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SPATIAL DISTRIBUTION OF POTENTIAL NEAR SURFACE MOISTURE FLUX AT YUCCA MOUNTAIN

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ABSTRACT

An estimate of the areal distribution of present-day surface liquid moisture flux at Yucca Mountain was made using field measured water contents and laboratory measured rock properties. Using available data for physical and hydrologic properties (porosity, saturated hydraulic conductivity, moisture retention functions) of the volcanic rocks, surface lithologic units that are hydrologically similar were delineated. Moisture retention and relative permeability functions were assigned to each surface unit based on the similarity of the mean porosity and saturated hydraulic conductivity of the surface unit to laboratory samples of the same lithology. The potential flux into the mountain was estimated for each surface hydrologic unit using the mean saturated hydraulic conductivity for each unit and assuming all matrix flow. Using measured moisture profiles for each of the surface units, estimates were made of the depth at which seasonal fluctuations diminish and steady state downward flux conditions are likely to exist. The hydrologic properties at that depth were used with the current relative saturation of the tuff, to estimate flux as the unsaturated hydraulic conductivity. This method assumes a unit gradient. The range in estimated flux was 0.02 mm/yr for the welded Tiva Canyon to 13.4 mm/yr for the nonwelded Paintbrush Tuff. The areally averaged flux was 1.4 mm/yr. The major zones of high flux occur to the north of the potential repository boundary where the nonwelded tuffs are exposed in the major drainages.

INTRODUCTION

Yucca Mountain, Nevada (Fig. 1), is currently being evaluated as a potential site for a geologic repository for high-level radioactive waste. Unsaturated groundwater flow may be a potential source of radionuclide transport to the accessible environment[1]. Shallow infiltration of natural precipitation is a potential source of water for deeper percolation of groundwater through the thick unsaturated zone which includes the potential repository horizon. Characterization of flux in the near surface volcanic tuffs is important for defining the upper surface boundary conditions for site-scale groundwater flow models. These models will be used to estimate moisture flux through the deep unsaturated zone at Yucca Mountain. A series of 1-D[2], 2-D[3], and 3-D[4] models are being developed to estimate moisture conditions and flux rates under present day saturations

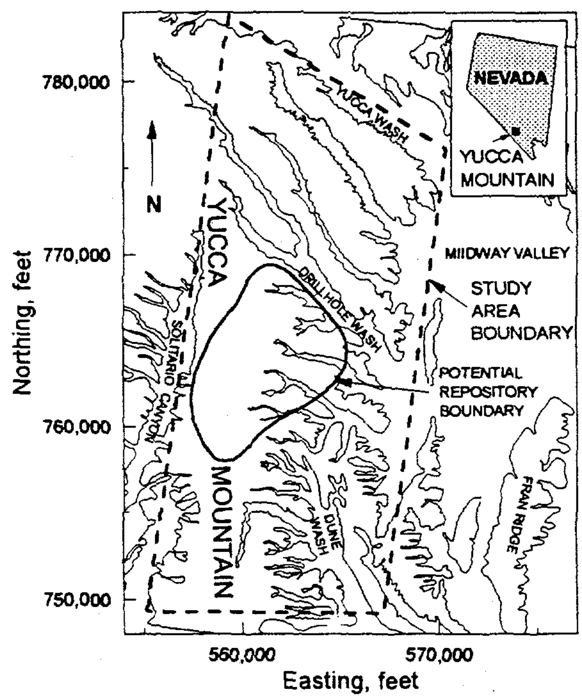

Figure 1. Location of site area in southern Nevada.

and climatic conditions. The spatial and seasonal variability of flux at the upper boundary needs to be determined to evaluate the appropriateness of 1-D or 2-D flow models or the necessity of a 3-D model. These models will be used to predict the behavior of the site under varying climatic and thermal conditions and to ascertain if Yucca Mountain is a suitable location to isolate radioactive waste from the accessible environment. Although the more complex 3-D models are more difficult to run, they may provide more realistic results. The model development and its dimensionality will require an understanding of the large scale surface heterogeneities and properties of the surface features that will control the near surface flux conditions under varying climatic scenarios.

