U.S NUCLEAR REGULATORY COMMISSION
DIVISION OF WASTE MANAGEMENT

NNWSI CONCEPTUAL MODEL UPDATE

NNWSI Repository Project
Subtask 1.4

Prepared by

Thomas Sniff
Water, Waste, & Land, Inc.

for

Nuclear Waste Consultants Inc.

TECHNICAL ASSISTANCE IN HYDROGEOLOGY
PROJECT B - ANALYSIS
RS-NMS-85-009

APRIL, 1988

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April 27, 1988

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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: Semi-Annual Update of NNWSI Conceptual Model Evaluation Report

Dear Mr. Pohle:

This cover letter transmits to the NRC staff Water, Waste and Land's (WWL) semi-annual update of the Conceptual Model Evaluation Report (Subtask 1.4). The report has received a management and technical review by M. Logsdon of Nuclear Waste Consultants. The reports have been completed under WWL's quality assurance procedures in compliance with NWC's project-specific QA Plan.

This conceptual model report presents a summary of those models presented by the Department of Energy (DOE) in the Consultation Draft Site Characterization Plan (CDSCP). WWL also summarizes an alternative model recently presented by Szymanski (1988), which is considerably different from those presented in the CDSCP. WWL notes that DOE recognizes the need for a fairly detailed knowledge of the potential field but has not addressed this problem in terms of requiring knowledge of recovery time necessary for initial conditions to return around the wellbore. WWL proposes several tasks which will lead to a better understanding of recovery time. WWL also recommends the use of apparent ages for the determination of groundwater velocities be investigated further. Task Descriptive Summaries regarding these matters will be submitted in the future.

Submission of this update report completes the contract deliverable for Subtask 1.4 at this time. WWL will update the Numerical Evaluation of Conceptual Models Report on a semi-annual basis, as directed in the current contract.

If you have any questions concerning this letter or the attached report, please contact me immediately.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS, INC.

Mark J. Logsdon, Project Manager

Att: NNWSI Conceptual Model Evaluation - Semi-Annual Update Report

cc: US NRC - Director, NMSS (ATTN PSB)
HLWM(ATTN Division Director)
Edna Knox, Contract Administrator
HLTR (ATTN Branch Chief)
D. Chery, HLTR
W. Ford, HLTR

bc: L. Davis, WWL

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

April 8, 1988

Nuclear Waste Consultants
ATTN: Mark Logsdon
155 South Madison Street, Suite 306
Denver, CO 80209-3014

Dear Mark:

Enclosed is the Task 1.4 update report which, according to our contract, was due at the end of March. Sorry for the delay in getting this to you, but I had difficulty finding the time to review it after Tom got it written. He is taking a copy with him to Las Vegas for the Conceptual Model meeting next week.

Also enclosed are new title pages for Technical Reports #7 and #8 with the authors listed as requested by the NRC. On future Technical Reports we will include this information with the draft as well as final reports.

Finally, the invoice for the month of March is enclosed. I did not have time to complete the Monthly Status Report today but did not want to hold up your invoice preparation. I will forward the MSR on Monday. Again, I apologize for any inconvenience this may cause you or Barb.

Please feel free to contact me if you have questions or comments.

Sincerely,

WATER, WASTE AND LAND, INC.

Lyle A. Davis

Lyle A. Davis, P.E.
Project Manager

Conceptual Model Update

Subtask 1.4

Submitted to

Nuclear Waste Consultants

Denver, Colorado 80209

and

U.S. Nuclear Regulatory Commission

Washington, D.C. 20555

Prepared By

Water, Waste and Land, Inc.

Fort Collins, Colorado

April, 1988

Contract No.: RS-NMS-85-009

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1.0 INTRODUCTION

The Consultation Draft Site Characterization Plan (CDSCP) prepared by the Department of Energy (DOE) describes the current conceptual models for flow in the hydrologic system occurring around and at Yucca Mountain in detail. For the purposes of site characterization, the DOE has divided the hydrologic regime into two study areas:

(1) A hydrographic, which delineates the regional surface water system

(2) A hydrogeologic which has been divided into regional and site systems. The regional hydrogeologic system consists of three groundwater subbasins that together form a part of the Death Valley groundwater basin.

The DOE considers the regional hydrology and hydrogeology to be fairly well understood. The site hydrology has considerable uncertainty primarily regarding the degree to which the limited data base represents the actual range of conditions at the site, especially in the unsaturated (vadose) zone.

With regard to the hydrographic study area, the DOE believes that the uncertainties are due to insufficient streamflow and flood records to allow predictions of future conditions with confidence. For the hydrographic study area, the uncertainties enumerated by the DOE are:

1. Conditions occurring at several portions of the regional flow system are uncertain.
2. The reasons for a locally steep hydraulic gradient near the site are unknown.
3. The nature and quantities of present and future infiltration are unknown.
4. There is insufficient water chemistry data for the verification of conceptual-flow models.
5. The potential field in the unsaturated zone is unknown.
6. The conceptual model of groundwater flow through the unsaturated zone at the site is incomplete.

The conceptual models presented in the following sections are a summary of those presented by the DOE in the CDSCP.

2.0 SURFACE WATER HYDROLOGY

The description of the surface hydrology is required primarily for two reasons: (1) the potential for floods and the potential hazards to the surface facilities due to floods, and (2) to help evaluate the amount of infiltration and establish the relationship between surface runoff and groundwater recharge.

The flood analyses to be performed in the hydrographic study are primarily needed to provide information needed for design and performance assessment of the surface facilities. Flood data will also be used to help quantify infiltration rates. Therefore, only the flood studies which are applicable to infiltration studies will be described in greater detail.

There are no perennial streams in or near the Yucca Mountain area. However, surface runoff does occur, most commonly in association with regional storms during autumn, winter, and spring as well as from localized summer thunderstorms. There is not yet adequate quantitative data on rainfall, runoff, and evaporation to determine rainfall-runoff-recharge relations for individual storms, seasons, or years. A number of investigations are currently underway to improve the surface-water hydrologic data base at Yucca Mountain and surrounding areas.

Water chemistry data has indicated that washes may be the principle source of groundwater recharge beneath Yucca Mountain. It has been established that modern rainfall and runoff contribute recharge to the shallow groundwater system in the tuffaceous valley-fill aquifer. However, the DOE has been unable to determine the amount of recharge based on the existing data.

The DOE states that a regional hydrologic budget is one method of estimating the amount of water that enters, percolates through, and recharges the saturated zone beneath Yucca Mountain. High accuracy of the data is required to keep the small recharge estimates from being masked by the uncertainty in the precipitation data. The DOE concludes that maintaining a high level of accuracy for the other elements of the water budget probably is unrealistic. Meaningful estimates of some of the components cannot be made at this time due to the lack of site specific data.

3.0 REGIONAL GROUNDWATER HYDROLOGY

The regional groundwater hydrology, as defined in the CDSCP, is based on the Death Valley groundwater basin. The description of this basin is described in the following sections.

