CONCEPTUAL MODEL EVALUATION (UPDATE)

Nevada Nuclear Waste Storage Investigation
Subtask 1.4 Report #2

Prepared by

Water, Waste & Land, Inc.

for

Nuclear Waste Consultants

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

OCTOBER 14, 1986

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

September 30, 1986

Nuclear Waste Consultants
ATTN: Mark Logsdon
8341 South Sangre de Cristo Road, Suite 6
Littleton, CO 80127

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

Dear Mark:

Attached is the update to our Subtask 1.4 report on the Evaluation of Conceptual Models 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 report has been divided into the following sections:

1.0 INTRODUCTION

2.0 POST-CLOSURE TECHNICAL GUIDELINES

3.0 DRILL HOLE INFORMATION
- 3.1 DRILL HOLE USW H-1
- 3.2 DRILL HOLE USW G-1
- 3.3 DRILL HOLE USW G-2
- 3.4 TEST HOLE USW UZ-1

4.0 EVALUATION OF DRILL HOLE DATA

5.0 UNSATURATED HYDRAULIC PROPERTIES OF FRACTURES

6.0 DETAILED WORK PLAN FOR NUMERICAL MODELING EVALUATION
- 6.1 ANALYSIS OF WATER LOSS IN USW G-1
- 6.2 ALTERNATIVE FRACTURE SYSTEM UNSATURATED HYDRAULIC PROPERTIES

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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

1.0 INTRODUCTION

This report updates the conceptual model evaluation report submitted by WWL on March 31, 1986. The initial report evaluated conceptual models presented by the DOE for both the regional and the local site (Yucca Mountain). This update to the initial report addresses potential problems which need to be resolved to allow evaluation of the local site conceptual model.

The local site conceptual model includes six hydrogeologic units at the Yucca Mountain site, which are, in order of increasing age:

Alluvium,
Tiva Canyon welded unit,
Paintbrush non-welded unit,
Topopah Spring welded unit,
Calico Hills non-welded unit, and
Crater Flat unit.

The conceptual model which the DOE uses to describe the flow of water in the unsaturated and saturated hydrogeologic units is the one proposed by Scott et al. (1983) and Montazer and Wilson, (1984). This model apparently has not changed significantly since the report submitted by WWL on March 31, 1986.

The general conceptual model proposed by the DOE in the Environmental Assessment (EA) includes the diversion of infiltrated water (by lateral flow and capillary barriers) and a free draining host rock due to a highly permeable fracture network. The net effect of these proposed physical phenomena is to limit the flux reaching the repository and the contact time of the water that does reach the repository containers.

The diversion of the downward flux is accomplished in the conceptual model by the presence of dipping anisotropic units having contrasting properties which can transmit up to 100 mm per year of lateral flux and by capillary barriers between the matrix of the Paintbrush non-welded unit and the fractures of the Topopah Spring welded unit. A capillary barrier is also proposed at the upper contact of the Paintbrush non-welded unit with the bottom of the Tiva Canyon welded unit.

Since the conceptual model has not materially changed since issuance of our initial report, this report has been directed at identification of potential problem areas within the local conceptual model as envisioned by DOE. In the following section the appropriate regulatory criteria are described. This is followed by a description of available data regarding the evaluation conducted by DOE. These data are then evaluated in the following section. The following section presents an alternative approach to estimating the unsaturated hydraulic properties of fracture systems. Finally, detailed plans for future numerical evaluation of the conceptual model are presented.

2.0 POST-CLOSURE TECHNICAL GUIDELINES

The post-closure technical guidelines which are addressed in this update report are concerned with the disposal of waste in the unsaturated zone. The pertinent portions of the regulations (10 CFR 960 4.2.1) require the following:

(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:

(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.

(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.

(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.

(iv) A host rock that provides for free drainage.

(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual evapotranspiration.