Surface infiltration is a function of the properties of the surficial materials and the availability of water as a result of climatic conditions. The properties define the maximum or potential flux, while the climatic conditions (i.e. precipitation amount, rate, seasonality), determine the input into the system and, therefore, the estimated flux rate. To identify the potential flux, the hydraulic properties of the surface materials must be estimated. The alluvial cover over the site is a mechanism that stores, concentrates, and evaporates water, thus influencing the timing and volume of the input into the bedrock. The influence of the alluvium is accounted for by evaluating the water content at the alluvium bedrock interface. Deeper alluvium results in smaller water content changes and hence is closer to a steady state flux rate. Shallow alluvium allows for a greater change in water content and makes estimating flux more difficult unless surface features can be incorporated[5]. Important surface features include welded and nonwelded volcanic tuff penetrated by varying concentrations of fractures. Most of the surface fractures are filled with calcium carbonate or other surficial materials (i.e. silts and clays). Although fractures may be important mechanisms in the near surface,[5] they are being excluded in this exercise. The small surface area of the exposed fracture under the alluvium and the small number of fractures in the nonwelded tuffs allow for a reasonable preliminary analysis.

The intent of this exercise is to test a method that combines an understanding of the factors controlling the flux at the near surface, and the hydrologic properties of the surface rocks, to produce a surface map of potential moisture flux into the mountain over a 6 square km area. This map provides insight as to the regions of the site that have the potential to produce the highest surface flux. It also helps to identify locations where additional information may be needed. In addition, it will provide preliminary input of surface flux for each grid block in the 3-D site-scale model currently being developed[4]. Fracture networks and fracture properties may be included in a similar analysis when more fracture information becomes available.

SITE DESCRIPTION

Yucca Mountain is located in the Mojave Desert, 160 km northwest of Las Vegas, Nevada (Fig. 1). It is an uplifted, tilted, and faulted ridge that is composed of layers of volcanic ash-flow and ash-fall tuffs with widely varying physical and hydrologic properties largely due to differences in welding. The surface of the mountain has been eroded to expose different units in different locations with varying hydrologic properties. The climate at Yucca Mountain is represented by average annual precipitation of 170 mm/yr with a range of 165 mm/yr at the south end of the mountain to 230 mm/yr at the north end of the mountain[6].

The extent of the study site for this exercise is represented by the boundaries selected for the site-scale model being produced cooperatively by the U.S. Geological Survey and Lawrence Berkeley Labs[4]. The boundaries on the east, west, and north coincide with locations of major faults and all boundaries were selected to represent no-flow boundary conditions for 3-dimensional numerical modeling of unsaturated zone flow (Fig. 2). Grid blocks for modeling were developed for the site-scale model to correspond roughly with major faults, known boreholes and topographic features and are presented in this exercise with the flux estimates to represent spatial distribution.

METHODOLOGY

Physical and Hydrologic Properties of Rocks

Samples were collected from surface outcrops in a series of 8 transects that produced 685 core samples which were used to obtain measurements of various physical and hydrologic properties. Properties which were used in this study included porosity for 467 samples using water saturation and Archimedes' displacement, saturated hydraulic conductivity for 287 samples using a steady state permeameter, and moisture retention characteristics for 45 samples representing all lithologic units using a chilled-mirror psychrometer. Van Genuchten functions[7] were fit to the moisture retention data. Saturated hydraulic