3.1 Overview

The saturated zone hydrogeologic units, as currently defined, have been discussed in detail in previous Conceptual Model updates. Only a brief listing will be given here. 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.

The generalized distribution of saturated zone hydrogeologic units in the region of interest are shown on Figure 1.

The hydrogeologic region of interest (study area) is the Death Valley groundwater basin, which includes three groundwater subbasins, Oasis Valley, Alkali Flat-Furnace Creek Ranch, and Ash Meadows, which are shown on Figure 2. The recharge areas shown on Figure 2 are those areas of the basin that receive an average annual precipitation of 200 mm or more. Surface-water runoff along major stream channels, such as Fortymile Wash, probably results in significant recharge. The DOE concludes that some uncertainty remains on the quantities and distribution of recharge over the region.

The groundwater is considered to move from recharge areas primarily in the northern and eastern part of the basin to the discharge areas in the western and southern part of the basin. Groundwater discharge from the groundwater basin is by:

(1) spring flow,

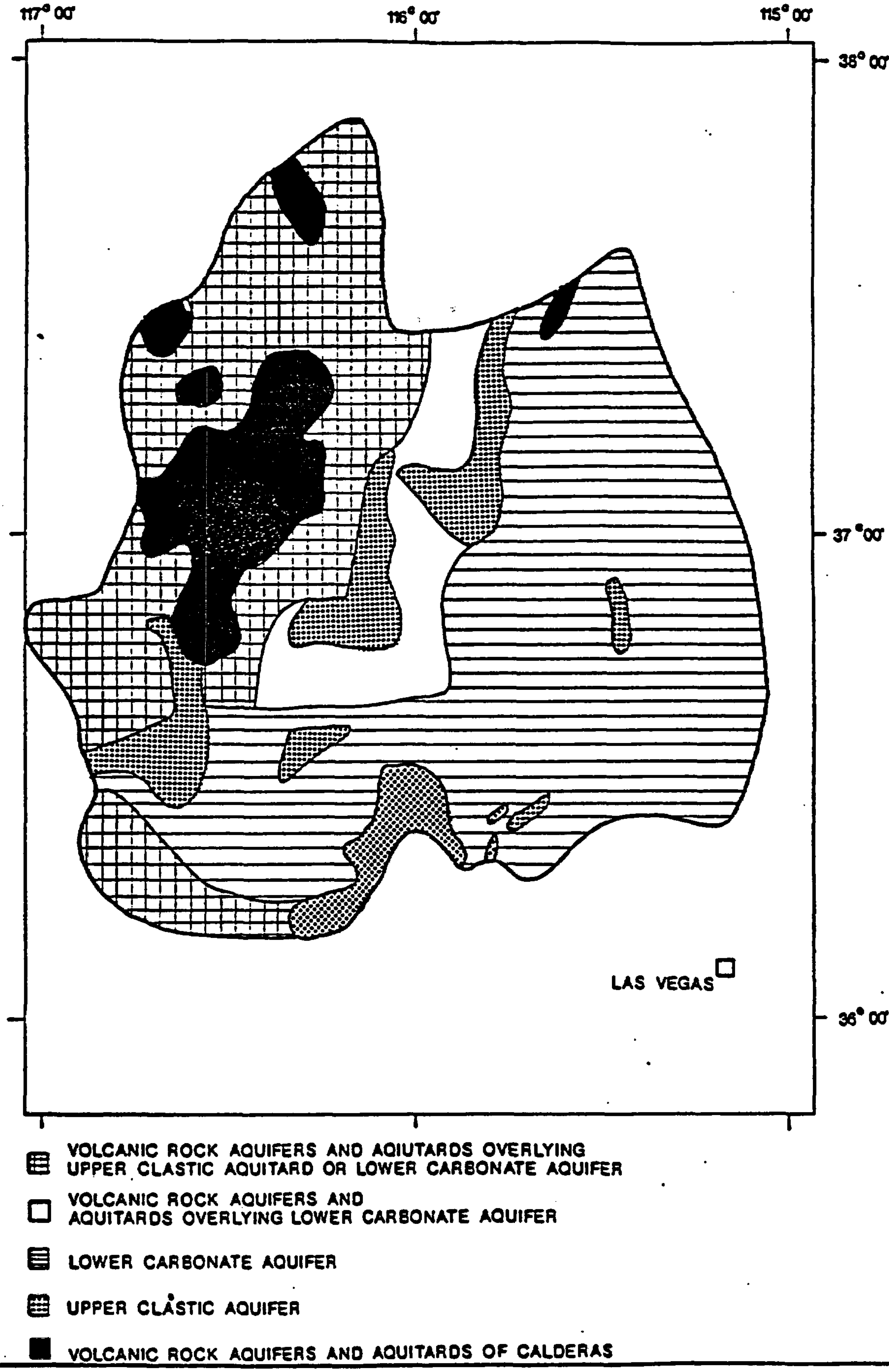

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Figure 1
Generalized Distribution of Hydrogeologic Units in the Saturated Zone

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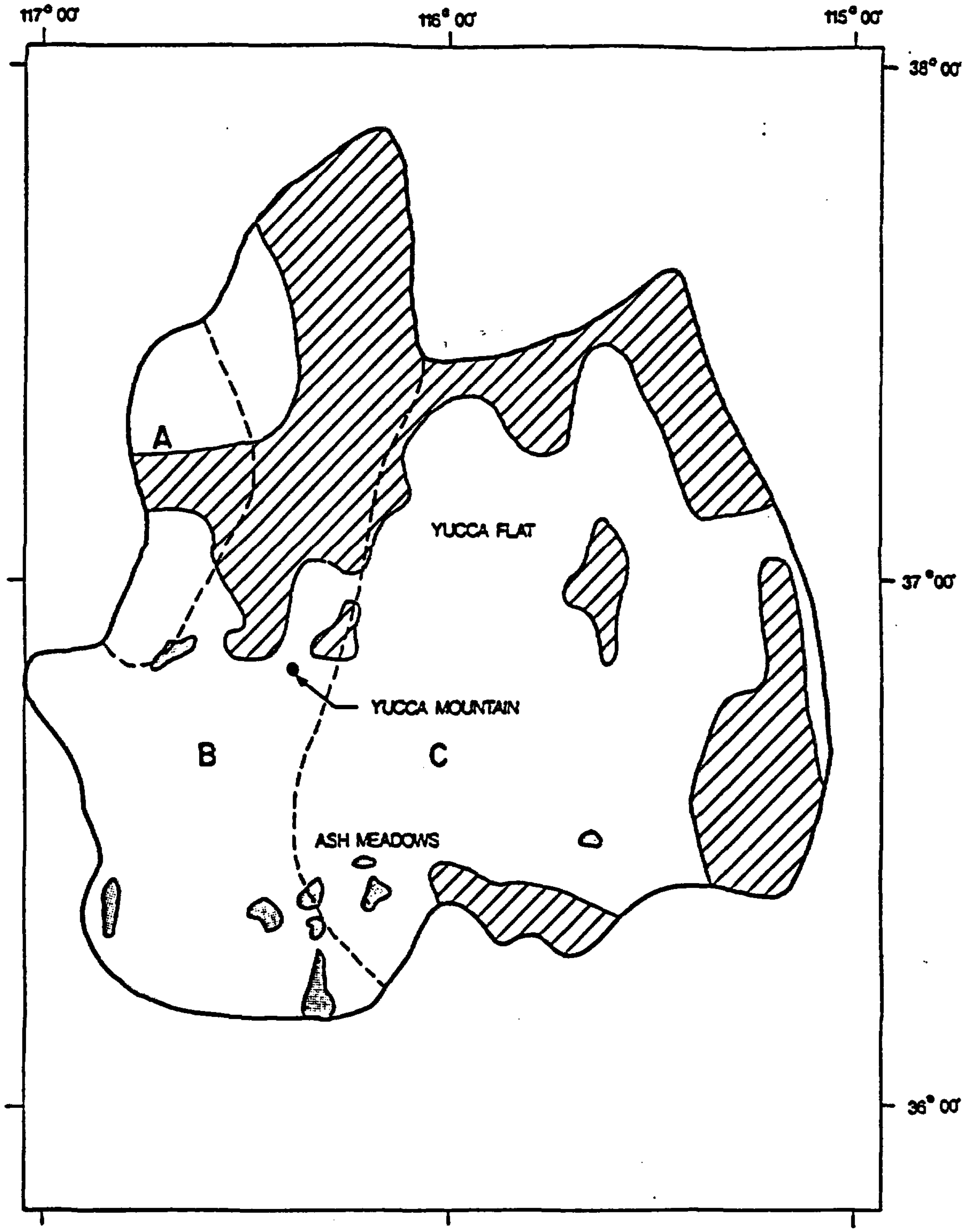

