Title
A site scale model for modeling unsaturated zone processes at Yucca Mountain, Nevada

Authors
Bodvarsson, G.S.
Wu, Y.S.
Sonnenthal, E.L.
et al.

Publication Date
1997-12-15

2A:L FINAL DRAFT
jh 12/15/97

A Site Scale Model for Modeling Unsaturated Zone Processes at Yucca Mountain, Nevada

G. S. Bodvarsson, Y. S. Wu, E. L. Sonnenthal, T. M. Bandurraga,
C. F. Ahlers, C. Haukwa, J. Fairley, J. Hinds, and A. Ritcey

Earth Sciences Division, Lawrence Berkeley National Laboratory,
One Cyclotron Road, MS 90-1116, Berkeley, CA 94720

INTRODUCTION

The U. S. Department of Energy (DOE) is currently investigating the feasibility of using the unsaturated zone at Yucca Mountain, Nevada, as a permanent storage facility for the geologic disposal of high-level nuclear waste. The site has been extensively studied for more than 15 years, and many types of data have been collected. These data have been used to develop conceptual and numerical process models of Yucca Mountain to simulate ambient conditions and perform predictive studies of physical and chemical changes in the mountain due to climate-related, thermal, and geochemical perturbations.

The primary objectives of the unsaturated-zone (UZ) flow model developed at the Lawrence Berkeley National Laboratory (LBNL) are the following:

(a) to integrate the available data from the unsaturated zone into a single comprehensive three-dimensional model,
(b) to quantify the flow of moisture, heat, and gas through the unsaturated zone,
(c) to evaluate the effects of repository loading on moisture, heat, and gas flow within the mountain, and
(d) to provide Performance Assessment and Repository Design with a defensible and credible model of all relevant unsaturated-zone processes.

The 3-D site-scale UZ flow model provides estimates for important parameters and processes such as:

(1) the spatial and temporal values of percolation flux at the potential repository horizon,
(2) the components of fracture and matrix flow within and below the potential repository horizon, and
(3) the probable flow pathways from the potential repository to the water table.

The UZ flow model also provides important input to various other Yucca Mountain process models, such as ambient and thermal drift-scale models, the mountain-scale thermohydrological model, and the UZ transport model.

OVERVIEW OF KEY CONCEPTUAL ISSUES

UZ flow simulations are performed with numerical grids that represent the conceptual model of the unsaturated zone at Yucca Mountain. The conceptual model develops a framework, based on evaluation of collected data, to explain unsaturated-zone flow processes such as liquid, heat, and gas flow. Important components of the conceptual model are highlighted below and are illustrated in Figure 1.

HYDROGEOLOGIC SETTING

Yucca Mountain lies in a tectonically complex, arid environment, comprised of heterogeneous layers of anisotropic, fractured volcanic rocks. Figure 2 shows the 3-D geological model of Yucca Mountain, with the location of the UZ flow model boundary and potential repository area provided as reference points. These variably welded tuffs display highly contrasting hydrologic characteristics (porosities, fracture densities, permeabilities, etc.). Alteration of volcanic glass into clays and zeolites is common in the non-welded units, especially near the water table, and greatly impacts matrix