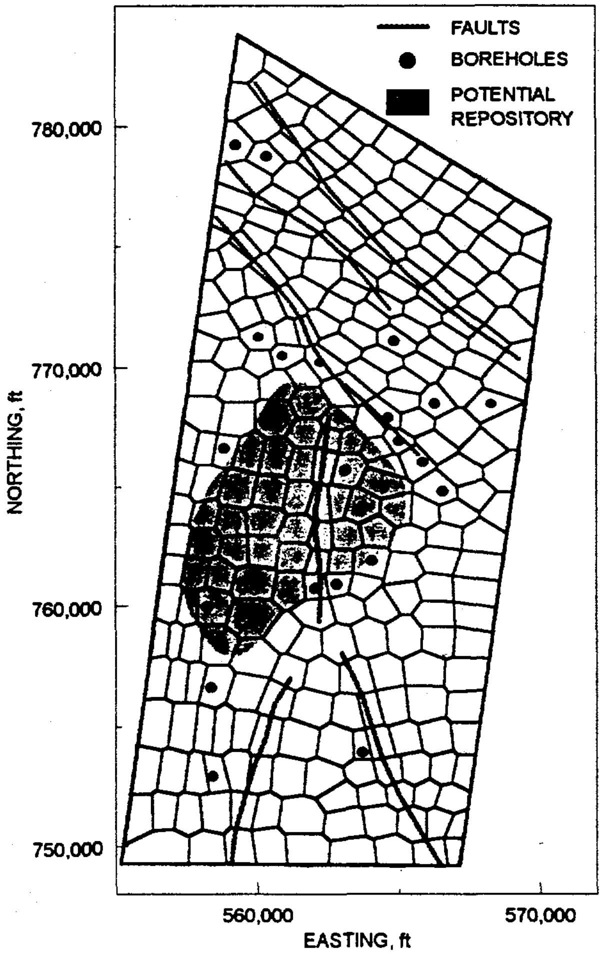

Figure 2. Surface grid blocks and boundary for the 3-D USGS/LBL site model.

conductivity could not be determined on a number of densely welded samples due to equipment limitations. These values were estimated by developing a relationship between porosity and the log of conductivity for 197 samples. The nonwelded zeolitic tuffs form the Tuffaceous Beds of Calico Hills and the highly vitric samples were excluded from this relationship because of zeolites or microfractures. Using linear regression, the equation, [log(conductivity, m/s) = -11.49 + 12.29 * porosity], was fit with an r^2 of 0.77 to estimate values of conductivity for the densely welded samples. No core samples were available for laboratory measurements on the Rainier Mesa unit located on the eastern edge of the study area. Lithologic features and welding were estimated from field observations and properties were estimated from similar core data of the moderately welded Base of the Tiva Canyon.

Volumetric Water Content and Saturation

Volumetric water content was measured monthly in 99 boreholes at 0.1-0.3 m increments using a neutron moisture meter (Model 503, Campbell Pacific Nuclear, Martinez, CA)*. Boreholes were drilled between 1986 and 1993 to depths of between 9 and 75 m in rock and alluvium, with almost all alluvium boreholes ending in tuff. Depth of annual fluctuations in water content are relatively obvious in these neutron logs when compared over several seasons. Annual wetting and drying of the upper parts of the boreholes above the depth of annual fluctuations are seen[5].

Average "steady state" depth was estimated in the neutron log water content profiles by organizing the boreholes by similar locations in the each of the different surface units. The hydrologic unit present at the depth where steady state conditions existed was reassigned as the surface hydrologic unit. The volumetric water contents of the rocks were calculated from the neutron moisture meter logs and the relative saturations were estimated from core samples to determine the mean values for all surface units (Table 1).

Core samples were collected from 23 neutron-access boreholes drilled in 1991 to 1993 to between 30 and 75 meters. Samples from approximately every meter were packaged to preserve field moisture conditions for laboratory measurement. Porosity and bulk density were determined on each core, saturation was calculated, and lithology was identified.

Table 1. *In situ* conditions for surface units estimated from volumetric water content profiles measured using the neutron moisture meter and from water content and saturation measured on core samples from neutron-access boreholes.

Surface Unit	Volumetric Water Content (cm^3/cm^3)	Relative Saturation
TCcr	0.09	0.75
TCmw	0.07	0.29
TCw	0.06	0.82
PTn	0.19	0.48
RM	0.10	0.81
TSw	0.08	0.83

Table 2. Properties used for calculation of potential and present-day flux of surface units at Yucca Mountain. Data used is from rock outcrop transects. # is number of samples used in calculation.