RECHARGE AREAS

DISCHARGE AREAS

A OASIS VALLEY SUBBASIN

B ALKALI FLAT - FURNACE CREEK RANCH SUBBASIN

C ASH MEADOWS SUBBASIN

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Figure 2
Death Valley Ground Water Basin

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(2) evapotranspiration from phreatophyte areas where depths to groundwater are less than about 15 m, and

(3) evaporation from bare soil areas such as playas, where depth to groundwater is less than about 5 m.

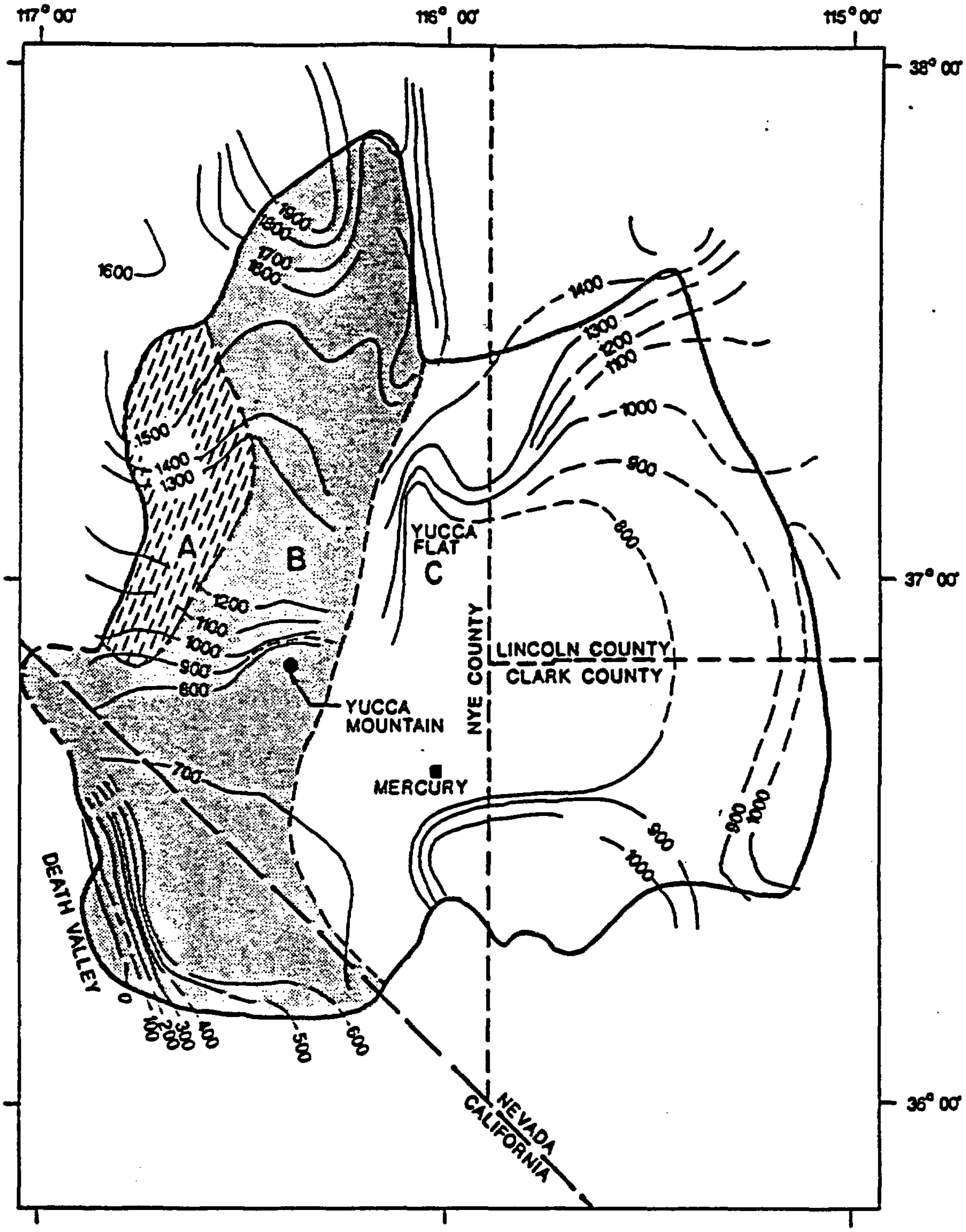
The general flow directions have been determined by the contour lines of the potentiometric surface, which is shown on Figure 3. The DOE believes that the local flow direction also depends on the anisotropy. Equipotential lines shown on Figure 3 are based upon composite water levels from several hydrogeologic units and are averages of the hydraulic heads in the boreholes.

As indicated on Figure 3, steep hydraulic gradients occur in several areas, including north of Yucca Mountain, near Death Valley, southeast of Mercury, and north of Yucca Flat. The DOE considers that these steep gradients may be due to stratigraphic, structural, or hydraulic conditions, or to a combination of these conditions. The definition of areas of steep gradients and evaluation of the causes of these gradients are important considerations in determining groundwater flow paths and velocities.