According to the EA, three of the five favorable conditions are present at Yucca Mountain (5(ii), 5(iv), 5(v)). The conclusions reached by the DOE for the required favorable conditions are (p. 6-140, EA):

> "The host rock and the immediately surrounding hydrogeologic units are not characterized by a low and nearly constant degree of saturation. The host rock is 200 meters or more above the water table and completely above the zone of continuous fully saturated voids. The Paintbrush non-welded unit, about 30 meters thick, overlies the Topopah Spring welded unit and will probably serve as a buffer to divert pulses of water, but not necessarily beyond the limits of emplaced waste. The highly fractured host rock would provide free drainage if fracture flow were to occur. Precipitation is estimated to be less than 20 percent of potential evapotranspiration."

Based on the above, it is evident that the DOE believes the following with respect to the regulatory criteria outlined previously:

(i) Results indicate that saturation in the Topopah Spring welded unit is quite variable.

(ii) The pores of the host rock are not continuous, fully saturated voids.

(iii) Percolating water cannot be conclusively demonstrated to be diverted beyond the limits of the emplaced waste.

(iv) The Topopah Springs welded unit is considered to be freely draining because its permeable fracture network would allow rapid flow if flux were to increase sufficiently to cause fracture flow.

(v) Precipitation is estimated to be less than 20 percent of potential evaporation.

Information presented by the DOE in the EA makes at least one of the three favorable conditions suspect. This information is presented in the following sections and the potential effects on the conceptual model are evaluated.

3.0 DRILL HOLE INFORMATION

Several holes have been drilled in the vicinity of Yucca Mountain during the past several years. The holes which provide the information on which the following discussion is based are listed in Table 1 along with pertinent physical data for each of the wells. Approximate well locations relative to the primary repository block are shown on Figure 1 which also demonstrates the current DOE piezometric surface map.

Table 1.
Pertinent Drill Hole Data

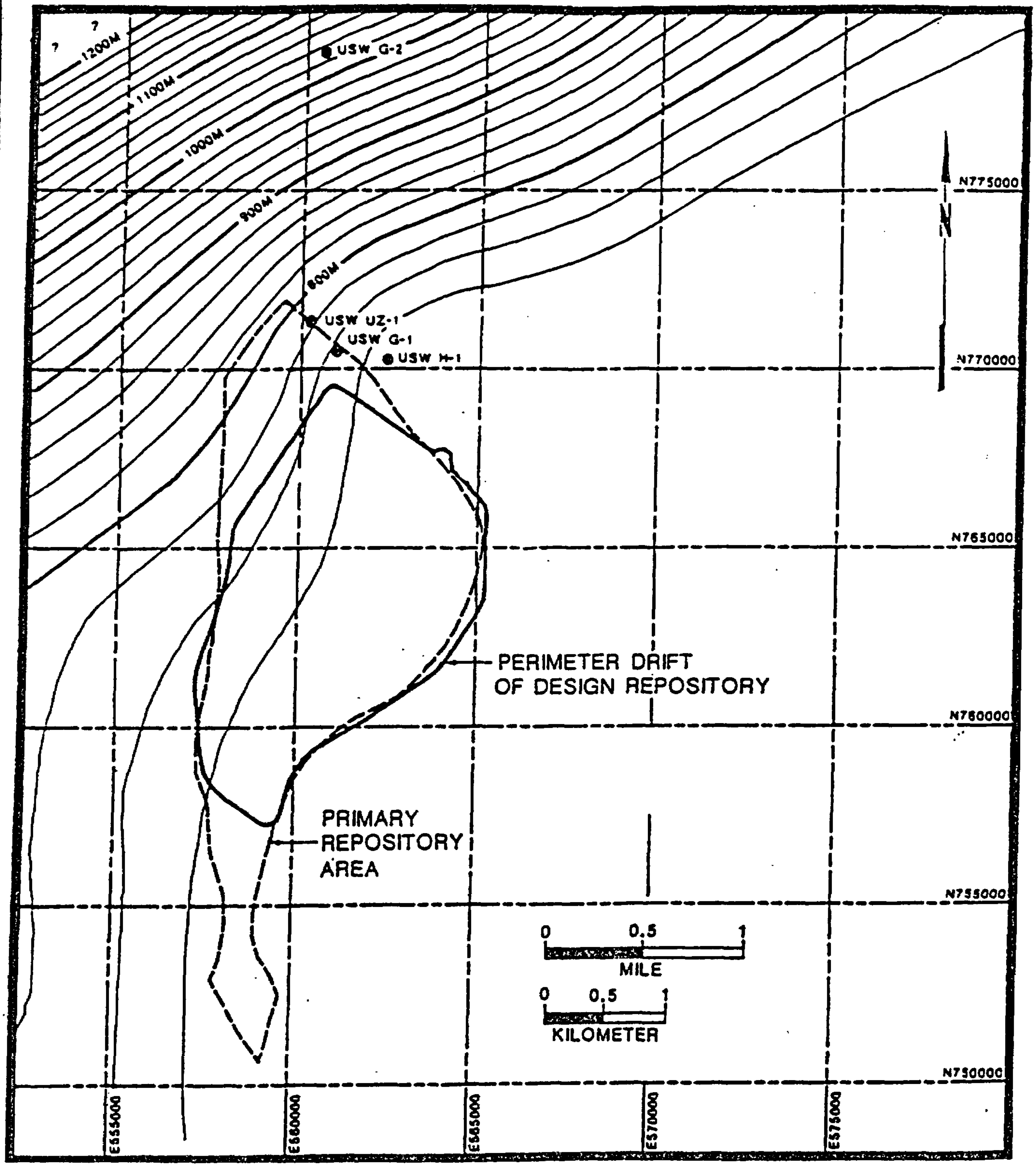
Hole Number	Location (feet) North	Location (feet) East	Hole Depth (m)	Land Surface Elevation (m)	Water Level Elevation (m)
USW H-1	770,254	562,388	1,829	1,302.8	730.7
USW G-1	770,500	561,000	1,829	1,325.5	753.8
USW G-2	778,824	560,504	1,831	1,554	1,029.1
USW UZ-1	771,530	560,240	387	1,350.0	963

