameters are defined to be model variables that have been selected for estimation by the inverse procedure. This parameter estimation technique derives values for the parameters to minimize the weighted sum of squared residuals of simulated head.

Sources of error which cause non-zero residuals between simulated and measured hydraulic heads are caused by errors in head measurement and/or errors due to model simulation. Waddell considers that errors in head measurement are not a significant source of error, and that the primary source of errors in the simulation are probably due to:

1. The use of a two-dimensional model to simulate three-dimensional flow,

2. Inaccurate definition of zonal boundaries,

3. Simplification of zonation,

4. Assumption of steady-state conditions,

5. Errors in distribution and rates of recharge, discharge, and leakage, and

6. Inappropriate boundary conditions.

Waddell (1982) states that all mismatch between measured and simulated heads is due to uncertainty in the conceptual model.

Residuals, which is the difference between measured and simulated heads, ranged from -61.0 to +85.2 m. Generally, absolute values of the residuals are less than 30 m. Pahute Mesa and Jackass Flats are two areas where the residuals remained large. Extensive well testing at Pahute Mesa showed both upward and downward flow in different parts of the mesa. Such conditions make it difficult for the model to accurately simulate the heads at those locations.

The conclusions reached by Waddell (1982) based on the numerical model are as follows:

1. Ground water barriers within the study area have a great effect on measured and, therefore, simulated heads. In particular, hydrologic properties of the Elena Formation and Precambrian and Cambrian clastic rocks have a major effect on flux through the Timber Mountain and Jackass Flats areas.

2. Hydrologic properties of Fortymile Canyon and Fortymile Wash significantly affect calculated fluxes beneath Jackass Flats and Yucca Mountain.

3. Recharge on Pahute Mesa and underflow from regions north of the mesa have a significant impact on the model. Because of the importance of this flux, it should be determined more accurately.

4. Sensitivity analysis confirm the qualitative impression (obtained from regional potentiometric and geologic maps) that hydrologic properties within the Ash Meadows subsystem are not important for determination of fluxes and head distributions within western Jackass Flats. It is not necessary to improve on the data base for the Ash Meadows system to evaluate a potential repository in western Jackass Flats or Yucca Mountain.

5. Estimates of rates of transport of radionuclides should not be made using the regional flow model.

3.2 TWO-DIMENSIONAL MODELS - 1984

3.2.1 Rice (1984)

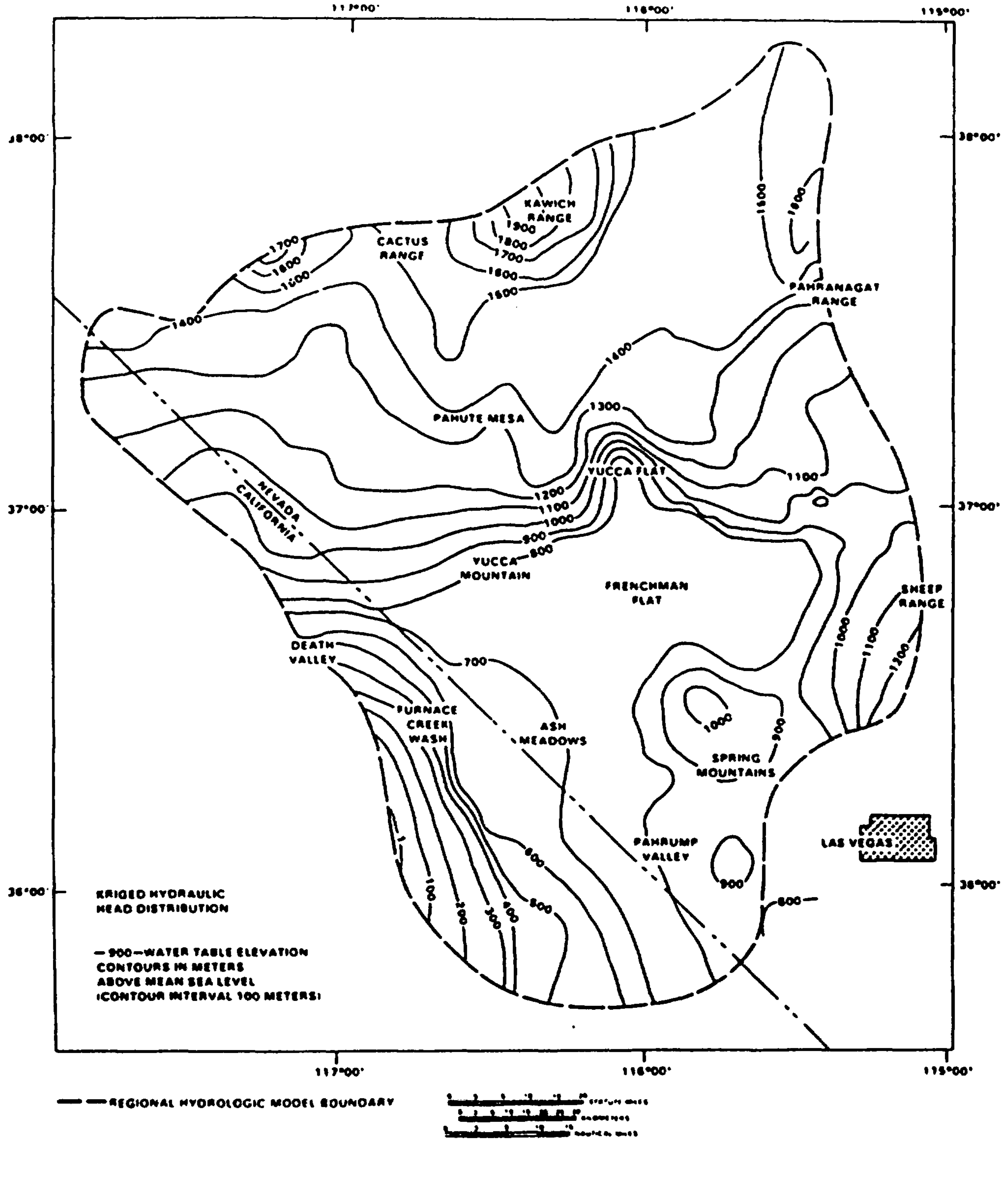
Rice (1984) reported the results of a two-dimensional regional hydrologic model. The model was numerically evaluated using a two-dimensional finite difference code for steady-state conditions. Rice simplified the conceptual model by assuming that the ground water flow is strictly horizontal and that the hydrologic parameters (transmissivity, rates of recharge and discharge) do not change with time, and the current hydraulic head distribution is at steady state. Two hydraulic head distributions were considered: (1) a hand-contoured ground-water elevation map by the USGS and (2) a kriged hydraulic head distribution of the 240 water table measurements. The head distributions were similar in shape. The kriged hydraulic head distribution from the regional model is shown in Figure 5. The transmissivities used by Waddell (1982) were used as initial estimates for Rice's model. Because uncertainty in transmissivity is greater than the uncertainty in the stress and recharge calculation, the former parameter was adjusted during the model calibration (Rice, 1984). The final calibrated transmissivity distribution is presented in Figure 6. Rice concluded that the model predicted hydraulic head distribution shown on Figure 7 indicated that the configuration of parameters used formed a working regional model of the Nevada Test Site.

3.2.2 Czarnecki and Waddell (1984)

In order to gain a better understanding of the ground water flow system beneath the Yucca Mountain area a subregional model was developed by Czarnecki and Waddell (1984). The results of the finite-element, parameter-estimation code were for steady-state simulations only. The model incorporated additional hydraulic-head data at Yucca Mountain and Franklin Lake playa which were not available for Waddell's (1982) report. The modeled area is about one third the size (6,000 km^2) of the area included in the model developed by Waddell (1982) and is presented on Figure 8. Recharge occurs along Fortymile Canyon and at Pahute Mesa. The study area is in a portion of the Alkali Flat-Furnace Creek Ranch ground water basin as defined in Waddell's 1982 report.