Thermal conditions may also affect gradients, but preliminary analyses lead the DOE to believe such effects probably are not significant influences on these steep gradients. Temperature variations with depth have been measured in selected boreholes in the hydrogeologic study area and surrounding area. The DOE considers local movement of the groundwater to be indicated by temperature profiles in wells.

The DOE's conceptual model has virtually all the groundwater discharge from Oasis Valley occurring by evapotranspiration and underflow to the Amargosa Desert. Flow paths are from the principal recharge areas, mostly in the central part of the subbasin, southward to the discharge area at the southern end of the subbasin. The flow is principally through volcanic-rock aquifers to the valley-fill aquifer underlying the discharge area. Some of the spring discharge is warm, which the DOE suggests is an indication of deep circulation of groundwater. Groundwater not discharged by evapotranspiration at the southern subbasin boundary flows southward through the valley fill aquifer, past an alluvium-filled narrows, and into the Amargosa Desert.

The Ash Meadows subbasin boundaries are associated with mountain ranges and are generally groundwater divides (potentiometric highs) resulting from greater amounts of precipitation associated with higher land surface altitudes. The boundary of the subbasin is based primarily on the Winograd and Thordarson



LINES OF EQUAL POTENTIOMETRIC LEVEL IN METERS ABOVE SEA LEVEL

A — OASIS VALLY SUBBASIN

B — ALKALI FLAT - FURNACE CREEK RANCH SUBBASIN

C — ASH MEADOWS SUBBASIN

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Figure 3
Potentiometric Surface

DATE: Mar. 1988

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(1975) interpretation. From northern Yucca Flat to Ash Meadows, groundwater apparently flows downward through the valley fill aquifer and volcanic-rock hydrogeologic units into the underlying carbonate aquifers beneath Yucca Flat.

The potentiometric level is as much as 43 m lower in the carbonate aquifer than in the overlying units. The lower carbonate aquifer transmits most of the water in the subbasin, but other lithologies are locally important. These interpretations are based primarily on data from two well locations. An unknown amount of groundwater flows past the springs at Ash Meadows to the Alkali Flat-Furnace Creek Ranch subbasin to the west.

The groundwater flow in the Alkali Flat-Furnace Creek Ranch subbasin is based upon two dimensional computer modeling. Groundwater is assumed to flow 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 to discharge areas located at Franklin Lake playa and Furnace Creek Ranch in Death Valley.

3.2 Geochemistry

The chemical composition of groundwater in the region is principally determined by:

1. Reactions with carbonate and volcanic rocks or rock fragments,
2. Concentration of dissolved chemicals by evaporation,
3. Formation of smectites, zeolites, and evaporite minerals,and
4. Mixing of waters of different compositions.

The DOE discusses the chemical composition of the groundwater within the hydrogeologic study area in terms of the tuffaceous, lower carbonate, and valley fill aquifers.

3.2.1 Tuffaceous Aquifers

The tuffaceous rocks are dominated by sodium bicarbonate water. The water evolves principally by dissolution of rhyolitic volcanic glass and subsequent precipitation of various zeolites and smectite clays. Incongruent dissolution in the tuff beds within Rainier Mesa preferentially releases sodium, calcium, and magnesium while retaining potassium. Calcium and magnesium show progressive depletion relative to sodium, not by ion exchange but due to the effective removal of bivalent ions as clinoptilolite and montmorillonite are precipitated.

Water samples from Oasis Valley show that the dominant anion is bicarbonate. The principal source and control of bicarbonate is the reaction of dissolved soil-zone carbon dioxide with various mineral phases. The Oasis Valley samples had pH values ranging from 7.6 to 8.7 and temperatures ranging from 18 to 41 degrees Celsius.

For 14 test wells in and near the exploratory block, sodium and bicarbonate ions predominate. The water temperatures range from 22 to 56 degrees Celsius and pH values are 6.6 to 9.2. The DOE states that the groundwater at Yucca Mountain is not chemically homogeneous. Groundwater from the wells in the Yucca Mountain area has a significant degree of lateral and vertical chemical variability. The data from 55 water samples from the pores and fractures of the saturated tuffs of Rainier Mesa show that the fracture water is predominantly of sodium bicarbonate type. In the unsaturated zone the interstitial water, however, shows much higher concentration of chloride and sulfate relative to bicarbonate.

3.2.2 Lower Carbonate Aquifer

Two varieties of waters, a calcium magnesium bicarbonate type and a mixed type, are characterized by the DOE as existing in the aquifer. The DOE considers that the variation in composition corresponds to the distance from recharge areas. Groundwater in close proximity to the Spring Mountains recharge area contained calcium, magnesium, and bicarbonate as primary constituents. At intermediate points along the flow system, the concentrations of sodium and sulfate are increased. Near the Ash Meadows discharge area sodium, sulfate, and chloride are present as major ions. Temperatures typically range between 26 and 38 degrees Celsius and pH values are between 7.0 and 8.3.

3.2.3 Valley Fill Aquifer

Water in the tuffaceous valley fill has a composition similar to that of water in the tuffaceous aquifer. Because of the shallowness of the water table in some areas, evapotranspiration results in increased concentrations of some species. Although additional reactions may occur between groundwater and tuffaceous detritus, the principal mechanism for concentrating sodium and bicarbonate is the decrease in volume of water due to the proximity of the water table to the atmosphere and soil zone. Temperatures vary between 18 and 31.5 degrees Celsius.

3.3 Summary

Recharge to the tuff aquifer in Oasis Valley is principally by underflow and flow from the northern tuffaceous highlands. The lower carbonate aquifer is recharged by precipitation in the Paleozoic carbonate highlands to the northeast. Other sources of recharge to this aquifer are interbasin underflow from the Pahranagat Valley and downward leakage from the Cenozoic strata. In addition to upward leakage from underlying Cenozoic and Paleozoic strata, the valley fill alluvium receives recharge from surface runoff infiltrating along present day stream channels.

Discharge from the tuff aquifer occurs as (1) vertical leakage to the underlying lower carbonate aquifer, (2) subsurface flow infiltrating into the valley fill, and (3) direct spring discharge. Ash Meadows, a fault-controlled spring line, is the primary discharge area for the lower carbonate aquifer. In other areas of the Amargosa Desert, water from the lower carbonate aquifer leaks upward into the valley fill. Evapotranspiration is the most likely mechanism for valley fill discharge.

The chemistry of groundwater in the NTS and vicinity is determined primarily by interactions between water and the reactive components of rock and soil zones through which the water has traveled. Water having moved only through tuff strata or through valley fill rich in tuffaceous detritus has a sodium-bicarbonate nature. Groundwater that has traveled only through the lower carbonate aquifer or valley fill rich in carbonate detritus is of calcium-magnesium-bicarbonate character. In areas of downward crossflow from the Cenozoic strata, the lower carbonate aquifer has water of a mixed nature, that is, a calcium-magnesium-sodium-bicarbonate type.