3.1 DRILL HOLE USW H-1

Test well USW H-1 was drilled between September and December, 1980, reaching a total depth of 1,829 m. The drilling fluid used was an air/foam that consisted of air, detergent, and water. During the drilling of the well, water level observations were made with the purpose of locating any perched water zones above the water table. As reported by Rush et al, 1984, a possible perched water zone was observed at a depth of 448 m. in the lower part of the Topopah Spring welded unit. The water was assumed to be perched above an underlying 5 meter thick bedded or reworked ash flow tuff. Air lift testing when the well was at a depth of 458 m produced a discharge to the land surface of from 1.3 to 1.6 l/s for 45 minutes. A video tape was made of the open hole to a depth of 687 meters using a downhole television camera. A number of water seeps above the zone of saturation were observed (Rush et. al 1983), however the source of the water was not identified.

3.2 DRILL HOLE USW G-1

The exploratory drill hole USW G-1 was continuously cored from a depth of 80 m to a total depth of 1,829 m during March to August, 1980. Even after



Water, Waste & Land Inc.	FIGURE 1 Piezometric Surface Map and Well Locations	Date: 10/86 Project: 4001

casing was set to a depth of 310 m, return circulation of drilling fluid was rarely achieved. About 7,000,000 liters of drilling fluid were lost below the casing (Ellis and Swolfs, 1983). This high loss of drilling fluid and the inability to maintain circulation, coupled with a known low matrix permeability, suggests that the fluid was lost to fractures in the drill hole. Information on the pressure history of the drilling of the hole indicated that, in some portions of the hole, hydraulic fracturing of the rock formation occurred during drilling. Therefore, it is likely that drilling fluid was lost to both pre-existing fractures, and to drilling induced fractures.

As reported by Ellis and Swolfs (1983) some of the fractures detected by the televiewer log of USW G-1 are interpreted as being drilling induced based on the following:

1. The fractures parallel the drill hole for long vertical distances.

2. Core obtained from comparable depths does not indicate such continuous fractures.

3. The fractures occur normal to the direction of maximum borehole ellipticity.

3.3 DRILL HOLE USW G-2

Test well USW G-2 was drilled between March and October, 1981. The well was continuously cored from a depth of 88.3 meters to the total depth of 1830.6 m. A circulating media of air foam and polymer mud was used during the drilling and coring operations.