The results from the model show that the simulated hydraulic-head altitudes range from 1,279.3 m near Timber Mountain to 284.6 m at Furnace Creek Ranch. The gradients near Furnace Creek Ranch are about 0.01 and reach a high of 0.19 in the east-west oriented barrier north of Yucca Mountain. Residuals of the 93 hydraulic-head measurements range from -28.6 to 21.4 m. Overall agreement between measured and simulated heads is good indicating an acceptable representation of the hydrologic system by the model. Exceptions occur in areas where vertical-flow components are present, such as Franklin Lake playa, and in areas where steep hydraulic gradients occur, such as directly north of Yucca Mountain. Czarnecki and Waddell (1984) concluded that while the two-dimensional flow model provided a good match throughout most of the modeled area, an aspect needing further investigation was the shape, orientation, and extent of the barrier which apparently exists to the north of Yucca Mountain.

A radionuclide travel time was bounded by calculating a flow path from the repository to a distance of 11.96 km. This is the distance of one possible route which the radionuclides might move downgradient from the potential repository site. Saturated thickness of 500 meters and porosity of 0.001 gave a calculated travel time of 100 years. A saturated thickness of 1000 m and a porosity of 0.10 resulted in a calculated travel time of 20,000 years. This large range indicates the uncertainty and relative importance of both the saturated thickness and porosity terms used to estimate travel time.



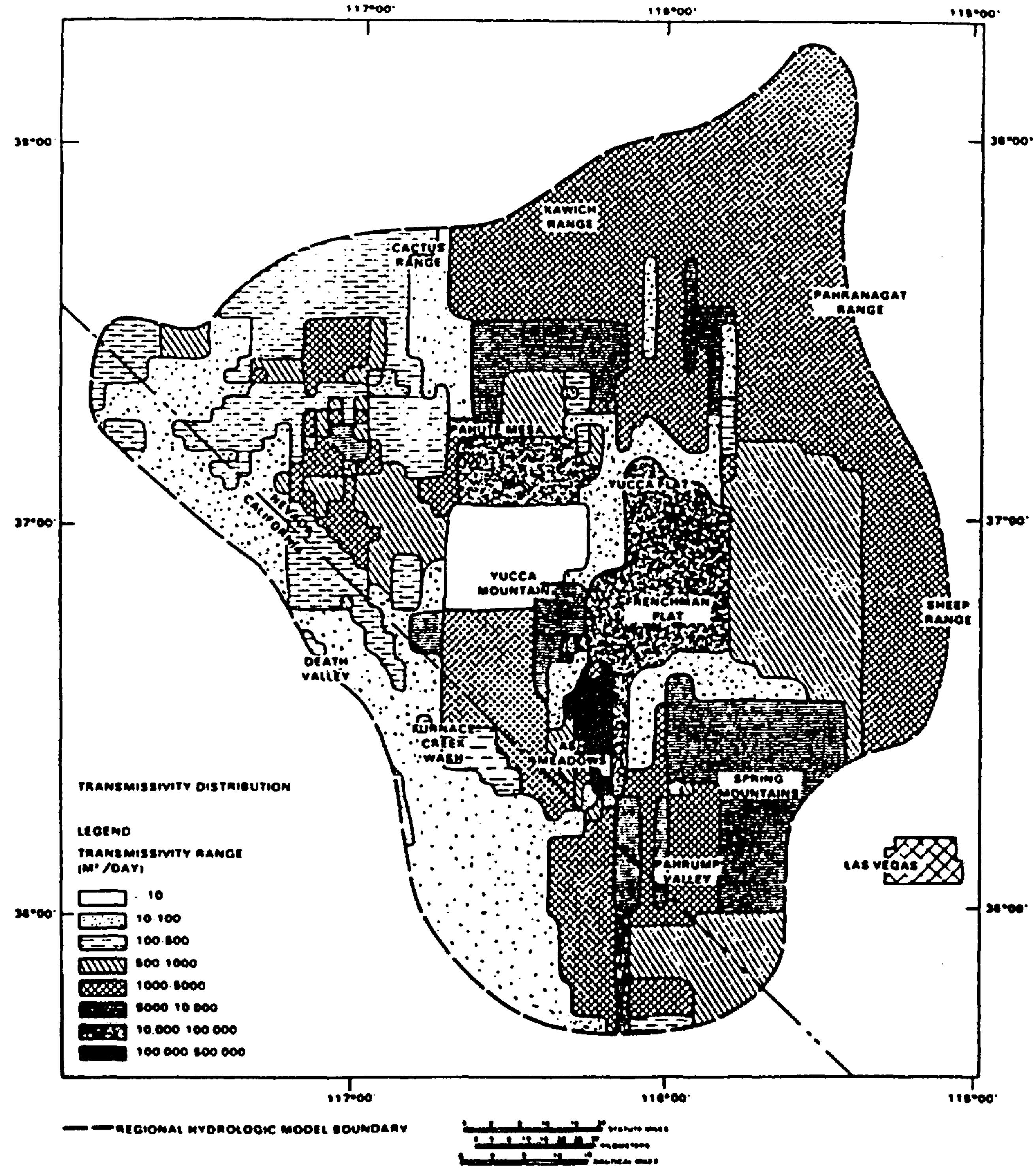
From: Rice (1984)

Water, Waste & Land Inc.

Figure 5
Kriged Hydraulic Head Distribution
Hydraulic Heads in Meters Above MSL

Date: 3/28/86

Project: 4001



From: Rice (1984)

Water, Waste & Land Inc.