4.0 SITE GROUNDWATER HYDROLOGY

The site hydrogeologic system includes both the vadose zone and the saturated zone at and near Yucca Mountain. At the beginning of Section 3.9, Site Hydrogeologic System, the DOE makes the following statement:

> "The fundamental concepts and theory of moisture flow and storage within variably saturated natural media...may not be applicable to indurated tuffs that have low porosity and low permeability and that also may be highly fractured. Consequently, a complete characterization of the site hydrologic system must examine the mechanisms by which moisture can be stored and transported within the fractures and interstices of deeply buried tuffs. Only then can a set of hypotheses be developed to construct a macroscopic conceptualization within which these mechanisms act to determine the present, naturally occurring hydrologic system."

Moisture, as used by the DOE, includes both liquid water and water vapor.

4.1 Conceptual Model

The unsaturated zone hydrogeologic units are still based on the divisions developed by Montazer and Wilson and are the same as those which have been used by WWL in previous reports. The conceptual flow model in the vadose and saturated zones remains essentially the same as previously presented and provides the starting point for the site characterization process. The DOE seems to be accepting the possibility that significant additional work needs to be performed to refine the conceptual model of the unsaturated zone. The DOE conceptual model is summarized in the following:

1. Moisture enters as liquid-water flow into and within the fractures of the surficial Tiva Canyon welded unit (TCw).

2. Lateral flow may occur at the contact between the TCw unit and the underlying Paintbrush nonwelded unit (PTn).

3. Both vertical and lateral flow may occur in the relatively high conductivity PTn unit.

4. Flow in the Topopah Springs welded unit (TSw) is expected to be essentially vertical. Under steady-state conditions, flow is expected to occur within the matrix for fluxes less than some critical value.

5. Lateral flow may be induced in the TSw unit at its contact with the underlying Calico Hills nonwelded unit (CHn).

6. Flow in both the CHnv (vitric) and CHnz (zeolitic) units is predominantly vertically through the matrix.

7. The fault zones may or may not be pathways for the vertical moisture flow depending on the adjoining formations.

8. Temperature-driven moisture transport may occur, especially within the highly fractured TSw unit.

9. Moisture flow within the deep unsaturated zone at Yucca Mountain may be occurring under essentially steady-state conditions.

10. 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 acknowledges that it will be difficult to assess the steady-state flow hypothesis during the short time span available for the site-characterization program. 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 analysis and interpretation of the Yucca Mountain hydrologic system will be complicated greatly if the steady-state approximation is proved invalid.

In the saturated zone, differences in potentiometric levels indicate general directions of groundwater flow. However, because of the nearly flat potentiometric surface under parts of Yucca Mountain, specific flowpath directions are currently difficult to define. Furthermore, the degree of anisotropy has not been determined.

Because of the presence of a natural geothermal gradient, moisture flow within the unsaturated zone at Yucca Mountain is not strictly isothermal. Thermal logging of drillhole USW G-1 yielded a mean gradient of 24.6 degrees C per 1000 meters which suggests a temperature difference of about 13 degrees C between the water table and land surface. The possible effects of thermal gradients on the groundwater flow system at Yucca Mountain are unknown at this time. Thermal gradients may be causing upward flow in the unsaturated zone. Little information exists on thermal gradients in the saturated zone.

4.2 Theoretical Flow Representations

One of the theoretical approaches which the DOE has advanced and which has been previously considered in the Conceptual Model Updates is the equivalent porous media model. A considerable difference may exist in the scale of (1) the bulk-rock volume appropriate for defining the rock-matrix hydrologic properties, which are averaged over the pore space, and (2) the volume containing many fractures that is required to define the bulk properties for the fractures. Pores and fractures may effectively define two overlapping continuum systems, each regarded as an equivalent porous medium.

The macroscopic continuum approach for fractures and rock matrix has been examined theoretically by Klavetter and Peters (1985), who conclude that it appears to be applicable to the unsaturated, fractured tuffs at Yucca Mountain. This approach would not be applicable to sparsely fractured media or to media in which the mean fracture apertures exceeded a few millimeters and, thus, for which the medium would cease to be approximated by a bundle of capillary tubes.

Theoretical models for liquid-water flow in single fractures have been developed but have not been fully tested in the field or laboratory. In a fractured medium, the matric potential within the fractures need not be equal to that within the enclosing rock matrix, although pressure equilibration will tend to be established over time. Large differences in matric potential between rock matrix and fractures may occur under transient conditions, however. Under most natural conditions, water vapor and liquid water will be in local thermodynamic phase equilibrium within the pore and fracture space with the equilibrium vapor pressure being a function of both temperature and matric potential. Liquid-water storage within fractures probably is insignificant, but the flow of liquid water within and across fractures is not yet well understood.

The permeability is likely to be anisotropic in layered media, such as bedded tuffs, and in fractured media in which the resultant directional dependence is determined by the geometry of the fracture network. The DOE believes it is not clear that the procedures developed for soils to infer closed-form analytic representations for the permeability-saturation dependence (e.g., van Genuchten, Brooks and Corey) are appropriate to indurated fractured tuffs, but such representations have been used in preliminary studies at Yucca Mountain (WWL, 1986a).

Because chemical alteration can be expected to destroy preferred orientation of rock properties, the matrix properties of the altered, zeolitized CHnz unit are thought to be largely isotropic. The fracture and fault systems within the densely welded units, however, probably introduce an inherent anisotropy wherever they are present and contribute significantly to moisture or pore-gas flow. Two principle fracture sets have been identified within the Yucca Mountain block with both fracture sets exhibiting steep to vertical dips. Quantitative data by which to characterize rock-matrix and fracture-induced anisotropy is currently lacking.

Air flow in fractures and pores is usually considered to be Darcian in nature. However, in pores and fractures whose apertures are a few times the mean free path of pore-gas molecules, the Klinkenberg effect will be noticeable. The TSw unit's permeability with respect to nitrogen gas has been shown to be a strongly dependent function of pore-gas pressure for which the Klinkenberg constant was 0.76 MPa.

4.3 Baseline Monitoring

Of eight monitoring boreholes drilled into the unsaturated zone, only one, drillhole USW UZ-1 is currently being monitored. The DOE states that "based on observations of instrument performance and analysis of data collected from drillhole USW UZ-1 the concept of long-term monitoring within the unsaturated zone in deep boreholes appears tenable." Details from the USW UZ-1 borehole are described by WWL (1986b). A summary of the instrumentation of USW UZ-1 is provided in the following paragraph.

Thermocouple psychrometers and heat-dissipation probes (to measure matric potential) were emplaced at various locations in the wellbore. Pressure transducers were emplaced to measure pore-gas pressure. Several operational problems were identified during the two year trial monitoring period. These included possible long-term drift of the pressure transducers, long equilibration times for the thermocouple psychrometers, and frequent failure of the heat-dissipation probes. Because the heat-dissipation probes and the thermocouple psychrometers were emplaced under differing initial conditions in different backfill materials with differing hydrologic properties, there is a considerable range of matric potential values measured simultaneously by different instruments at the same level within the borehole.