Surface Unit	Porosity (cm^3/cm^3)	Standard Deviation	#	Saturated Hydraulic Conduct. (m/s)	Standard Deviation	#	van Genuchten parameters* alpha	n
TCcr	0.119	0.022	6	1.1E-10	1.9	6	0.648	1.40
TCmw	0.240	0.050	77	3.9E-9	4.5	77	0.237	2.20
TCw	0.078	0.029	60	2.7E-11	24	16	0.065	1.38
PTn	0.403	0.127	126	5.2E-7	28	159	1.371	1.48
RM	0.120	0	0	4.2E-9	0	0	0.177	1.23
TSw	0.092	0.046	198	5.9E-11	33	29	0.210	1.45

* Values determined from moisture retention data collected on samples with similar porosity and conductivity as above mean values.

Development of Maps

The exercise was conducted in a series of steps. 1) Surface lithologic units that are hydrologically similar were delineated using available data for physical and hydrologic properties (porosity, saturated hydraulic conductivity, moisture retention functions) of the volcanic rocks at Yucca Mountain . Transect samples were organized stratigraphically and major hydrologic units were identified based on porosity and saturated hydraulic conductivity. The identified surface hydrologic units have relatively small standard deviations of properties within each unit. Moisture retention functions were assigned to each surface unit based on the similarity of the mean porosity and hydraulic conductivity of the surface unit to the rocks for which moisture retention was determined. 2) Using a geologic map of the site and estimates of lithology under alluvium from borehole descriptions, the surface units were identified and outlined. 3) The potential flux into the mountain was estimated for each of the surface hydrologic units using the mean saturated hydraulic conductivity for each unit which assumes all matrix flow and a vertical unit gradient. 4) Using measured moisture profiles for each of the surface units, estimates were made of the depth at which seasonal fluctuations diminish and steady state downward flux conditions exist. 5) The surface hydrologic unit at that steady state depth was determined and the current relative saturation of the tuff was estimated using the volumetric water content profiles from neutron logs and *in situ* saturations and porosity determined on borehole core samples. 6) The estimated, present-time flux for each surface unit was calculated using the relative saturation of the tuff at the steady state depth, moisture retention functions and relative permeability estimated using van Genuchten parameters[7]. 7) Potential and present-day flux values were then assigned to the surface units, and 8) overlaying the model grid from the site scale model, the unit encompassing the highest percentage of each grid block was determined visually and the corresponding flux value was assigned to each block.

RESULTS

Physical and Hydrologic Properties of Tuffs

The surface rocks were separated into 6 main surface hydrologic units based on their porosity and saturated hydraulic conductivity (Table 2). The Tiva Canyon and Topopah Spring Members of the Paintbrush Tuffs were kept separate rather than combined, even though their properties are similar, to maintain some stratigraphic significance in the units. The 6 units in stratigraphic order are the caprock of the Tiva Canyon Member (TCcr), the moderately welded Tiva Canyon Member (TCmw), the welded Tiva Canyon Member (TCw), the nonwelded Paintbrush Tuffs (PTn), the partially welded Rainier Mesa (RM) and the welded Topopah Spring Member (TSw). The TCmw includes some of the higher porosity rocks generally included in the lithologic descriptions of the lower part of the caprock and only includes the upper portions of what is generally described as the upper cliff zone of the Tiva Canyon Member. The PTn includes all nonwelded rocks as well as some moderately welded rocks located stratigraphically in the base of the Tiva

Canyon Member that have porosities greater than 16 percent.

Potential Surface Flux

The TCw is the unit with the lowest porosity and conductivity, but is fairly similar to the TSw. The TCmw and the RM have intermediate conductivities and the PTn has a relatively large mean porosity and high conductivity. These surface hydrologic units were outlined on the geologic map within the site-scale model boundaries (Fig. 3).

Table 3. Calculated potential and present-day flux (mm/yr) for surface units.