Figure 6
Transmissivity Distribution for the Calibrated Regional Model

Date: 3/28/86

Project: 4001

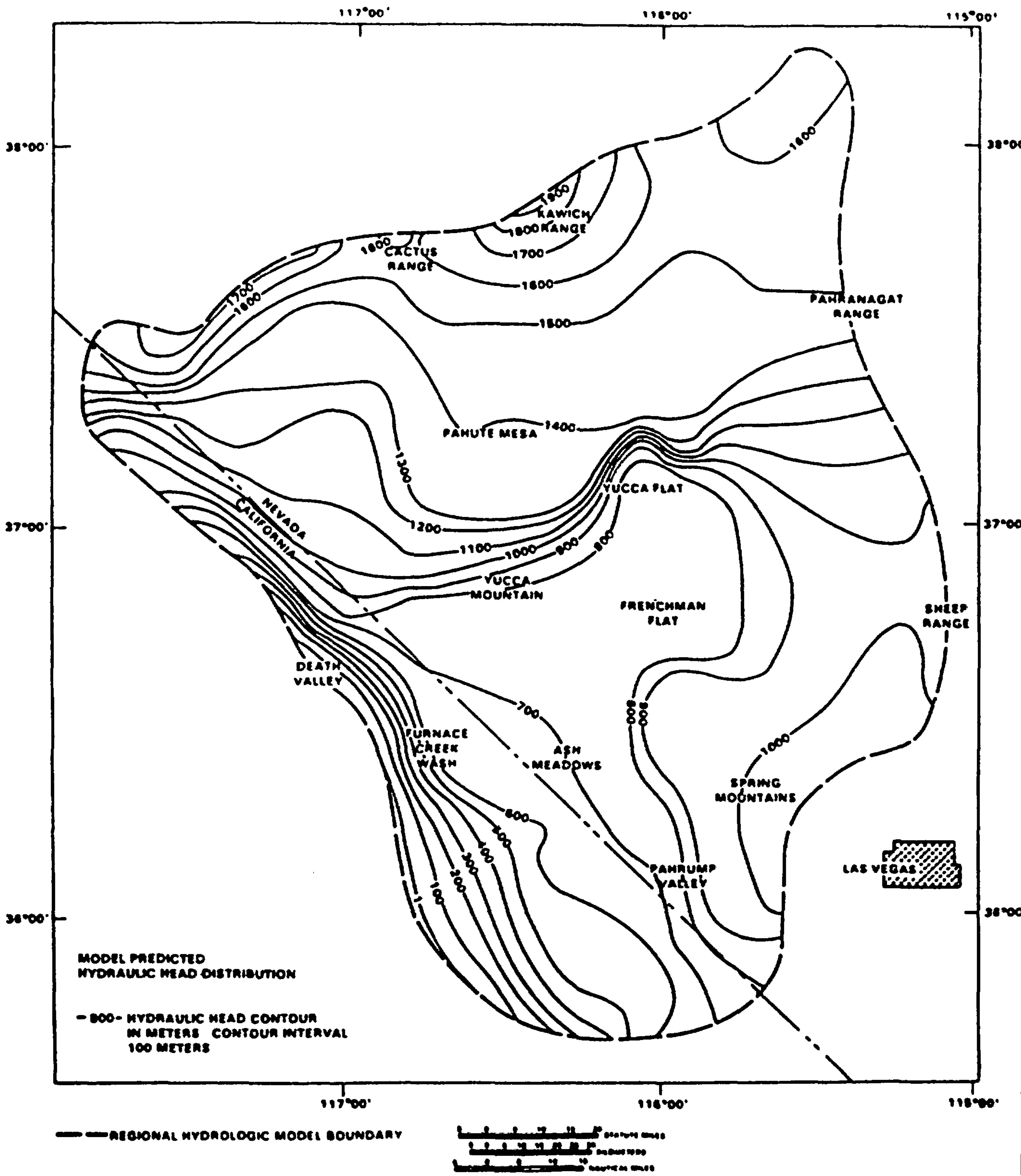


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Figure 7

Model Predicted Hydraulic Heads for Steady-State Confined Conditions

Date: 3/28/86

Project: 4001

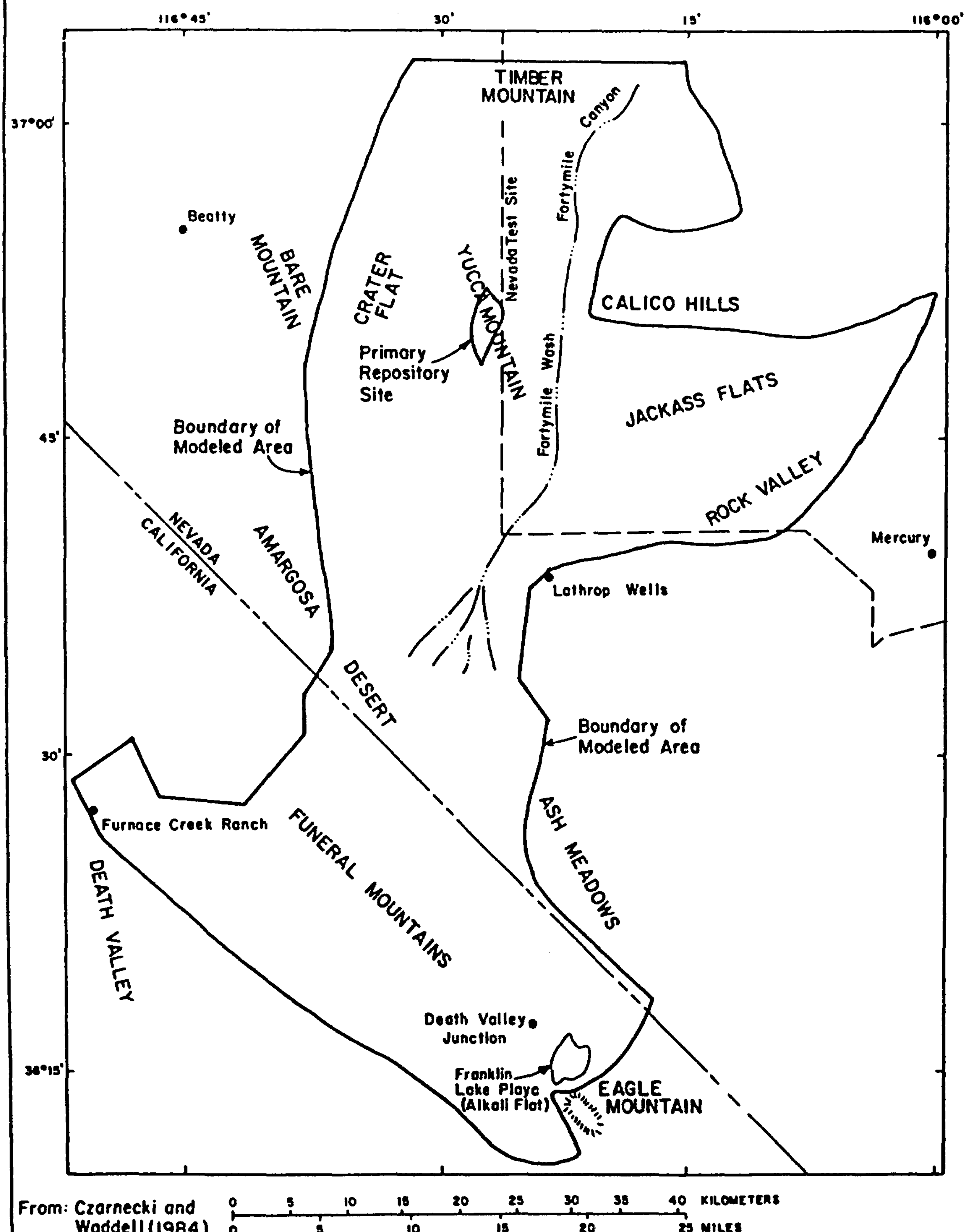

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Figure 8
Location of Subregional Modeled Area
and Nearby Geographic Features

Date: 3/28/86
Project: 4001

4.0 LOCAL SITE DESCRIPTION

Of the four major groups of rocks defined in Section 2.1, two are known to be present at Yucca Mountain. The Tertiary volcanic rocks and the Quaternary (and uppermost Tertiary) deposits, the Tertiary volcanic rocks are composed chiefly of rhyolitic ash-flow tuffs, with smaller amounts of dactic lava flows and flow breccias. Some minor amounts of tuffaceous sedimentary rocks and air-fall tuffs are also present. The other group of rocks primarily consist of alluvium and unsorted debris-flow deposits in channels.

4.1 LOCAL GEOLOGY

The major stratigraphic units and approximate ages of the Tertiary volcanic rocks which exist at Yucca Mountain are listed as follows:

1. Timber Mountain Tuff: Only the Rainier Mesa Member is preserved at Yucca Mountain. The unit was formed approximately 11.3 million years ago by ash flow from the Timber Mountain calderal. Where it occurs at Yucca Mountain it is a moderately welded, devitrified tuff that grades downward into a nonwelded vitric tuff at the base.

2. Paintbrush Tuff: The four members of this unit which are present at Yucca Mountain are (from youngest to oldest): the Tiva Canyon Member, the Yucca Mountain Member, the Pah Canyon Member, and the Topopah Spring Member. This unit was formed about 12 million years ago by the Claim Canyon caldera although portions of this unit may have been formed 13.2 million years ago by the Oasis valley caldera.

3. Tuffaceous Beds of the Calico Hills: This unit consists of tuffaceous rocks, primarily nonwelded ash-flow tuffs, numerous thin tuffaceous sedimentary beds and minor air-fall tuffs. The rocks in the southern and western portions of the Yucca Mountain site are vitric, while the rocks in the northern and eastern part of the site are typically zeolitized. The volcanic center is uncertain but the tuffaceous rocks comprising this unit are approximately 13.4 million years old.

4. Crater Flat Tuff: This unit consists of three members, the Prow Pass Member, the Bullfrog Member, and the Tram Member (from youngest to oldest). The Prow Pass and Bullfrog Members were formed by the Crater Flat Caldera about 13.5 million years ago. The Tram Member is of similar age and may have been formed by the Tram Caldera.

5. Older Tuffs: All rocks below the Crater Flat Tuff are included in this unit. The total thickness and approximate age of the older tuffs are unknown.