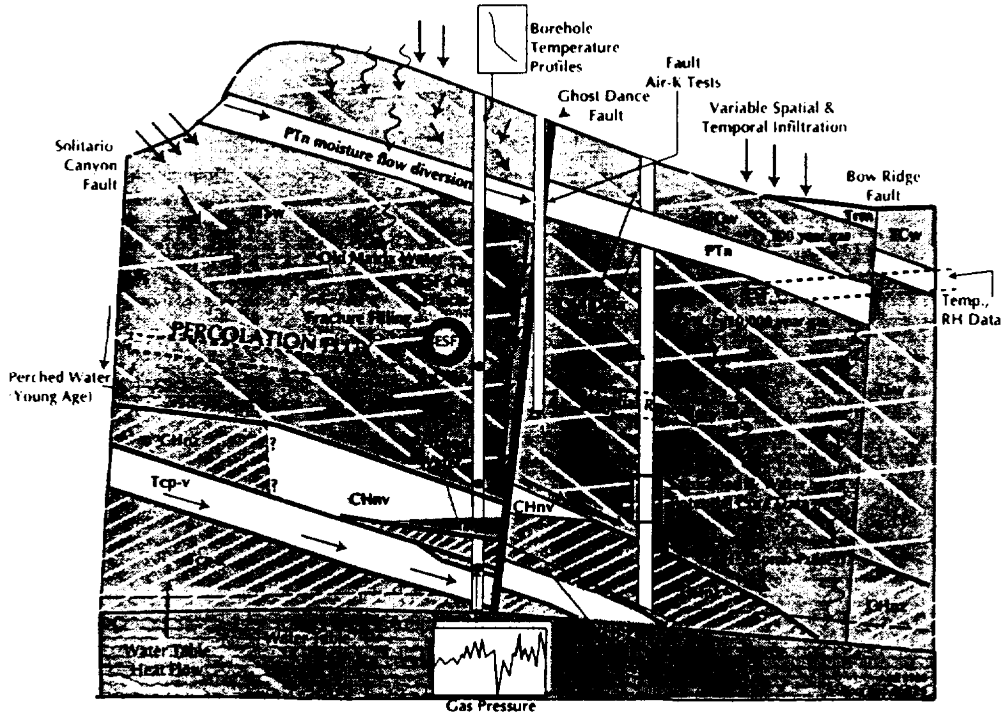

Figure 1. Schematic cross section through Yucca Mountain showing various conceptual model data and processes.

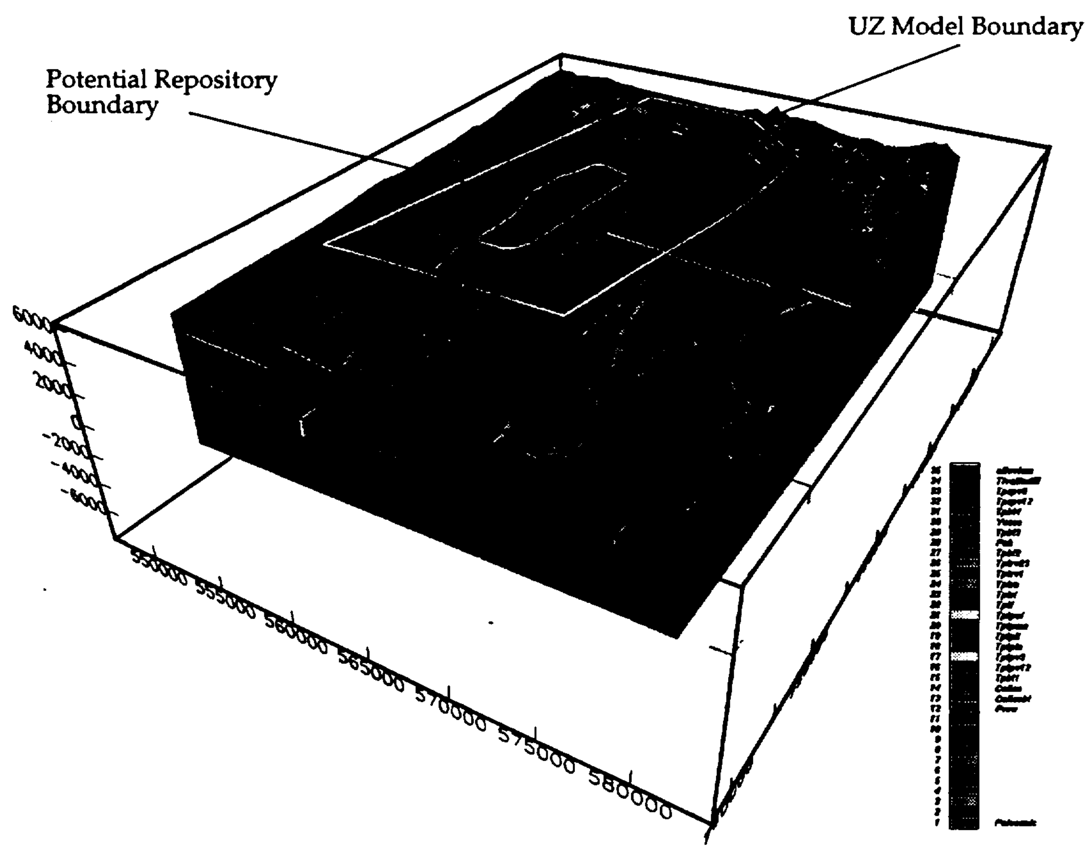

Figure 2. 3D geological framework (Clayton et al., 1997)

saturations, permeabilites, and groundwater flowpaths and travel times. Lateral diversion occurs below the repository horizon above the low-permeability zeolitic material, often resulting in the formation of perched water, as observed in several boreholes in the potential repository area.

INFILTRATION

Infiltration to the repository is spatially and temporally variable due to the nature of precipitation, near-surface geology, and variations in soil cover and topography. Estimated average infiltration rates over the UZ model area range from about 0–15 mm/yr. Lower infiltration rates are assumed where significant thicknesses of alluvium overlie volcanic bedrock because of the high storage capacity in the alluvium (leading to near-surface evaporation). Higher infiltration rates are believed to occur on ridgetops and sideslopes where outcrops are exposed and fracture flow can be directly initiated into the bedrock. Current infiltration conceptual models are based on shallow borehole measurements and are verified by evaluation of geothermal profiles and geochemical data.