Surface Unit	Percent of Area	Potential Flux (mm/yr)	Present-day Flux (mm/yr)
TCcr	6	3.4	0.04
TCmw	6	122.0	0.22
TCw	68	0.9	0.02
PTn	12	16398.7	13.40
RM	1	133.7	0.60
TSw	6	1.9	0.08

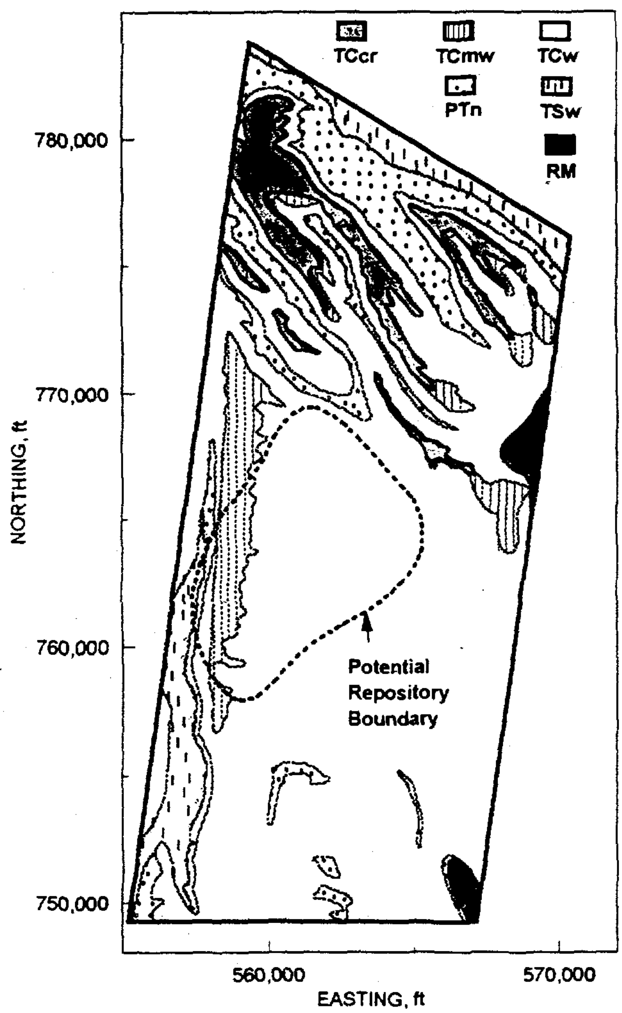

Figure 3. Geologic units at the surface of Yucca Mountain or directly under the alluvium.

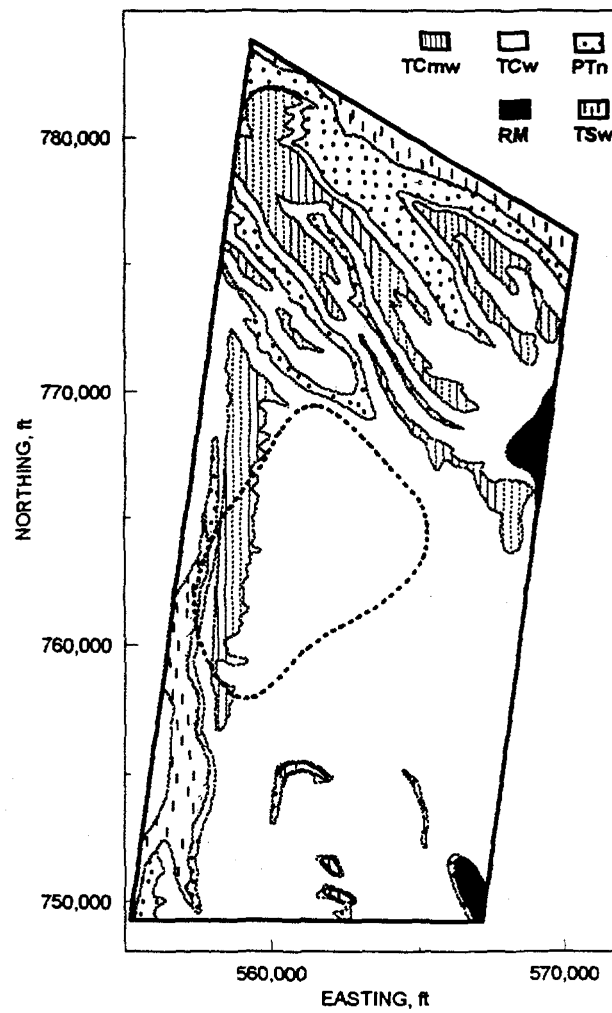

Figure 4. Geologic units at steady state over the surface of Yucca Mountain.