4.2 LOCAL HYDROLOGIC SETTING

Six hydrogeologic units are considered to exist at the Yucca Mountain site. These units, in order of increasing age are: Alluvium, Tiva Canyon welded unit, Paintbrush nonwelded unit, Topopah Spring welded unit, Calico Hills nonwelded unit, and Crater Flat unit as shown on Figure 9.

4.2.1 Description of Hydrologic Units

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

The Tiva Canyon welded unit is part of the Tiva Canyon Member of the Paintbrush Tuff. The welded unit overlies a nonwelded to partially welded portion of the Tiva Canyon Member. The welded unit forms the caprock of Yucca Mountain and is densely fractured.

Underneath the Tiva Canyon welded unit lies the Paintbrush Nonwelded unit. This hydrologic unit is composed of tuffs which are vitric, nonwelded, very porous, partially bedded and slightly indurated. The non-welded units are made up of the following stratigraphic units: the non-welded to partially welded base of the Tiva Canyon Member, the Yucca Mountain member, the Pah Canyon member, the non-welded and partially welded upper part of the Topopah Spring member, and associated bedded tuffs. The unit crops out above Solitario Canyon on the west side of Yucca Mountain.

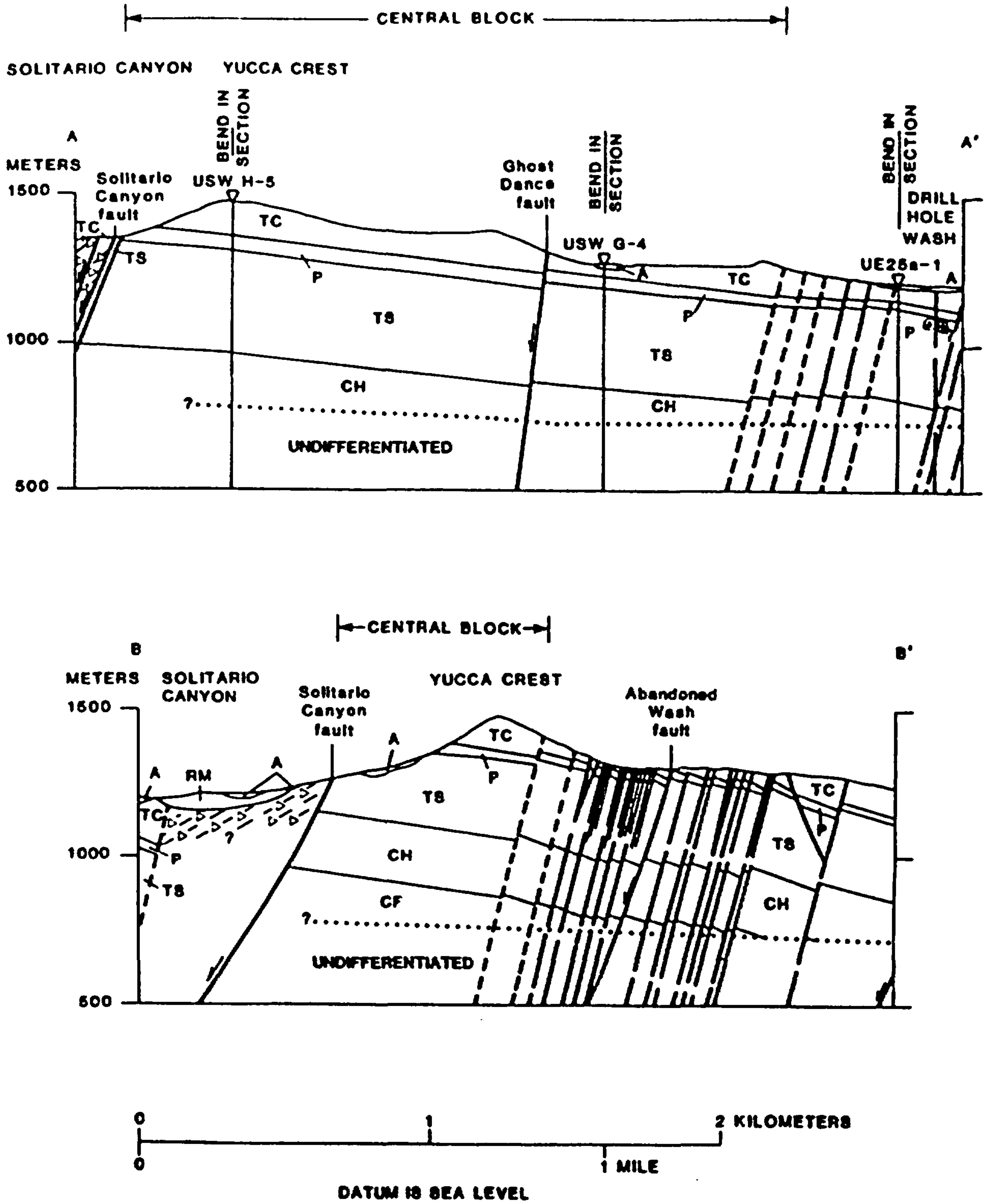
The Topopah Spring welded unit consists of all but the non-welded to partially welded vitric layer (i.e., the uppermost and lowest portion) of the Topopah Spring Member of the Paintbrush Tuff. The welded unit consists of a very thin upper vitrophyre, a thick zone in the central part which is densely welded and highly fractured, and a thin lower vitrophyre. The unit crops out on the west side of Yucca Mountain and is the proposed unit for the repository.

The Calico Hills nonwelded unit consists of the lowermost part of the Topopah Spring Member, the Tuffaceous beds of Calico Hills, and the Prow Pass Member of the Crater Flat Tuff and the nonwelded to partially welded upper part of the Bullfrog Member of the Crater Flat Tuff where they are in the unsaturated zone.

The Crater Flat unit consists of the unsaturated welded and underlying nonwelded parts of the Bullfrog Member of the Crater Flat Tuff. Because of the limited extent of the unit in the unsaturated zone beneath the central block, no differentiation is made between the welded and nonwelded components of the Crater Flat unit.

4.2.2 Conceptual Flow Model

The current conceptual flow model is based largely on the work performed and reported by Montazer and Wilson (1984). Flow into the unsaturated system begins with a precipitation event and is presented schematically on Figure 10. Most precipitation produces nonuniform, moderately intense infiltration, principally into the Tiva Canyon welded unit fracture system. Upon reaching the Paintbrush nonwelded unit, Montazer and Wilson propose that hysteresis



From: Montazer and Wilson (1984)

Water, Waste & Land Inc.	Figure 9 Hydrologic Sections Across Yucca Mountain	Date: 3/28/86 Project: 4001

EXPLANATION

A	ALLUVIUM AND COLLUVIUM	QUATERNARY AND TERTIARY
RM	RAINIER MESA MEMBER OF TIMBER MOUNTAIN TUFF	TERTIARY (MIOCENE)
TC	TIVA CANYON WELDED UNIT	
P	PAINTBRUSH NONWELDED UNIT	
TS	TOPOPAH SPRING WELDED UNIT	
CH	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;

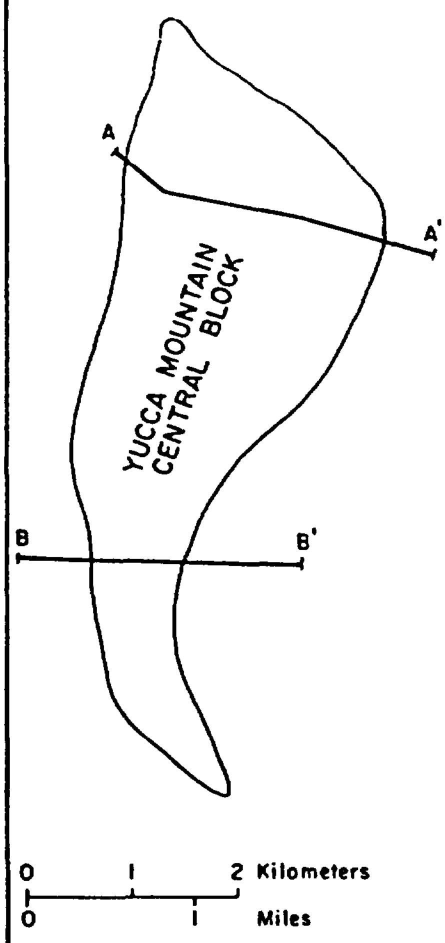
? Queried where relative displacement is doubtful