As reported by Maldonado and Koether (1983), fracture analysis of the core resulted in tabulation of 7,848 fractures, predominately open and high angle. Three major faults were penetrated by the well bore. Two of these faults intersect the ground surface and have displacements of at least 20 meters and possibly as much as 52 meters.

3.4 TEST HOLE USW UZ-1

Test well USW UZ-1 was drilled using the vacuum reverse-air circulation technique. This technique entails the application of a vacuum on the inner string of a dual-string reverse vacuum assembly thus removing the drill cuttings through the inner string. Compressed air was injected into the dual string annulus for cooling the bit and to help keep the inner string clean.

The primary objectives for drilling the test hole was to obtain a vertical moisture-content profile of the rocks drilled, check for the presence of perched water zones, and emplace hydrologic instruments at depth to obtain long-term records of pressure and moisture-potential data. The use of the vacuum reverse air circulation drilling in the unsaturated zone permits detection of moist or saturated zones as soon as they are penetrated. In addition, this drilling technique prevents the rocks in the unsaturated zone from becoming contaminated with drilling liquids.

As reported by the DOE in the EA, test well USW UZ-1 was drilled to a total depth of 387 meters. What was not stated in the EA, however, is that the drilling was discontinued at this depth because a large volume of water was encountered, and the water level could not be lowered significantly (Whitfield, 1985). Because of this water the entire Topopah Spring welded unit was not penetrated. Whitfield (1985) offers two explanations for the unexpected water encountered in the drilling of UZ-1. They are:

1. All of the water may be contamination from geologic test holes. About 8,780,000 liters of polymer drilling fluid were lost during the drilling and coring of USW G-1. Polymer identical to that used in the drilling fluids of USW G-1 was found in water samples from USW UZ-1.

2. A naturally occurring perched-water zone may have been encountered, however, it has been contaminated with G-1 drilling polymer.

The DOE asserts, then, that the water encountered while drilling of USW UZ-1 is perched water. However, the water encountered could also be the actual water table. Since the well was not drilled through the Topopah Springs welded unit to the predicted water table, as originally planned, it is not known if the water encountered is perched or is the water table at that location.

4.0 EVALUATION OF DRILL HOLE DATA

Encountering the water in USW UZ-1 at an elevation of 963 m which is significantly higher than the predicted elevation of about 780 and the determination that the water contained drilling fluid polymer from a well 305 meters away (USW G-1) raises serious questions about the fracture network in the Topopah Spring welded unit. First, fluid has moved laterally a significant distance, and secondly, the water has not rapidly "drained" through the unit. Since UZ-1 was completed in October, 1983, a period in excess of three years was available for the water from USW G-1 to drain from the fracture system. It has been postulated by the DOE that the drilling fluid "lost" during the drilling of borehole USW G-1 formed a perched water zone extending to borehole USW UZ-1.

If the water found in USW UZ-1 is indeed perched, then the Topopah Springs welded unit may not be as free draining as anticipated by the DOE. If the repository is placed in the Topopah Springs welded unit, the possibility of a saturated zone encompassing the waste at some point in the future may then exist. The saturated zone may be caused by increased infiltration due to a change in climatic conditions or due to a condensed layer of water formed by the heat load from the canisters. After condensing, the water could move downward and eventually pass through the repository layer.

If the water at USW UZ-1 is not perched, but is indeed the water table, then the water table altitude contours presented by the DOE in the EA would need to be radically changed. Based on the above discussion and information available thus far, the DOE has not proven conclusively that the water found at USW UZ-1 is perched. In the event that the water located in USW UZ-1 is the water table at that location, then it will probably be important to determine the reason for the large gradient which exists between the two wells, UZ-1 and G-1. Water levels (assuming the water in UZ-1 is the water table) along with surface elevations are depicted schematically on Figure 2 to demonstrate the change in gradient between the two wells.

Information obtained during the drilling of the USW UZ-1 well as to the amount of water pumped, drawdown during pumping (if any), and length of time the well was pumped before the decision was reached to cease drilling operations may give insights into the anomaly. This information may lead to the need to further characterize the Topopah Springs welded unit and the water table at the area near USW UZ-1.