The TCcr (6% of the total area within the model boundaries) is only located on the north end of the study site, as is the majority of the PTn (12% total area). The majority of the crest is composed of the more highly permeable TCmw (6% total area), with TSw (7%) located on the north and western boundaries and only a small percentage (1%) of the RM unit found at the surface. The large majority of rocks that are exposed at the surface or directly underlying alluvium are the TCw (68% of the total area) and encompass over 85% of the potential repository boundary (Fig. 3). The calculation of potential flux of the various units based on saturated hydraulic conductivity results in extremely high values in some cases, as in the PTn with over 16,000 mm/yr flux under saturated conditions (Table 3). The lower porosity units have much lower estimated fluxes.

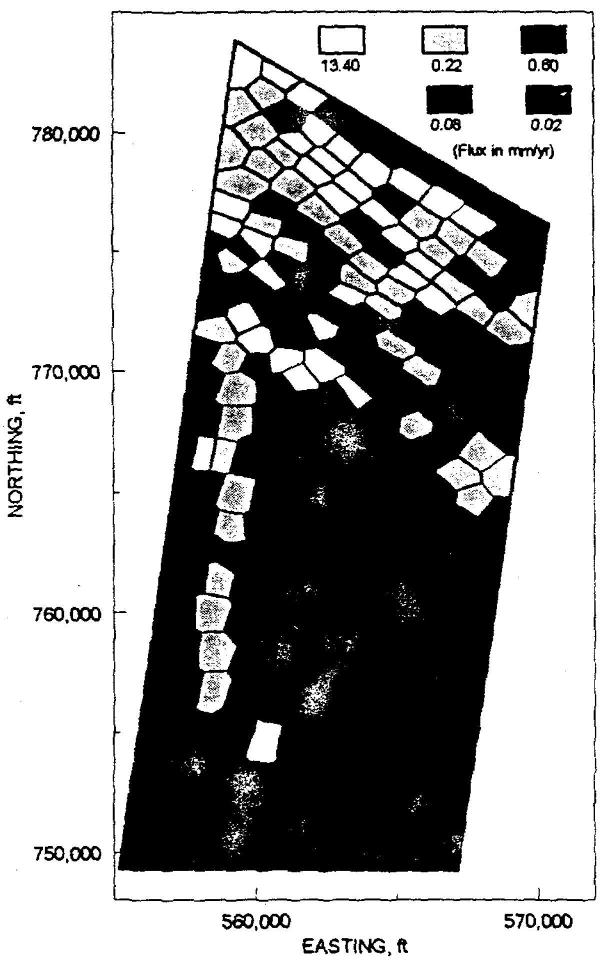

Figure 5. Estimate of flux, in mm/yr, for the surface grid blocks for the 3-D USGS-LBL site model.

Present-Day Flux

Differences between the surface units were found to be greater when analyzed in terms of the depth at which there was observed to be a potential for steady state conditions. Surface fluctuations of water content were observed to be shallow in the alluvium and usually the "steady state" depth is selected as the contact with the tuff directly underlying the alluvium[5]. In locations with shallow or no alluvium seasonal fluctuations vary in depth and magnitude in different topographic positions, as well as in different rocks. The "steady state" depth in all of the boreholes located in the TCcr on the northern ridges was deeper than the extent of that unit and penetrated into the underlying TCmw (Fig. 4). This location was the major difference with some small differences evident in the 3 PTn units located in the south central portion of the study area which penetrated to the underlying TSw. This revised surface unit map now increases the TCmw percent coverage to 13% of the total area.