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

USW H-6

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)

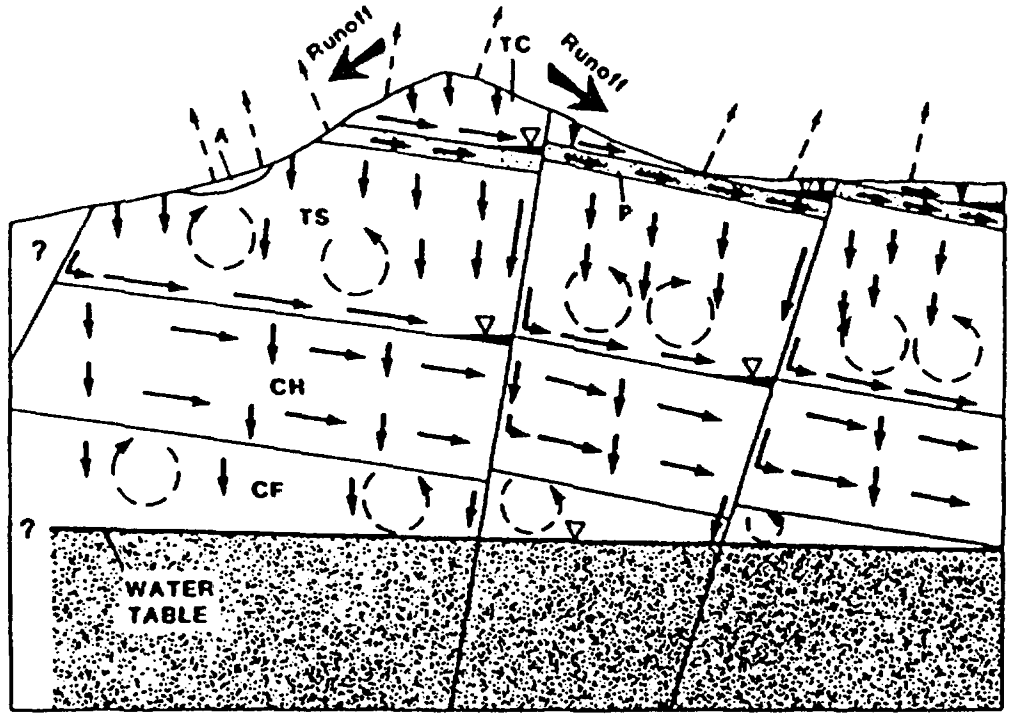
Water, Waste & Land Inc.

Figure 9 (continued)

Symbols and Location Map for Hydrologic Sections Across Yucca Mountain

Date: 3/28/86

Project: 4001



NOT TO SCALE

EXPLANATION

A	ALLUVIUM	QUATERNARY AND TERTIARY	CONTACT
TC	TIVA CANYON WELDED UNIT	TERTIARY (MIOCENE)	DIRECTION OF LIQUID FLOW
P	PAINTBRUSH NONWELDED UNIT		DIRECTION OF VAPOR MOVEMENT
TS	TOPOPAH SPRING WELDED UNIT		PERCHED WATER
CH	CALICO HILLS NONWELDED UNIT		
CF	CRATER FLAT UNIT		

From: Montazer and Wilson (1984)

Water, Waste & Land Inc.

Figure 10

Generalized Section Across Yucca Mountain Showing Flow Regime Under Baseline Cond.

Date: 3/28/86

Project: 4001

effects contribute to the slowing of the water movement may cause a subsequent unsaturated lateral flow development along the contact between the Tiva Canyon welded and the Paintbrush nonwelded units. Some of the water drains into the underlying matrix of the Paintbrush nonwelded unit. The remaining water at the boundary can form perched water bodies in the Tiva Canyon welded unit with drainage at structural features. Much of this water drains directly down these structural features into the water table.

At the contact between the Topopah Spring welded unit and the Paintbrush nonwelded unit, Montazer and Wilson (1984) conclude that while some matrix to matrix flow occurs, fracture flow into the Topopah Spring welded unit is retarded by capillary barrier effects. Near the upper contact of the Topopah Spring welded unit limited fracture flow may occur, however, as flow proceeds downward in the fracture, movement into the matrix diminishes the fracture flow.

From the Topopah Spring welded unit, flow enters the Calico Hills nonwelded unit either from the matrix or through structural flowpaths. Perched water and downdip flow may occur along the upper contact of the Calico Hills nonwelded unit (lateral flow may also occur).

5.0 LOCAL NUMERICAL MODELING

Wang and Narasimhan (1985) developed a general statistical theory to describe the flow phenomena in fractures and the flow phenomena which occurs between the matrix and fractures. The theory yields expressions for fracture saturation, fracture permeability and effective areas of matrix fracture flow as functions of pressure. Using data from laboratory measurements of core samples from different boreholes at Yucca Mountain, and the developed expressions, a numerical simulation for drainage of a fractured tuff column was simulated. The physical data used was from the Topopah Spring welded unit.

Wang and Narisimhan (1985) concluded that the quasi-steady state changes of the fluid-flow field of an unsaturated, porous, fractured system could be simulated approximately without taking fractures into account. In addition, it was concluded that the ambient, steady-state flow field of an unsaturated, fractured porous tuff system could probably be understood without detailed knowledge of the discrete fracture network properties, with the porous matrix the main conduit for fluid flow under large suctions. For transient conditions, detailed information on the fracture characteristics and network geometry is needed to understand the response.

Travis et. al (1984) examined the effects of lithology and the presence of fractures on water flow and radionuclide transport in Yucca Mountain. They assumed two-dimensional flow and transport, and ignored the lateral spreading of water and contaminant fronts. Infiltration was assumed to enter fractures in pulses and travel down the fractures as slugs. Both analytical and numerical solutions were applied to the fracture flow problem using the welded, fractured Topopah Springs data available at that time. In addition, heat load effects due to the high level waste on the surrounding tuff was addressed. The authors made these conclusions based on the results of the models:

1. Significant fracture flow can occur above the water table, but only through high-saturation, low permeability tuff.

2. Diffusion into the matrix and adsorption have a profound effect on transport.

3. Heat load in partially saturated tuff can result in a dry, steam-filled region extending several meters above and below a repository with recharge likely during cooldown phase.

6.0 FUTURE CONDITIONS

Paleoecologic and paleoclimatologic data indicate that the region surrounding the Yucca Mountain and Nevada Test sites was significantly wetter in the past. Geologic evidence also indicates that the water table was significantly higher in the past than it is today. Future pluvial conditions could again cause the water table to rise and thus shorten the unsaturated zone flow paths from the potential repository. In addition, an increased rise in the water table may reduce the distance of ground-water flow from the repository to natural discharge points. With a higher water table, the unsaturated zone thickness beneath the repository would also be reduced. An increase in recharge may be accompanied by an increase in ground water velocity which could lead to shorter residence times for any dissolved radionuclides.

Winograd and Doty (1980) used tufa deposits, calcitic veins, and strand-lines to estimate the places and altitudes of the pluvial ground-water discharge. They assumed that the regional topography had not changed significantly during the last 100,000 years. Some of the conclusions which are stated in their report are:

1. The potentiometric level in the regional carbonate aquifer may have been as much as 50 m higher (altitude 770 m) than the modern level (altitude 720 m) during a past Pleistocene pluvial.