PERCOLATION FLUX

One of the most important hydrological parameters that can be investigated through the use of the UZ flow model is percolation flux at the level of the potential repository, as it quantifies the amount of water available to contact the waste canisters. Geochemical and isotopic data suggest that percolation flux is greater in highly-fractured, welded rocks because fracture networks allow water to bypass the low-porosity matrix. Conversely, percolation flux is believed to be dampened in the relatively unfractured, high-porosity non-welded rocks, as indicated by pneumatic data and chlorine-36 concentrations. Furthermore, capillary barriers may exist between welded and nonwelded units above the potential repository horizon creating lateral diversion and moisture redistribution, thus limiting the amount of water available to reach the repository horizon. Analyses of temperature and heat flow data with the UZ model suggest that the percolation flux across the repository area is on the order of 5 to 10 mm/yr. Faults may also have a large impact on percolation flux by providing fast pathways for infiltration, allowing moisture to travel to great depths at Yucca Mountain without significant attenuation in the non-welded units.

FRACTURE FLOW & FRACTURE-MATRIX INTERACTION

Fracture flow accounts for the majority of the mass flux in the welded units (and thus in the repository unit) at Yucca Mountain because the low-permeability matrix allows only a few mm/yr of flow. It is likely that most of the perched water bodies are fed by vertical flow through fractures based on the relatively young ages of the water (on the order of 2000–6000 years) and the extremely slow travel times of water through the matrix. Isotopic concentrations suggest that limited mixing of matrix pore waters and perched water bodies occurs, thus prompting a reduction in the fracture-matrix interaction coefficient used in the dual-permeability formulation of the UZ model.

SUMMARY OF UZ MODELING STUDIES AND RESULTS

Incorporating extensive data that are available from numerous studies of Yucca Mountain, the UZ flow model captures the important flow proccesses that occur in the unsaturated zone, such as: moisture flow, capillary pressure effects, gas flow, convective and conductive heat transfer, evaporation and condensation, moisture and gas flow travel times, and transport of conservative and reactive species in the mountain. Figure 3 shows the major components of the UZ flow model.

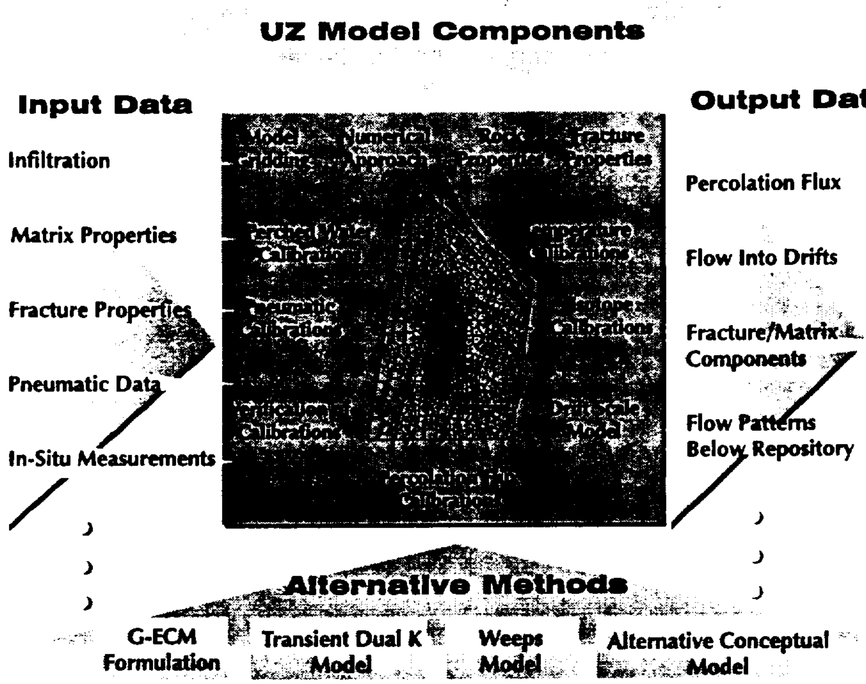

Figure 3. Major components of the UZ Site Scale Flow Model.

The UZ model uses USGS matrix property data that describe the important hydrogeologic layers at Yucca Mountain to develop rock parameters sets for each model layer. A detailed fracture property model has been developed by LBNL using pneumatic data, fracture data from boreholes, and detailed fracture data from the ESF. This model yields results for fracture permeabilities, porosities, effective spacing, and derived van Genuchten parameters.

Much effort has been devoted to calibration of the UZ flow model. The model is calibrated against water potential and liquid saturation data using various infiltration maps and conceptual models for fracture–matrix interaction, pneumatic data, borehole temperature data and thermal properties, perched water data, and environmental isotopes, including chlorine–36, total chlorides, strontium and carbon–14. Figure 4 is an example of a calibrated saturation distribution over the UZ model domain.