Pneumatic potentials (pore-gas pressures) have also been measured within a piezometer nest installed in borehole UE-25a#4, about 1.6 km southeast of drillhole USW UZ-1. Diurnal and barometrically induced fluctuations of gas pressure of about 0.25 kPa have been observed in these boreholes to depths of about 30 m. Seasonally induced pressure variations were observed at greater depths.

Twenty-five boreholes for the measurement of water-levels of the saturated zone currently exist at and near the site. 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 drillholes are planned to further define the gradient of the potentiometric surface. To the east and south of Yucca Mountain, high accuracy and precision are needed because in parts of this area the water table is nearly flat and calculation of the gradient is sensitive to small errors in water-level measurements.

Water levels in the vicinity of Yucca Mountain range in altitude from about 730 m to 1,030 m above sea level and generally represent water-table or unconfined conditions. It is not known whether the slope of the water table is uniform, or if there are abrupt flections. The cause for the steep slope to the north and west is not yet known. The DOE believes it may be that 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 planned.

The apparent range of water-level fluctuations, as indicated by recently installed downhole pressure transducers in some drillholes, is commonly smaller than the precision from periodic or repetitive measurements made with calibrated tapes or cables, and, therefore, hydrographs of the limited data available might be imprecise and possibly misleading. Therefore, none of the hydrographs have yet been published. The DOE states that apparent trends in water levels (beyond the earth-tide or other cyclic variations that occur within a few days or less) cannot be confirmed until the downhole measuring equipment is removed, checked, and recalibrated.

Techniques for the measurement of relative hydraulic conductivity on very low permeability tuffs, such as welded tuff matrix material from the TSw, are under development. Standard laboratory methods are not yet available by which the moisture-characteristic relations for fractures and fractured rocks can be determined, and reliance must be made on theoretically based models and approximations.

Available data on the magnitude and distribution of moisture content within the unsaturated zone are scanty and incomplete. Based on gravimetric moisture content of drill cuttings continuously collected at USW UZ-1 and USW

UZ-6, the TSw unit had a mean saturation of about 0.5. When this saturation is utilized in the van Genuchten (WWL, 1986a) equation with parameters assumed to be representative (Peters, et al, 1986) for the TSw unit, a corresponding matric potential of about -7 MPa is obtained. This is quite different from the mean of about -0.3 MPa for the TSw unit implied from the matric-potential data reported for drillhole USW UZ-1.

Hydraulic conductivity of tuffs may decrease with increasing depth. At greater depths, formation of minerals in fractures or closing of fractures because of greater lithostatic stresses tend to decrease the aperture of fractures. The DOE considers that no fracture flow may occur below a depth of 790 m in rocks penetrated by drillhole USW H-1 because the greater overburden pressure decreases fracture porosity. It is not known if these conditions prevail throughout the Yucca Mountain area.

The minimum compressive stress is oriented N 50 to 60 degrees W, which is coincident with the regional direction of tectonic extension. Fractures with these orientations may tend to be closed by tectonic stresses whereas fractures with orientations of N 30 to 40 degrees E may tend to be more open. Therefore, the system may not be hydraulically isotropic because the north-northeast-striking fracture set may be more transmissive.

The DOE concludes:

> "Knowledge of the role of fractures in controlling paths and velocities of groundwater flow at Yucca Mountain is insufficient to characterize the flow system adequately. An understanding is also needed of the applicability of the concepts of porous-media equivalents for describing the flow system."

5.0 AN ALTERNATIVE CONCEPTUAL MODEL

Szymanski (1988) presents a conceptual model of the Death Valley groundwater system which is considerably different than that presented in the CDSCP. The following sections contain a summary of the conceptual model presented by Szymansi (1988) and does not necessarily represent opinions of or endorsement by WWL or Nuclear Waste Consultants (NWC). Szymanski's primary argument against the DOE's model is that it does not consider the volcano-tectonic setting of the Yucca Mountain site. Szymanski's model considers the fact that the regional groundwater system is influenced to a greater degree by the volcano-tectonic setting. According to his model, the site area has convective mass and heat transfer occurring because of mantle upwelling. This in turn is responsible for two tectonophysical factors:

1. Heat flow and the gravitational hydraulic pressures acting at the flow system boundaries are the energy sources which together are responsible for the movement of groundwater. The area has high, and according to Szymanski, spatially heterogeneous heat flow.

2. Because of the mantle upwelling, strain energy is being supplied into the flow field on a continuous basis. This dynamic strain energy field plays an important role in controlling the resistance offered by the fractured medium against the coupled flow of heat and fluid.

The linkage between behavior of the fluid flow field which contains dissolved radionuclides and tectonically generated energy and/or substance in various forms and quantities is poorly known. The main purpose of Szymanski's paper was to offer a "proposal regarding the relationship between the tectonics of the Yucca Mountain site region and the groundwater flow system operation at this site and in the region surrounding it." A summary of his development of this relationship is given in the following paragraphs.

According to Szymanski, the basic structure of a mathematical model of any simple groundwater flow system involves three separate equations:

1) the governing equation

2) the boundary conditions, and

3) the initial conditions.

For most groundwater systems, the above three equations have two common characteristics. The first is that they describe single phase flow, where the groundwater velocity vector is a result of the gradient of hydraulic potential whose origin is solely related to hydraulic pressures acting at boundaries of the flow system and hydraulic losses sustained during the flow process. The second characteristic is that a medium in which this flow occurs, as expressed in terms of its hydraulic parameters, does not involve time dependency. Szymanski expects that a groundwater flow field developed in a medium which is subjected to various tectonic stimulations would not be adequately represented by this formulation.

Deformational systems which are dominated by extension are commonly associated with basaltic volcanism. These systems are the result of convective mass and heat transfer between the asthenosphere (the zone within the earth' mantle where plastic movements take place to permit isostatic adjustments) and the continental lithosphere by a diapiric upwelling of a high-temperature, less-dense, and low-viscosity asthenospheric material into the overlying lithosphere. This upwelling can cause locally increased temperature as well as decreased density and viscosity of materials forming the upper mantle and the crust of the earth. Under these conditions, surface heat flow is strongly nonhomogeneous and the state of stress in the crust varies with both time and space. Strain energy is being supplied into the system on a continuous basis causing deformation of the crust through uplift, faulting, tilting and viscous flow at deeper crustal levels.

These two processes, heat flow and the continuous introduction of strain energy, simultaneously lead to the establishment of two energy fields. For time scales of geologic proportion, these fields are interactive as well as dynamic or transient. For the strain energy field, the time dependence expresses itself as a change in position of the equipotential surfaces relative to a fixed reference surface and as a change in shape of these surfaces relative to the reference surface and relative to each other. At most times, the rate of these changes is exceedingly small. During short intervals of time, however, this rate may be dramatically increased. This occurs in association with faulting which may entail a substantial reduction of the strain energy in a substantial volume of the crustal medium.