2. The potentiometric level was possibly 6 to 90 m higher beneath central Frenchman Flat. During Wisconsin time, the rise probably did not exceed 30 m.

3. The methods utilized do not permit an estimation of pluvial ground-water level rise in the Cenozoic aquifers beneath the Nevada Test Site. The water table rise in these aquifers might locally have exceeded that in the regional carbonate aquifer.

Spaulding, Robinson, and Paillet (1984) used plant microfossils found in packrat midden to reconstruct the climatic variations in the southern Great Basin of Nevada during the last one-half of the late Wisconsin glacial age. The authors indicate that marked climatic change occurred during the last 6,000 years of the late Wisconsin age (from about 16,000 to 12,000 years ago). Some of the conclusions reached are:

1. Two distinct pluvial climates probably occurred in the southern Great Basin. A full-glacial climate, which ended about 16,000 years ago, was both cooler and drier than the terminal Wisconsin pluvial climate. By about 12,000 to 9,000 years ago increased precipitation during winter and summer caused average annual precipitation to be more than 100 percent greater than present precipitation.

2. Because average annual temperatures during the terminal Wisconsin Age approached those of the present, a substantial relative increase in precipitation is required to maintain high water levels in the southern Great Basin Paleolakes. The terminal Wisconsin pluvial climate probably had considerable effects on the hydrologic and biotic systems of the southern Great Basin.

Carlos (1985) presents evidence, based on mineral analyses of core from test wells at Yucca Mountain, that the paleo water table was relatively higher than the present one (either the water table was higher or the rock mass was lower). The presence of a higher paleo water table would explain the similarity of rock matrix alteration and minerals which occur in fractures and their continuity across lithologic formations. Based on this analysis, the water table may have been about 100 meters higher at the USW G-4 well site in the past.

Available evidence indicates that in the relatively recent past, increased precipitation has led to increased recharge and thus a higher paleo ground water table. Future changes in the climate, which could change the current arid environment to a wetter climate, are possible and could have serious consequences for radionuclide travel times. Czarnecki (1984) performed a study to evaluate what changes that an increase in precipitation would have on the water table around Yucca Mountain. Czarnecki used the two-dimensional, finite element, parameter-estimation model developed by Czarnecki and Waddell (1984) to simulate a 100-percent increase in precipitation (compared to modern-day conditions). The results of the modeling showed that a maximum hydraulic head increase of 130 m would occur near the primary repository area at Yucca Mountain. Also, a change in flux of from 2 to 4 times the present values would occur near the primary repository area which would decrease ground-water travel times.

7.0 AREAS OF UNCERTAINTY AND ADDITIONAL DATA NEEDS

7.1 REGIONAL MODEL

7.1.1 Areas of Uncertainty

All of the regional models (both numerical and conceptual) which have been developed to date concentrate on the saturated zone. This is probably appropriate since the important features of unsaturated flow need only be considered in the immediate vicinity of Yucca Mountain. However, the coupling of the unsaturated zone is not directly addressed in the regional models.

All numerical modeling which has been conducted for the regional system also considers only the saturated flow system. All of the interpretations of the regional geohydrology indicate an extremely complex regime consisting of several aquifers interspersed with aquitards. The modeling conducted to date has consisted of two-dimensional steady-state parameter estimation models. Although the results obtained with these models appear reasonable, it does not appear the 'calibrated' models have been used for predicting ground water travel times in the saturated zone. Indeed, the modelers caution against such use on at least one occasion.

In addition, two important flow considerations are downplayed in the modeling process:

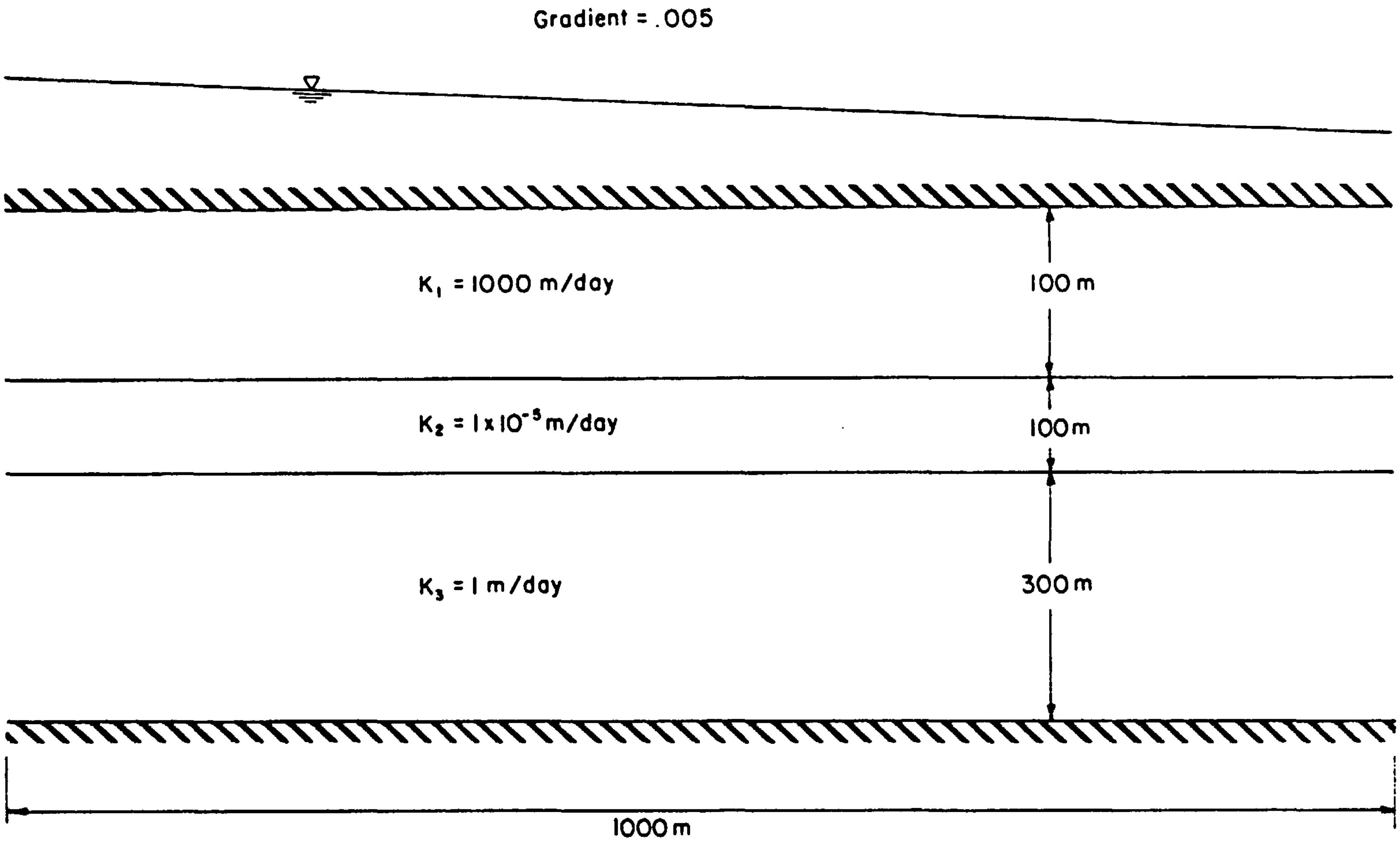
1. Vertical flow components known to exist in certain areas, and,

2. The effects of the parameter lumping (mean transmissivity) as compared to permeabilities in the actual discontinuous, layered system.

The modelers tend to acknowledge the former and concluded that insufficient data is available to justify use of a three-dimensional model. While this may be true, it is commonly known that the assumptions invoked to develop a two-dimensional flow model are grossly violated if the vertical flow component becomes significant. It seems that it may be prudent to evaluate, theoretically if the field problem proves intractable, the effects that this simplification has on the solution obtained.