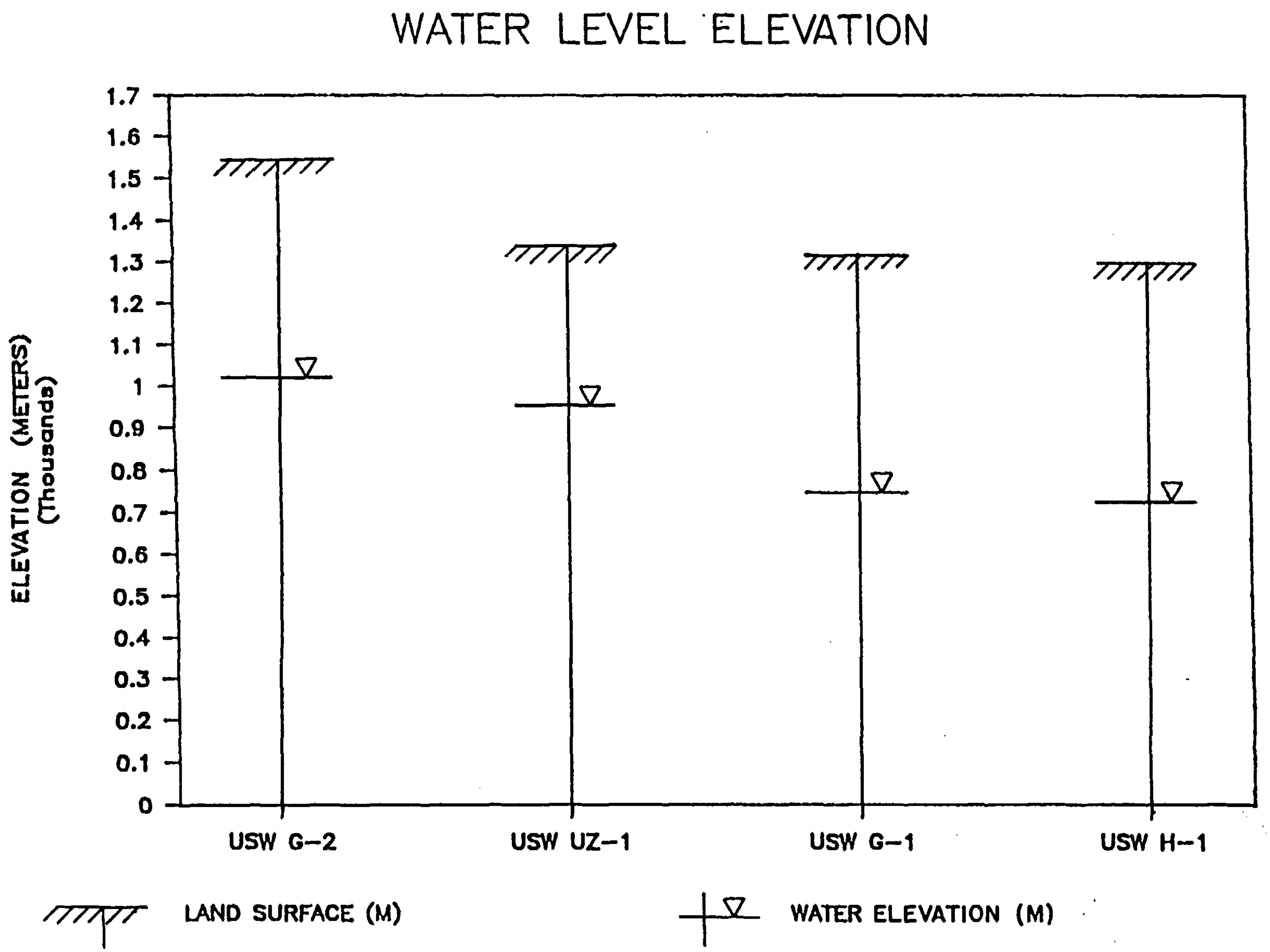


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FIGURE 2

Schematic of Water Levels at Yucca Mountain

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5.0 UNSATURATED HYDRAULIC PROPERTIES OF FRACTURES

The geologic formations in the unsaturated zone at Yucca Mountain are characterized by varying degrees of fractures. In the welded tuff, the number of fractures per unit volume has been determined to be relatively high. To obtain the travel times through the fractured tuff from the repository to the water table, the effect that the matrix and fractures have on unsaturated flow must be determined.