Flow Above The Potential Repository

Net infiltration into the bedrock at the land surface is episodic, and significant pulses are thought to occur only every few years. After traveling relatively rapidly through fractures in the upper welded tuff (TCw), the pulses are attenuated by the high storage capacity of the Paintbrush non–welded unit (PTn). As a result, flow reaching the underlying welded repository unit is fairly uniformly distributed. However, some proportion of percolation flux travels along structural fast pathways, such as major faults that cut through the entire thickness of the PTn.

Percolation Flux At The Potential Repository Horizon

Since the repository horizon, located in the Topopah Spring welded tuff (TSw), contains a dense network of fractures with permeabilities several orders of magnitude greater than matrix permeabilities, moisture flux through this unit is predominately through fractures. From total chloride, strontium, and carbon–14 analyses, in addition to temperature studies, percolation flux through the TSw ranges from 1–10 mm/yr. Figure 5 is a result of percolation flux studies using the UZ flow model.

Water Saturation at TP Horizon

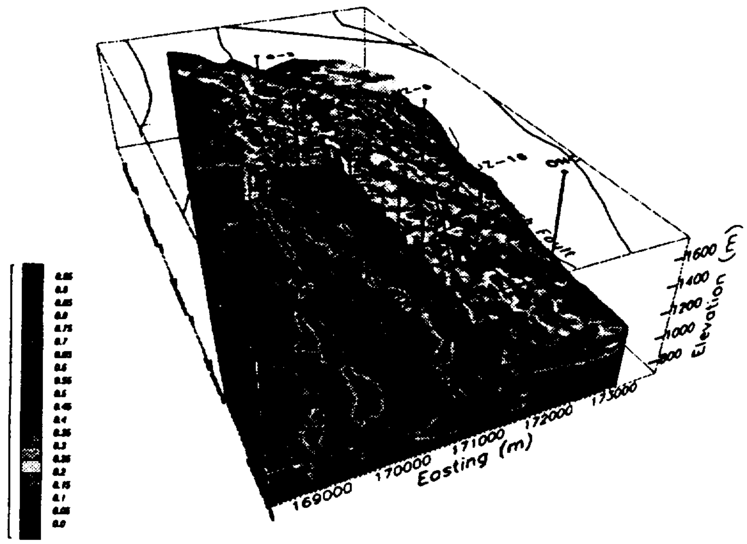

Figure 4. Chair cut display of liquid saturation in the UZ model domain.

FLOW PATTERNS BELOW THE REPOSITORY

Zeolitic rocks affect flow patterns below the potential repository, resulting in the formation of perched water, and potentially retarding radionuclide migration to the water table. Laterally diverted flow above zeolites may encounter a fault or extensive fracture system that can re-initiate predominantly vertical flow to the water table. Though characterization of flow below the repository is essential, available data are limited as to the spatial distribution and fracture characteristics of zeolitic horizons. Future work will hopefully shed light on these important issues.

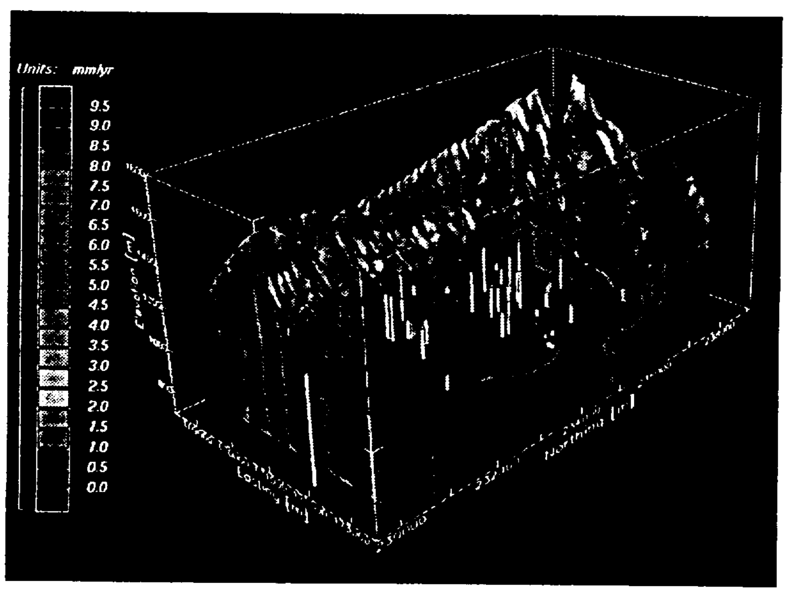

Figure 5. Simulated percolation flux through Yucca Mountain.

All aspects of the UZ site-scale flow model are described in detail, and all appropriate references are cited, in the LBNL report entitled, "The Site-Scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment," G. S. Bodvarsson, T. M. Bandurraga, and Y. S. Wu, eds. (1997), LBNL-40376, UC-814.