The basic purpose of parameter estimation models is to develop estimates of aquifer properties (specifically transmissivity for the steady-state case) based on known values of more easily measured parameters (piezometric head distributions and boundary fluxes). While the data is not fully available on which the published model results were based, it appears that the head values which were input to the models were used without regard to whether the value was obtained from a well completed in a particular hydrogeologic unit (e.g. the lower carbonate aquifer) or across a sequence of units. The net effect of this is to obtain an average transmissivity which may mask out zones of large hydraulic conductivity and grossly underestimate the travel times to the accessible environment.

As an example of the effects of the parameter lumping procedures, consider the very simple flow system depicted on Figure 11. While the system at Yucca Mountain is drastically more complex, this simple system will be used to



$$\overline{K} = \frac{K_1 b_1 + K_2 b_2 + K_3 b_3}{b_1 + b_2 + b_3} = \frac{1000(100) + (1 \times 10^{-5})100 + 1(300)}{500}$$

$$= 200.6 \text{ m/day}$$

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Figure 11

Schematic for Example Layered Flow System

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illustrate the potential effects of the parameter estimation techniques employed in the region modeling. The simple system used in this example consists of a highly permeable zone overlying an aquitard which in turn overlies another relatively permeable zone. The average hydraulic conductivity of the layered system can be estimated as the aquifer thickness weighted mean hydraulic conductivity:

$$\bar{K} = \frac{K_1 b_1 + K_2 b_2 + K_3 b_3}{b_1 + b_2 + b_3}$$

Using the parameter values presented on Figure 11, a mean K of 200.6 m/d is obtained. Assuming for convenience a uniform effective porosity, n, of 0.10 allows the seepage velocities to be calculated:

$$v_1 = \frac{K_1 I}{n} = \frac{1000(.005)}{0.10} = 50 \text{ m/d}$$

$$v_2 = \frac{K_2 I}{n} = \frac{1 \times 10^{-5}(.005)}{0.10} = 5 \times 10^{-7} \text{ m/d}$$

$$v_3 = \frac{K_2 I}{n} = \frac{1(.005)}{0.10} = 0.05 \text{ m/d}$$

$$\bar{v} = \frac{\bar{K}\ I}{n} = \frac{200.6(.005)}{0.10} = 10 \text{ m/d}$$

With the above calculated velocities, travel times across the 1000 m distance can be estimated:

$$t_1 = \frac{1000}{50} = 20 \text{ days}$$

$$t_2 = \frac{1000}{5 \times 10^{-7}} = 2 \times 10^{6} \text{ days}$$

$$t_3 = \frac{1000}{0.05} = 2 \times 10^{4} \text{ days}$$

$$\bar{t} = \frac{1000}{10} = 100 \text{ days}$$

As the above calculations demonstrate, the averaging process would provide a travel time of 100 days while contaminants would actually begin to be discharged from the upper layer in about 20 days. As stated previously, the example is substantially less complex than the actual system which exists at

Yucca Mountain. It does provide insight, however, into some of the inherent masking effects which exist in parameter estimation models. Additional data needs to address these problems are presented in the following section.

7.1.2 Additional Data Needs

Waddell (1982) indicated that significant parameters for determining flux through western Jackass Flats and Yucca Mountain are recharge on Pahute Mesa and underflow from regions north of the mesa and stated that because of the importance of this flux, it needs to be determined more accurately. He summarized data needs as follows for the southwestern quadrant of the test site:

1. Determination of hydraulic conductivities or transmissivities by means of well tests.

2. Measurement of head variation with depth.

3. Collection of geochemical information necessary for understanding chemical mechanisms that may retard or facilitate transport of radionuclides.

4. Determination of the properties of the high transmissivity fracture zones.

Czarnecki and Waddell (1984) simulated a subregion of the 1982 model and summarized data needs as follows:

1. Rate of evapotranspiration at Franklin Lake playa.

2. Determination of the shape, orientation, and extent of the barrier north of Yucca Mountain.

The numerical simulations of Waddell (1982), Czarnecki and Waddell (1984), and Rice (1984) are based to a large extent on head measurements from wells across the entire region. Well production rates are not provided and data describing the actual production zones within the test wells are provided only in limited instances.

7.2 LOCAL MODEL

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. As reported in the formal document review by WWL (1986), 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 tendency for flow to occur preferentially in the fracture or in the matrix is extremely sensitive to the hydraulic properties of both of these flow paths and to the imposed net infiltration.

The effectiveness of the textural discontinuities above the Topopah Springs welded unit in limiting flux into the repository horizon may be overstated. Since it is likely that flow at depth is approximately steady, the pressure and permeability at the discontinuities simply adjust to the conditions required to transmit the imposed flux.

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. Again the potential for fracture flow or matrix flow and the conditions for which one flow phenomena dominates need to be resolved.

8.0 WORK PLAN FOR NUMERICAL EVALUATION

Since the proposed repository location is in the unsaturated zone at the Yucca Mountain site, most of the effort up to this time has been concentrated on evaluation of this portion of the flow regime. This is deemed appropriate since it is anticipated that the primary mechanisms which may retard contaminant movement occur in the unsaturated zone. In other words, it is presumed that if it cannot be established that contaminant migration is limited to the unsaturated zone for the time of concern (10,000 years), the Yucca Mountain site will prove unsuitable for a repository, at least in the configuration which is presently proposed. With these considerations in mind, it is anticipated that the modeling which will be conducted during subtask 1.5 will primarily be concerned with flow in the unsaturated regions of Yucca Mountain.

8.1 SATURATED ZONE MODELING

As discussed previously, it is anticipated that saturated zone modeling will be minimal. The saturated zone (regional) modeling which has been presented by the DOE has consisted of using parameter-estimation, steady-state models to determine the transmissivity distribution which occurs within the ground water basin containing Yucca Mountain. The documents pertaining to previously conducted modeling have been reviewed in detail and the methods and procedures utilized appear to have been appropriate. The major problem, as pointed out by the authors of these documents, is the paucity of data which exists for the regional system. Overcoming this problem will be difficult since the basin is extremely large and the major regional system, the lower carbonate aquifer, occurs at great depth. In addition, the extremely complex geology will require that a large number of wells be drilled in order to fully understand the regional groundwater system.

All of the references presented by DOE's regional ground water modelers to support their formulation have not been fully reviewed. As discussed previously, we have identified some areas which should be addressed. The primary concerns are:

1. Effects of vertical flow on the two-dimensional formulation for numerical modeling, and

2. Effects of the averaging process by which the transmissivity distributions were obtained.

The approach to numerical evaluation of the conceptual model for the saturated region will be to more fully review the references by the DOE to the reports on regional modeling. The purpose of this review will be to identify any problem areas in the model formulation.

It is also proposed that an independent saturated flow model be developed to check the results presented by the DOE. It is anticipated that a standard groundwater flow model can be used, as opposed to a parameter estimation model. In other words, a two-dimensional saturated flow model (e.g. the finite difference model described by Prickett and Lonnquist, 1971, or the GRWATER as described by McWhorter and Sunada, 1977) can be developed based on the head and transmissivity data provided by DOE. This will provide a convenient method by which the presented results can be checked. Such modeling would probably consist of the following steps:

1. Select an appropriate two-dimensional ground water flow model for horizontal plane flow. The selection would be based on model availability and consistency of the model with DOE models.

2. Discretize the ground water basin (finite elements or finite difference grids depending on model selected) so that the discretization is consistent with that used by DOE.

3. Determine input values for the model. The values selected would be based on those presented by DOE. For example, transmissivities would be those developed by the regional modeling performed by DOE and the initial heads would be those used as input to their models.

4. Select boundary conditions for the model which are consistent with those used by DOE.

5. Compute the steady-state distribution of heads and compare with those input to the model.

If the results indicate that the differences in input heads and final heads are approximately the same as those presented by DOE, it can be concluded that the modeling conducted by DOE is suitable. In addition, this approach will provide a vehicle to check future modeling conducted by DOE.

