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MODELING UNSATURATED-ZONE FLOW AT RAINIER MESA AS A POSSIBLE ANALOG FOR A FUTURE YUCCA MOUNTAIN

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INTRODUCTION

Rainier Mesa is structurally similar to Yucca Mountain, and receives precipitation similar to the estimated long-term average for Yucca Mountain. Tunnels through the unsaturated zone at Rainier Mesa have encountered perched water and, after the perched water was drained, flow in fractures and faults. Although flow observations have been primarily qualitative, Rainier Mesa hydrology is a potential analog for Yucca Mountain hydrology in a wetter climate. In this paper, a groundwater flow model that has been used in the performance assessment of Yucca Mountain–the weeps model–is applied to Rainier Mesa. The intent is to gain insight in both Rainier Mesa and the weeps flow model.

RAINIER MESA

Rainier Mesa is located some 50 km northeast of Yucca Mountain near the center of the Nevada Test Site. The elevation at the crest is about 2200 m, or about 700 m higher than Yucca Mountain. Annual precipitation is approximately twice that at Yucca Mountain (~320 mm/yr vs. ~180 mm/yr). Like Yucca Mountain, Rainier Mesa is composed of a series of tilted ash-fall and ash-flow tuffs resulting from volcanic activity in the region of the Timber Mountain–Oasis Valley caldera. A moderately welded cap covers a thick nonwelded stratum (thicker and more permeable than the corresponding PTn stratum at Yucca Mountain), which overlies a thin welded stratum, and a thick, nonwelded, zeolitized stratum (the Tunnel Beds).

Tunnels have been excavated at the base of Rainier Mesa into the Tunnel Beds, about 500 m below the crest but about 500 m above the regional water table. Numerous discrete perched-water bodies were encountered and, after the perched water drained, groundwater flow in fractures and faults was observed. The perched-water bodies were primarily vertical and poorly connected—i.e., draining one perched-water body did not appear to affect others. In this work, the emphasis is on tunnels U12e and U12n (Figure 1).[1]

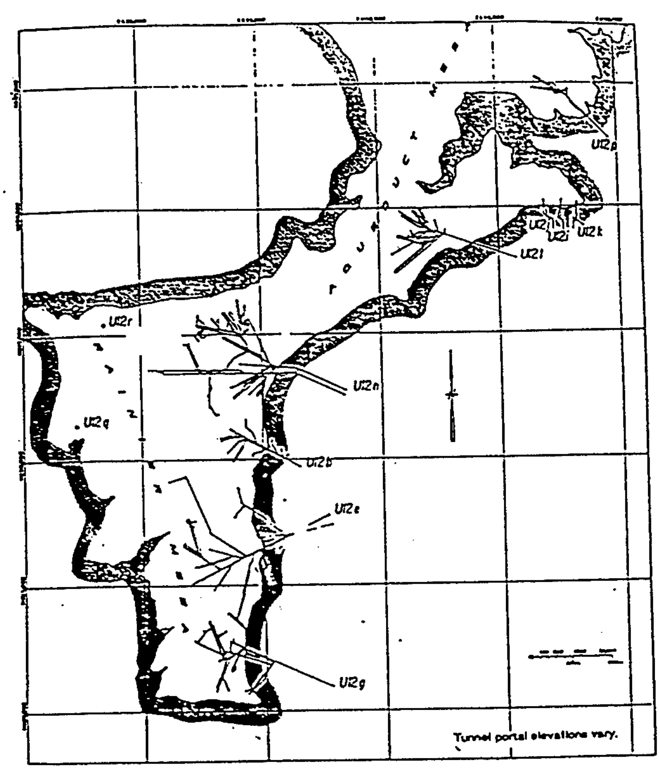

Figure 1. Rainier Mesa and tunnel complexes.[1]

In U12e tunnel, 177 perched-water bodies were encountered; of the 113 faults noted, approximately 50% contained perched water, accounting for 33% of the perched water bodies.[2] The average linear spacing of the perched water bodies was about 38 m. Most perched-water bodies drained at <1 gpm, although some drained at >20 gpm; draining continued for several years, although undoubtedly enhanced by continuing groundwater flow. No observations of flow patterns after the perched-water drainage are known, except for the bulk tunnel drainage (Table 1).