The bulk thermal conductivity of a fractured rock medium (at certain stress levels) is stress dependent. If a local development of the strain energy field reaches a certain level, continued introduction of the strain energy into this field will cause time and space dependent alterations in the three dimensional distribution of thermal conductivity. A relatively rapid change in a local temperature field may be associated with faulting which may cause a permanent change in the bulk thermal conductivity.

The question presented by Szymanski is how do the strain energy field, temperature energy field, and the groundwater flow system interact? To answer this question, Szymanski divided the problem into the following three parts:

1. The strain energy field operates in a fractured rock medium which also contains the groundwater flow field. The temperature field is considered as having no influence on either the strain energy field or the groundwater flow process.

2. This part deals with the relationship between the temperature field and the groundwater flow field. It has been assumed that there is no interactive relationship between the temperature field and the strain energy field and that the strain energy field plays no role in the groundwater flow process.

3. This part is concerned with a partial three way coupling between the temperature field, the strain energy field, and the groundwater flow field. Neither the temperature field nor the groundwater flow field influence the strain energy field. The strain energy field, however, influences both the temperature field and the groundwater flow field.

The important point with regard to hydrologic considerations is the fact that the regional deformation occurs on a continuous basis and that it involves extension. Presence of additional factors, such as compression and rotation about either a vertical axis or a horizontal axis, are important from the point of view of structural geology. These factors may only indicate presence of local inhomogeneities in the stress field. They may, nevertheless, have some regional tectonic significance. However, for purposes of these conceptual hydrologic considerations, these factors are not of great importance.

Long term extension rates across the Southern Great Basin, at latitude 37^{o} N, are of the order of 1 cm/year (strain rate of $+0.07 \times 10^{-6}$ m/m per year). At any given time, however, the extension seems to be confined to relatively narrow belts, as appears to be the case today in the Death Valley region. Local extension rates may be different than the average and may vary with time. At the Nevada Test Site (NTS) in the area of Yucca Flat and Pahute Mesa the horizontal principal strains are almost exactly N-S and E-W. The strain rate in a north-south direction is -0.10×10^{-6} per year (shortening) and in an east-west direction the strain rate is $+0.08 \times 10^{-6}$ per year (extension).

From a tectonic point of view the Death Valley groundwater system is active. A substantial body of evidence points toward a complicated displacement field with surface displacement velocities far exceeding those expected to be associated with a steady-state viscous or visco-elastic flow. The contemporary strain rates and accumulated shear strains for the surface deformation of the Death Valley groundwater system are far too large to be accounted for by the viscous or visco-elastic flow. Szymanski cites the occurrences of earthquakes and of surface ruptures along numerous faults to support this conclusion.

Therefore, Szymanski states that it is reasonable to expect that a dynamic strain energy field is involved where the strain energy or potential energy changes with time. During short intervals of time the rate may become quite large, as is the case for a seismogenic fault rupture or for a fault displacement induced by vibratory ground motion. Szymanski presents the tectonic deformation as occurring in repeated cycles of deformation with each cycle being subdivided into two phases:

1. Pre-dilatant phase begins with an onset of build-up of tectonic stress in response to a regional tectonic deformation. The rate of this local tectonic deformation is very low, but it will increase gradually.

2. The second phase (earthquake nucleation process) of deformation begins when a local failure is initiated. This phase can be subdivided further into four distinct stages

   i. Dilatent Stage - Formation of new cracks (microcracks) occurs uniformly throughout the medium. The microcracks grow in a direction roughly parallel to the trajectory of the greatest principal stress.

   ii. Inclusion Stage - Clusters of microcracks develop within the medium. Throughout the dilatant zone microcrack density is variable, therefore, the changes in the principal stresses are not only time dependent but they are also space dependent. The focal region containing the highest density of microcracks is known as the inclusion.

   iii. Closure Stage - Closure of the microcracks occurs in the focal region and in particular within the focal inclusion. The stress concentration in the focal region increases and becomes a maximum once all cracks are closed. Macrocrack growth within the inclusion begins.

iv. Growth Stage - Fault growth commences. The system becomes unstable and the rapid growth of the macrocrack occurs once the length of the macrocrack exceeds a critical value.

Collapse of the focal inclusion is associated with a release of large quantities of strain energy stored in the deforming medium. Part of this energy is released in the form of vibratory ground motion. The feature of fundamental importance to the hydrologic system is the time and space dependence of the principal stress. The hydraulic conductivity of fractures is sensitive to the confining pressure and has been attributed to changes of conducting aperture caused by a change in the normal effective stress. The dynamic stress field or the dynamic strain energy field is of fundamental hydrologic importance. This field may cause time dependence of important hydrologic parameters.

The primary water conducting medium is composed of two units in the Death Valley groundwater system. The valley fill aquifer groundwater flow mechanism involves predominantly porous flow through the material matrix. The second unit comprises the bulk of the water conducting medium of the Death Valley groundwater system and includes a large lithology. The groundwater flow mechanism is primarily by fracture flow. Szymanski states that because of the complexity of this unit, a further division of this hydrogeologic unit is of limited practical value. The subdivision cannot be introduced into numerical modeling efforts and expressed as the three-dimensional distribution of material properties with any degree of specificity.

The most important data are those which relate values of the hydraulic potentials in the flow field to time. Szymanski states that the data were collected during a nearly 10 year long process of evaluating the suitability of the Yucca Mountain site to accommodate the nuclear waste repository. Continuous and periodic monitoring was performed in a number of deep wells which were drilled in an area of approximately 25 square kilometers. The data, however, are not yet available in an accessible and reliable form. Therefore, Szymanski states that his conceptual considerations cannot yet be carried out to their logical and completely reliable conclusion.

Perched waters were encountered in many exploratory boreholes at the NTS. According to Szymanski, there are two very important conceptual alternatives to explain the perched water. The first is that the perched waters represent recent meteoric waters caught during their downward passage (infiltration) through the vadose zone by rocks whose hydraulic conductivity is very low. In this case, the perched waters should not exhibit hydraulic, thermal and chemical affiliation with waters occurring below the water table. The second alternative is that some of the perched waters are the result of the expressions of hydraulic mounds. These mounds would occur in areas where the in-situ stress conditions are such that a true value of hydraulic potentials can display itself in the near ground surface conditions. In this case, the perched waters should exhibit either hydraulic or thermal and chemical affiliation with waters occurring below the water table.

Szymanski chose three areas where perched water exists for examination. These areas are:

1. around the town of Beatty, Nevada
2. the NTS, between Jackass Flat and Frenchman Flat
3. the NTS, around Pahute and Rainier Mesas

He then presents information regarding the chemical concentrations, temperatures, and hydraulic characteristics of perched water zones at these three sites. He concludes that it appears that the body of evidence pertaining to some of the perched waters indicates that they may be related to tectonic processes. If further investigation proves this hypothesis, then:

1. The Death Valley groundwater system is a system for which the position and configuration of the water table is not an expression of the durable characteristics of the flow field. Both of these parameters are a matter of tectonic consensus and, therefore, subject to a random change.
2. The magnitudes of potential rises of the water table, caused by tectonic processes, are very substantial and may be long lasting.