To evaluate the concerns previously mentioned, it will be necessary to use a three-dimensional model or a two-dimensional vertical plane flow model. It is proposed to use the latter, at least initially, since formulation is more straightforward and computer costs would be reduced significantly. The exact formulation will require a more thorough evaluation of published data and, hopefully, additional data which has been or is currently being collected by DOE. Review of the NNWSI monthly progress reports indicates that substantial data collection efforts are occurring at the present time. It is anticipated that some of the concerns can be conceptually evaluated using the existing data and relatively simple formulations with a two-dimensional, vertical plane model.

8.2 UNSATURATED ZONE MODELING

As with the saturated region, the data which exists (or at least which has been made available by DOE) is not sufficient to warrant development of a numerical model which fully evaluates all of the flow mechanisms as presented in the DOE conceptual model by Montazer and Wilson (1984). Several aspects of the conceptual model which may have significant effects on the geohydrologic performance of a repository at Yucca Mountain have been identified. The facets of the conceptual model that warrant further consideration are described in the following sections. It is felt that the proposed approach of evaluating the significant portions of the model versus development of a full-fledged numerical simulation of the complete model will provide dual advantages:

1. The relative importance of all aspects of the flow regime can be more easily assessed, and

2. Possible interference between important aspects may be difficult to sort out in a complete simulation model.

8.2.1 Fracture/Matrix Flow Analyses

Wang and Narasimhan (1985) provide the framework for using conventional numerical methods to model the flow which may occur in fractured, unsaturated tuff. The first modeling proposed would consist of duplicating their work using a different model (UNSAT2 as opposed to TRUST). This would not only provide an independent evaluation of their work but would also provide confidence in the use of UNSAT2 for future analyses. Because the modeled area is quite small (on the order of a few fracture blocks) such modeling would be very inexpensive to perform.

After this initial test, it is proposed to use the same numerical methods to evaluate other, more complex flow phenomena within the fractured system which exists at Yucca Mountain. While it is not anticipated that such modeling will lead to a complete definition of the flow regime, it should provide insight into which aspects of flow in fractured, porous media are the most important and will provide the evaluation team with experience as to some of the problems that can be experienced when modeling such complex systems.

One proposed use of the model is to evaluate how the system works with different fracture orientations. Wang and Narasimhan (1985) investigated a simple system with only two sets of fractures, one set of horizontal and one set of vertical fractures. The effects of more realistic fracture orientations were not evaluated. It is anticipated that simple changes will be investigated first (i.e. changes in fracture orientation while retaining the same block size). As experience is gained, it is anticipated that larger systems of fractures can be modeled.

A second proposed use of the model is to investigate how the system reacts to more complex boundary conditions. The modeling conducted by Wang and Narasimhan (1985) evaluated drainage of a saturated column of fracture blocks in response to a constant high capillary pressure applied at the base of the column. While such results provide insight into the flow phenomena which may occur, the boundary conditions imposed are substantially different from those which actually exist at the site. Because transient conditions are shown to be important with the model utilized by Wang and Narasimhan, it is believed that investigation of more realistic boundary conditions, such as, short term, high flux boundaries at the surface may effect the solution. While it is realized that the Topopah Springs outcrop area is of limited extent, the similar Tiva Canyon welded unit is exposed at the surface and may cause pulses of flow through the system.

8.2.2 Capillary Barrier Analyses

The conceptual model presented by Montazer and Wilson (1984) relies on capillary barrier effects to reduce the vertical flow component and thus deep aquifer recharge. It is postulated that a capillary barrier is formed at the interface between the nonwelded Paintbrush tuff and the Topopah Spring welded unit. The perceived effect of such a barrier is that vertical flow in the Paintbrush unit would be transformed into horizontal flow along the interface until a boundary feature (e.g. fault) is reached. The existence of such mechanisms would greatly enhance repository performance because much of the deep aquifer recharge fluid would not percolate through the repository area.

Capillary barriers are difficult flow mechanisms to evaluate. In many cases it is very easy to conclude that such a barrier is impeding flow based on transient conditions when the steady conditions clearly demonstrate that no such barrier exists. For the simple case of horizontal layering, it is not difficult to show that the initial formation of a capillary barrier during downward flow retards that flow into an underlying layer for a period of time. However, assuming persistence of the conditions which caused the downward flow to occur, the pressure and permeability in the overlying unit adjust so that steady downward flow occurs.

Evaluation of a dipping layered system is substantially more difficult than for a simple horizontal, layered system. While the apparent barrier may cause some lateral flow to occur, it is probable that such effects are local and the predominant flow direction is downward. It is also anticipated that capillary barrier effects are extremely sensitive to the type of boundary condition as well as distance to the boundary. Because of the possible relative importance of this aspect of the flow, it is believed that the best approach to modeling will be to evaluate a simple porous media system initially. As experience is gained, more complex systems will be evaluated. The culmination of this modeling is anticipated to be the combination of the fractured matrix system evaluated in the previous section with the capillary barrier models developed in this section. The results will, hopefully, provide clarification of the performance of capillary barriers in fractured, porous tuff.

8.2.3 Persistence of Water Flow in Fractures Affected by Air in the Matrix

Current models for transient flow of water in the partially saturated, fractured tuff indicate that adsorption of water into the matrix blocks rapidly depletes fracture flow and limits the depth of penetration of flow in the fractures. However, the models that we have reviewed, either conceptual or numerical, do not account for the effects that resistance to flow of the displaced air in the matrix may have on the rate of water adsorption. There appear to be two circumstances at Yucca Mountain that cause us to believe that air in the matrix blocks may be important to questions relating to fracture vs. matrix flow of water in the transient state:

1. Large water saturation values in the matrix (~80 percent).

2. Potential for large scale air entrapment by rapid saturation of bounding fractures.

Clearly, the entry of water into matrix blocks from the bounding fractures must be accompanied by a corresponding change in the air volume. The air volume may change to accommodate additional water by compression, by displacement of air, or by both compression and displacement.

Resistance to flow of displaced air exerts a "back pressure" on the absorbing water, causing the rate of absorption to be reduced. In most circumstances the small viscosity of air relative to that of water causes this to be a negligible factor. However, at large water saturation the permeability to air becomes much less than that of water and the resistance to air flow becomes significant even though it has a small viscosity. We believe this may be the prevailing situation in the matrix blocks at Yucca Mountain.

Rapid saturation of the fractures bounding a matrix block effectively entraps the air in the matrix porosity. The only mechanism for escape of the air is by countercurrent flow of the air through the invading water. The resistance to air flow under this circumstance is very large and causes a very marked reduction in water penetration of the matrix. Correspondingly, water tends to persist in the fracture for a longer time and may penetrate much more deeply than would otherwise be expected.

The importance or lack of importance of the resistance to air flow in the Yucca Mountain unsaturated zone has not been demonstrated. A simple analytical calculation that includes the resistance to air flow in the matrix should suffice to investigate whether further consideration of this aspect is warranted. This analytic calculation would establish a bounding solution and be useful for assessment of more complex calculations should they be warranted.

8.2.4 Vapor Transport

The entire question of the effects of vapor transport on the water balance of the unsaturated zone at Yucca Mountain remains unresolved. Water may be transported in the vapor phase by diffusion and by convection (advection) with the flowing air phase. It is difficult to imagine at this time that vapor transport by diffusion alone can have a significant effect on the overall water balance. However, it is expected that vapor diffusion from the matrix to the fractures would play a significant role in supplying water vapor to a gas phase flowing in the fractures due to natural convection. Whether circumstances at Yucca Mountain are such to permit or promote natural convection have not been investigated. Given the very small magnitudes of liquid water fluxes at Yucca Mountain, it is possible that vapor fluxes may have a relatively significant effect on the overall water balance. Certainly more attention in the conceptual model to the vapor transport mechanism is warranted. This attention should be directed toward reconciliation and comparison of the physical atmospheric conditions at Yucca Mountain with the basic physics that act to create free and forced convection.

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