DISCLAIMER

Table 1. Fluid discharge (after perched-water drainage) from several tunnels in Rainier Mesa.[3]

Tunnel	Discharge (m^3/yr)
U12g	19
U12e	28,000
U12n	10,000
U12t	14,000

In U12n, the amount of fluid discharge (plus an estimate of water-vapor discharge caused by ventilation—~5300 m^3/yr) has been used to estimate a recharge rate of 23.7 mm/yr.[3] An assumption was that all infitrating water from the watershed entered the tunnel. The volume of discharge was seen to increase somewhat about 4 months after major winter precipitation events, indicating a minimum hydrologic response time; geochemical evidence suggests a travel time of less than 6 yr. Qualitative observations (C. Russell, DRI, personal communication) indicate that most seeps drip and most occur where there were perched-water bodies. Seeps are highly concentrated in the area in which U12n tunnel intersects what is known as the axis of the aqueduct syncline. (The aqueduct syncline was formed by the successive deposition of the tuffs on top of a topographic valley in the underlying paleozoic rocks.) Seeps occurring within the tunnel away from the syncline appear to have a spacing on the order of 100 m. The largest seeps appear in the walls of the tunnel and not from the ceiling (although tunnel shoring could have replumbed the seeps).

WEEPS MODEL

The major premise behind the weeps model is that flow in unsaturated fractured rock is in isolated, fast moving, episodic pulses. A more complete description of the model can be found in other sources.[4,5] Here a brief overview is given.

The weeps model follows directly from a number of postulates and assumptions: (1) all advective flow is restricted to locally saturated streams; (2) flow is distributed into these streams by dividing the infiltrating volume into as many fractures as can carry it at capacity (conserving mass); (3) flow is gravity driven (capillary forces are negligible); (4) the volume of an individual weep is dependent on fracture characteristics and episodicity (not infiltration volume); (5) locations of the flow streams are unknown (typically assumed to be uniformly distributed in space) and could change with time; (6) the number of fractures and weeps is large enough to characterize probabilistically. Major parameters of the model are the fracture (weep) aperture and width, the episodicity of flow, and the groundwater flux. Here, because data concerning hydrologic properties of fractures and faults at Rainier Mesa are unavailable, Yucca Mountain estimates are used: the weep aperture is defined to be exponentially distributed with a mean of 180-μm, and the width is uniformly distributed between 0.01 and 1 m. Infiltration episodes are defined with a loguniform distribution between constant flow and flow only a few days per year.

Of importance to this work is how the model handles weep spacing and weep volume—results that can be compared with observations from Rainier Mesa. Weep spacing (a) is calculated with the assumption that weeps are points in a horizontal plane: $a = \sqrt{A_w/N_w}$, where A_w is the area of the watershed and N_w is the number of weeps in the watershed calculated by the model. The number of weeps (N_t) intersecting a tunnel of horizontal area (A_t, where A_t is the product of tunnel length l_t and diameter w_t) is then $N_t = N_w A_t / A_w$. And the average linear spacing of weeps (a_t) down the length of a tunnel is $a_t = l_t/N_t$. Although the model calculates the flow rate for each weep, the average flow rate (Q_{ave}) can be defined as: $Q_{ave} = qA_w/N_w$, where q is the infiltration rate. The total discharge (Q_t) of weeps entering a tunnel can then be estimated as $Q_t = N_t Q_{ave}$.

CALCULATIONS AND INTERPRETATIONS

Weeps-model calculations were performed for several different infiltration rates and weeps-related statistics were collected for a tunnel 6700-m long and 5-m wide (similar to U12e; U12n is about 9000-m long). Results are presented in Table 2. Large variances are associated with these numbers, but their interpretation must be postponed.

Assuming that the infiltration rate is 24 mm/yr over U12n, as estimated by Russell et al., and 7 mm/yr over U12e (preserving the ratio of measured discharges), then the model is reasonably consistent with qualitative observations and interpretations of numbers of weeps, spacings, and volumes. For example, the model predicts a spacing of 75 m for an influx of 24 mm/yr, which is reasonable for U12n. Also the average weep flow rate of 9 m^3/yr corresponds to a dripping seep.