A review of the configuration of the water table in the Death Valley flow system reveals that features expected to be present in a tectonically controlled flow field are also present in this system. The configuration of the water table includes steep slopes, hydraulic "plateaus" where the horizontal gradients of hydraulic potentials are small, hydraulic mounds, and hydraulic sinks.

The presence or absence of vertical gradients of hydraulic potentials acting in a flow field determines how well the actual equipotential surfaces are represented by the water table. If there are significant vertical components of groundwater flow, the water table constitutes a very poor representation of the actual three-dimensional distribution of the hydraulic potentials. Calculations and interpretations performed based on this representation can be grossly misleading. Szymanski's examination of data revealed that the vertical gradients of hydraulic potentials occurring in the Death Valley flow system display all characteristics which might be expected in areas where tectonic processes influence groundwater flow.

Szymanski's review of in-situ stress determinations at the NTS lead him to conclude that the in-situ stress plays a very important, perhaps dominant, role in the Death Valley flow system. The contemporary straining and seismicity together with the pattern of Plio-Quaternary deformation and faulting in the area all indicate that the dynamic strain energy field must be involved. Any hydrologic consideration not accounting for this circumstance may contain serious errors in judgment amounting to a complete misunderstanding and misrepresentation of the flow field.

Szymanski also reviewed the thermal characteristics of the Death Valley groundwater system. The flow field appears to be characterized by a substantial degree of thermal inhomogeneity in three dimensions. At a depth of approximately 2 or 3 kilometers, the intensity of heat flow is high and may be the same as that characteristic of the Great Basin in general. At the base of the flow field, the distribution of the intensity of heat flow appears to be heterogeneous. This distribution seems to be related to the fundamental tectonic fabric of the area, as shown by the seismic velocity structure of the upper crust.

Szymanski offers the following conclusions and recommendations regarding the flow system in the vicinity of Yucca Mountain:

1. The Death Valley groundwater flow field is considerably different than the flow system currently envisaged by the NNWSI Project. The conceptual model of this flow system, as used in performing site suitability assessments for purposes of developing the Final Environmental Assessment for the Yucca Mountain site and for purposes of establishing an approach to the forthcoming site characterization activities, is far too simple and much too far removed from reality. This conceptual model completely ignores completely the volcano-tectonic setting of the Yucca Mountain site.

2. In the case of deforming fractured medium, the temporal stability of the water table is not only related to global or regional climatic

fluctuations, but it is also related to tectonic factors, in particular, the in-situ stress conditions. Both short term and long term instabilities of the water table can be expected at the Yucca Mountain site. The short term instabilities involve perhaps tens of meters, of displacement of the water table. They are short lived, say days or weeks at most, and occur with a frequency related to the degree of heterogeneity in the local strain energy field.

3. These short lived instabilities are caused by the minor restructuring of the strain energy field which may or may not require an external triggering mechanism. Fault creep, local and temporary uplift or subsidence, vibratory ground motion induced slip, etc. are examples of the manifestation of these restructurings. It is not known whether or not the short lived instabilities of the water table were observed at the Yucca Mountain site. These instabilities, however, are very important because they can directly confirm that the deforming fractured medium is, indeed, involved in the flow process. Furthermore, these instabilities, if occurring with a meaningful frequency and magnitude, would constitute a "pumping" mechanism for gaseous transport through the vadose zone.

4. The long term displacements of the water table involve tens and perhaps hundreds of meters. They are caused by the large scale restructuring of the strain energy field occurring at the end of a deformation cycle and with a frequency measured in terms of tens of thousands of years. These displacements would directly impact the radionuclide migration path and the radionuclide migration time. In extreme cases, however, these displacements can result in the flooding of the repository and in expulsion of groundwater at the ground surface.

6.0 CONCLUSIONS

The DOE has presented their current conceptual model of the areas around and near Yucca Mountain for the flow of water and gas through the unsaturated and saturated zones. This conceptual model(s) is the basis for the testing which will occur during the site characterization process. The DOE acknowledges that a great deal of information must yet be obtained and the conceptual models currently presented may be revised as the site characterization progresses.

The uncertainty in the regional model seems to be primarily due to the following concerns:

1. The locations of recharge areas are based on a simple precipitation relationship. Areas receiving above 200 mm/yr of precipitation are considered to be recharge areas for the regional model.

2. The reasons for the very steep gradients located in areas across the entire regional model are as yet unknown. Testing presented in the CDSCP will be implemented to refine the reasons these steep gradients exist.

3. The actual flow paths of groundwater in the saturated zone are known only on a qualitative basis.

The uncertainty in the site model seems to be primarily related to the following concerns:

1. Determination of the in-situ potential field may be difficult.

2. If the potential between the matrix and fracture systems are not in equilibrium, then quantitative modeling of the site hydrogeologic system may be very difficult.

The conceptual model as presented by Szymanski provides an unusual scenario for the regional hydrogeologic system. The DOE, in their site characterization process, may have to determine the actual influence which the tectonic and thermal perturbations have on the groundwater flow.

7.0 RECOMMENDATIONS

The DOE recognizes the importance of obtaining the in-situ potentials for the unsaturated zone. However, the evidence presented from well USW UZ-1 shows the difficulty in collecting the required data. The required time for initial conditions to return around the wellbore is an associated problem which the DOE has seemed not to have addressed. The CDSCP states that "it is not known if in-situ conditions will return within the time period allotted for monitoring (3 to 5 yrs.)." Validation of the proposed conceptual model(s) will require a fairly detailed knowledge of the potential field.

Simplified assumptions of the hydrologic regime could be utilized to determine the upper bounds for the time required to have a return to predrilling conditions. A review of the available analytic models and data from core tests is being evaluated to determine what types of simplifying assumptions are conservative. Once this review is completed, a proposal (Task Descriptive Summary) will be submitted regarding specific numerical models which can be used to predict the time necessary for equilibrium conditions to be reached around a drillhole. If these types of calculations indicate that pre-existing conditions are unlikely to return during the monitoring period, then alternative methods for obtaining in-situ potentials may be required.

The conceptual model of the regional groundwater flow system has been based in part on the hydrochemistry data obtained from wells and springs in the Death Valley basin. The DOE has assumed that the saturated flow in the greater portion of this basin is two-dimensional. The use of radioactive isotopes for the dating of groundwater has lead to an estimation of groundwater velocities for portions of the saturated zone.

These velocities are based on groundwater flowing from a defined recharge area to a defined discharge area. Based on the "age" of the water at the discharge area, an average water velocity can be obtained. It does not appear that the DOE has considered the mixing of the various waters which exist along a given streamline. Mixing of waters will yield apparent radioactive ages which must be corrected to adequately determine the velocity along the flow path. The DOE has noted that age stratification occurs at wells at Yucca Mountain. It is recommended that the use of apparent ages for the determination of groundwater velocities and hence travel times be investigated further. A Task Descriptive Summary will be submitted for this purpose.

8.0 REFERENCES

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