The DOE, as stated in the EA, has assumed that flow in the fractures does not move rapidly until the flux approaches the saturated matrix hydraulic conductivity. Flow may take place in thin layers along the walls of fractures under unsaturated conditions, however, such flow would likely have the same properties as flow in the matrix. (DOE, 1986)

The approach taken by the DOE in characterizing the movement of water through the fractured rock mass assumes that the pressure heads in the fractures and the matrix are identical along a line perpendicular to flow. The flow characteristics for the matrix and the fractures as a function of pressure head are then developed. Given an input flux to the unsaturated system, the amount of flow in the matrix and the fractures can be calculated, and thus travel time can be predicted for each of the matrix and fracture subsystems.

The water retention data obtained from testing performed on tuffaceous core samples of the matrix was fit using the Van Genuchten curve and the method of Mualem to obtain an equation for the conductivity as a function of head. Similar equations were used to relate the fracture hydraulic conductivity to pressure head. However, the fracture saturation coefficients were the same for every hydrogeologic unit.

The DOE (1986) calculates the unsaturated zone travel times in the fractures by the following method:

1. For flux greater than 95% of the matrix saturated hydraulic conductivity (K_s) the amount of flux greater than 0.95 X K_s is assumed to flow in the fracture.

2. An effective porosity of 0.0001 was assumed for all fracture flow, and the velocity of flow in fractures for each element was determined by dividing the calculated value of flux in the fracture by 0.0001.

3. The travel time is then the distance traveled divided by the velocity of water in the fracture.

As indicated above, the relation between the matrix and fracture flow has not been determined with any great confidence. A further definition of the relationships between pressure head and matrix and fracture flow would be useful. Various theoretical methods are available to estimate the partitioning of flow between fractures and matrix. These will be discussed in section 6.0

6.0 DETAILED WORK PLAN FOR NUMERICAL MODELING EVALUATION

Some of the numerical modeling outlined in the initial conceptual model evaluation report has not been completed at this time. It is still deemed appropriate to perform the saturated zone modeling as described in the initial report at a later date while continuing to concentrate on evaluation of the unsaturated zone. We still feel that the following modeling efforts should be completed:

Fracture/Matrix Flow Analyses
Capillary Barrier Analyses
Persistence of Water Flow in Fractures Affected by Air in the Matrix
Vapor Transport Analyses

Each of the above is described in our original report and will not be further discussed in this report.

Additional numerical analyses which we feel may enhance our understanding of site hydrogeologic conditions include the following:

1. Analyses of Water Loss in USW G-1
2. Alternative Fracture System Unsaturated Hydraulic Properties

Each of the above modeling endeavors is described in the following subsections.

6.1 ANALYSIS OF WATER LOSS IN USW G-1

Records kept during the drilling of USW G-1 include the loss of drilling fluid versus depth. By making some very simple calculations the fracture porosity may be bounded for a portion of the Topopah Springs welded unit. If pseudo-radial flow is assumed in the fracture system around USW G-1, and the drilling fluid observed at USW UZ-1 is considered to be just the front of the fracture flow, then the maximum possible fracture porosity can be determined. Bounds on the hydraulic conductivity can also be estimated for the same hydrogeologic unit's fracture system and can be compared with values predicted by theoretical methods.

6.2 ALTERNATIVE FRACTURE SYSTEM UNSATURATED HYDRAULIC PROPERTIES

Various theoretical methods are available to predict the fracture flow characteristics in the unsaturated zone. An example is the use of the Navier-Stokes equation to calculate the gravity drainage in a vertical plane fissure. The use of this approach allows relative permeability curves to be developed based on theoretical methods for the fractures. These curves can then be compared with field data to determine how far from ideal the fracture flow may be in the unsaturated zone.

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