However, the model severely underpredicts the total discharge of water pumped from U12e and U12n. If the total discharge were entirely due to weeps directly intersecting these tunnels, it is estimated that the infiltration rate would be between ~300 and ~1000 mm/yr—rates greater than the precipitation rate ($q = Q_{obs}/A_t$, where Q_{obs} is the observed discharge rate). An explanation of the large total discharge that is consistent with the weeps model is that most weeps

Table 2. Results (median values) of weeps-model calculations, using 1000 realizations for each infiltration rate.

q (mm/yr)	N_t	a (m)	a_t (m)	Q_{ave} (m^3/yr)	Q_t (m^3/yr)
1	4	95	1820	9	33
7	26	36	257	9	235
24	90	19	75	9	805
100	377	9	18	9	3330

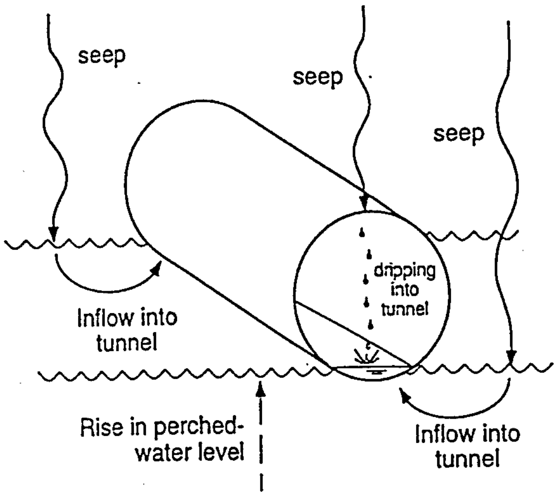

Figure 2. Diagram of how weeps not directly intersecting a tunnel can increase the water influx.

miss the tunnels but raise the perched-water level, thus causing water to enter the tunnel from the bottom or sides (Figure 2). This interpretation is also consistent with the assumption by Russell et al. that all infiltrating water is captured by the tunnel.

Another complication involves the number of observed perched water bodies in U12e. If the tunnel intersects 177 perched-water bodies, it is reasonable to assume that there are 177 weeps feeding these waters (whether the weeps directly intersect the tunnel or not). At an average of 9 m^3/yr per weep, only 1600 m^3/yr would enter the tunnel, suggesting that the average weep flow rate is too small. Weep size can be increased in the model by adjusting one or more of the following parameters: (1) increasing the weep aperture to a mean of $\sim$500 μm, (2) decreasing the episodicity to flow about half the time, or (3) increasing the weep width (effectively allowing several weeps to be located in close proximity).

CONCLUSIONS

This work supports the following conclusions about Rainier Mesa and the weeps model. (1) Most water entering tunnels at Rainier Mesa probably comes from a rise in the perched-water level and not from seeps that directly intersect the tunnels. (2) Flux estimates of of 7 mm/yr around U12e and 24 mm/yr around U12n are lower bounds, but reasonable. (3) The weeps model does not unambiguously describe flow at Rainier Mesa—more data are needed concerning seep numbers, individual flow rates, and the relation of seeps to geologic structure. (4) If the weeps model is applicable to Rainier Mesa, then either the use of Yucca Mountain seep parameters is not appropriate, or seeps tend to cluster within Rainier Mesa.

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REFERENCES

1. N.G.W. Cook, C.F. Tsang, and 10 others, *A Review of Rainier Mesa Tunnel and Borehole Data and Thier Possible Implications to Yucca Mountain Site Study Plans*, LBL-32068, Lawrence Berkeley Laboratory, Berkeley, CA (1991).

2. W. Thordarson, *Perched Ground Water in Zeolitized-Bedded Tuff, Rainier Mesa and Vicinity, Nevada Test Site, Nevada* (preliminary), TEI-862, U.S. Geological Survey, Denver, CO (1965).

3. C.E. Russell, J.W. Hess, and S.W. Tyler, "Hydrogeologic Investigations of Flow in Fractured Tuffs, Rainier Mesa, Nevada Test Site," in D.D. Evans and T.J. Nicholson, eds., Flow and Transport through Unsaturated Fractured Rock, Geophysical Monograph 42, American Geophysical Union, Washington, D.C. (1987).

4. J.H. Gauthier, M.L. Wilson, and F.C. Lauffer, "Estimating the Consequences of Significant Fracture Flow at Yucca Mountain," in *Proceedings of the Third International Conference on High Level Radioactive Waste Management*, American Nuclear Society, Inc., La Grange Park, IL, 891–898 (1992).

5. M.L. Wilson, J.H. Gauthier, R.W. Barnard, and 22 others, *Total-System Performance Assessment for Yucca Mountain—SNL Second Iteration (TSPA-1993)*, Ch. 15, SAND93-2675, Sandia National Laboratories, Albuquerque, NM (1994).

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