These flux values can be directly applied to the various surface hydrologic units and a visualization of where the most significant surface infiltration should occur can be made. When the relative permeability is taken into account to calculate present-time fluxes, the values are greatly reduced from the potential flux discussed above, resulting in fluxes less than 1 mm/yr for all but the PTn which is 13.4 mm/yr, with the areally averaged flux over the study area being 1.4 The majority of surface flux should occur in the northern washes where there is surface PTn, while the largest percentage of surface area, which is TCw, has present-day fluxes on the order of 0.02 mm/yr.

For modeling purposes a network of grid blocks used in the 3-D site-scale model (Fig. 4) can be overlaid on the surface hydrologic unit map. Each grid block then receives a flux value according to the largest percentage of surface unit occupying that block. When transformed into a flux map for the model, it is readily apparent where the largest fluxes will occur *(Fig. 5). Of 286 grid blocks, 11.5 % are occupied by* PTn at 13 mm/yr flux, 15% are TCmw, 6% are TSw, 1% is RM, while the remaining 66% are occupied by TCw which is the lowest flux.

CONCLUSIONS

An estimate of the areal distribution of present-day surface flux was made using field measured water contents and laboratory measured rock properties. Measured variations in the near surface water content were accounted for by evaluating neutron hole data to determine the depth at which seasonal variations were minimized. In many cases the alluvium reduced the changes in moisture content so that a near steady state condition existed at the tuff alluvium interface. Where the alluvium was thinner or missing several meters of the surface tuff had to be discounted to estimate a near steady state flux. The final estimate of flux into the mountain was estimated for each of the steady state hydrologic units using the mean unsaturated hydraulic conductivity for each unit, and assuming all matrix flow and a unit gradient. The range in flux was 0.02 mm/yr for the welded Tiva Canyon to 13.4 mm/yr for the nonwelded Paintbrush Tuff. The areally averaged flux was 1.4 mm/yr. This method has identified zones where high fluxes are likely. These zones, generally north of the potential repository boundary, have the potential to establish lateral flow which should be accounted for by using 3-D models.

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[a] The use of brand, trade, or firm names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

REFERENCES

1. U.S. Department of Energy, *Yucca Mountain Site Characterization Plan.* DOE/RW-0199, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C. Section 8.3.1.2.2.1.2. (1988).

2. A.L. Flint, L.E. Flint and J.A. Hevesi, "Influence of Long Term Climate Change on Net Infiltration at Yucca Mountain, Nevada", *Proceedings, International High Level Nuclear Waste Conference*, Las Vegas, NV., April (1993).

3. M.A. McGraw, G.S. Bodvarsson, L.E. Flint, and A.L. Flint, "Numerical modeling of lateral infiltration into the Paintbrush Tuff at Yucca Mountain, Nevada", LBL Report, January (1994).

4. C.S. Wittwer, G.S. Bodvarsson, M.P. Chornack, A.L. Flint, L.E. Flint, B.D. Lewis, R.W. Spengler, and C.A. Rautman, "Development of a three-dimensional site-scale model for the unsaturated zone at Yucca Mountain, Nevada", *Proceedings, International High Level Nuclear Waste Conference*, Las Vegas, NV., April (1992).

5. L.E. Flint, A.L. Flint and J.A. Hevesi, "Shallow infiltration processes in arid watersheds at Yucca Mountain, Nevada", *Proceedings, International High Level Nuclear Waste Conference*, Las Vegas, NV., May (1994).

6. J.A. Hevesi, A.L. Flint, and J.D. Istok, "Precipitation estimation in mountainous terrain using multivariate geostatistics. Part II: isohyetal maps", *Journal of Applied Meteorology* 31:677-688 (1993).

7. M. Th. Van Genuchten, "A closed-form equation for predicting the hydraulic conductivity of unsaturated soils", *Soil Science Soc. Am. J.* 44:892-898 (1980).

8. R.B. Scott, J. Bonk, "Preliminary geologic map of Yucca Mountain with geologic sections, Nye County, Nevada", *Open-File Report 84-494*, U.S. Geological Survey, scale 1:12,000 (1984).

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