SAND2000-2785C

Flowing Interval Spacing Parameter for Matrix Diffusion in the Saturated Zone

Stephanie P. Kuzio
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87187-0776
spkuzio@sandia.gov

Bill W. Arnold
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87187-0776
bwarnol@sandia.gov

John H. Gauthier
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87187-0778
jhgauth@sandia.gov

Introduction

Groundwater flow is a possible avenue by which radionuclides leaking from a potential radioactive waste repository at Yucca Mountain (YM) could affect inhabitants of the region. The extent that the saturated zone (SZ) delays the release of radionuclides is of importance to SZ transport calculations to support performance assessment of YM. The migration of radionuclides through the fractured volcanic rocks depends to a large degree on the diffusive coupling between the advective water in the fractures and the relatively stagnant water in the matrix. This coupling is known as matrix diffusion and is a function of the fracture spacing. Typically, the distances between every fracture is used to determine the fracture spacing regardless of whether the fracture transmits significant groundwater or not. In this paper we present a new way of determining the fracture spacing, using only fractures that support advective flow, based on flow meter survey data from wells. Since flow meter data is taken over a wellbore interval, the measured groundwater flow is indicative of the flow within all or some of the fractures intersecting the interval, rather than a single fracture. We call the distance between the midpoints of adjacent flowing intervals the flowing interval spacing.

Parameter Development Approach

The best available data to determine the flowing interval spacing are borehole flow meter survey data collected by the United States Geological Survey (USGS). USGS has performed various borehole flow meter surveys in the Yucca Mountain region to identify groundwater flow in particular intervals in addition to other hydrologic data. Data were extracted only from borehole

DISCLAIMER

flow meter survey reports that also contained fracture orientation data. The flowing interval data consisted of tabular and graphical data. The data indicate the percentage of flow within an interval. For the graphical data, flowing intervals were identified at the location where the graphed flow rate changed slope significantly. As shown in Figure 1, the spacing between the midpoint of each identified flowing interval was then considered the flowing interval spacing. Figure 2 shows all of the boreholes and the flowing intervals used in this analysis. The shaded area indicates the flowing intervals, including the percentage of flow within the indicated interval. This figure also shows the (limited) number of data points within each interval and how the flowing interval spacings can span adjoining hydrogeological units.

A limitation of the borehole flow meter survey data is the difference in the types of flow meter tests. The data used in this analysis include flow meter survey tests such as radioactive-tracer tests and spinner tests. These flow meter survey tests are described in CRWMS 1997[1]. The various tests may introduce uncertainties to the results.

Results

There were 32 data points extracted from the USGS reports for the flowing interval spacing and 165 data points for the fracture orientation data (dip angle). Fracture orientation data within the flowing intervals was used with the Terzaghi correction to correct for flowing intervals not normal to the borehole[2]. Cumulative distribution functions (CDFs) were generated separately for the flowing interval spacing raw data and the fracture orientation raw data. These CDFs were then sampled using Latin Hypercubed Sampling[3]. The resulting 1000 sampled values for the flowing interval spacing and fracture orientation were then used to calculate the corrected flowing interval spacing using the Terzaghi equation:

$$F_c = F_{uc} \cos(D_f) \quad (1)$$

where F_c is the corrected flowing interval spacing, F_{uc} is the uncorrected flowing interval spacing and D_f is the flowing interval orientation. The geometric mean of the uncorrected flowing interval spacing was found to be 48 m and the geometric mean of the corrected flowing interval spacing was found to be 20 m. The geometric mean is used because the data was best represented by a log-normal distribution. The average orientation used for the correction was approximately 60 degrees. The spacing between the midpoint of each corrected flowing interval was then considered the spacing between the flowing intervals in Yucca Mountain SZ transport calculations.

A limitation of this method is that the flowing interval spacing may be overestimated because the number of fractures that contribute to a flowing interval cannot be determined from the data and because the width of the flowing interval is neglected in the computation of the spacing. Because each flowing interval probably has more than one fracture contributing to a flowing interval, the true flowing interval spacing would be less than the spacing determined in this analysis. Larger flowing interval spacing causes a decrease in the matrix diffusion processes in simulations of radionuclide transport in fractured tuff. Therefore, in terms of repository performance the results of this analysis may underestimate the effect of matrix diffusion in SZ transport models, thereby causing an overestimate of radiounclide migration velocity through the fractured media of the SZ.

For comparison purposes a second probability distribution was developed for the fracture spacing within the SZ. This second distribution, taken from the well logs, includes all fracture spacing in the SZ, not just the flowing intervals. The same methodology was followed for this second distribution as outlined above for flowing interval spacing and fracture orientation data, including the Terzaghi correction. The fracture spacing distributions and the flowing interval spacing probability distributions are compared in Figure 3. The geometric mean of the fracture spacing was found to be 0.25 m, which is approximately two orders of magnitude less than the geometric mean of the flowing interval spacing of 20 m.

Correlation of Flowing Interval Spacing to Hydrogeologic Units

To investigate the assumption that flowing intervals are correlated with hydrogeologic units, a statistical test was performed to determine if there are significant differences between the hydrogeologic units in terms of the amount of flow within the flowing intervals. A nonparametric rank test called the Kruskal-Wallis test was used to assess the null hypothesis that the populations of flowing intervals in each hydrogeologic unit, as measured by the percentage of flow in each flowing interval, were from the same distribution[4]. The Kruskal-Wallis test gave a *p*-level of 0.58, indicating that the differences in the flow in flowing intervals among different hydrogeologic units are not significant. In other words, based on the available data, the flowing intervals are not correlated with hydrogeologic units.

Conclusions and Discussion

Probability distributions for flowing interval spacing and fracture spacing in the SZ were determined through this analysis. The flowing interval spacing distribution was derived from flow meter survey data. The flowing interval spacing and fracture spacing in the SZ resulted in a lognormal probability distribution functions for both variables and are shown in Figure 3. The geometric means of the flowing interval and fracture spacing data are 20 m and 0.25 m, respectively.

This analysis did not correlate flowing interval spacing with the hydrogeologic units as has typically been done in the studies of the UZ. This assumption was analyzed using the Kruskal-Wallis test for statistical differences between the hydrogeologic units, based on the percentage of flow in each interval. The Kruskal-Wallis test indicated that there is no correlation between amount of flow within a flowing interval and hydrogeological units.

The results of this analysis may underestimate the effect of matrix diffusion, since the flowing interval spacing calculated is probably greater than the true spacing between the flowing intervals. The true flowing interval spacing would be less than the spacing determined in this analysis because, each flowing interval probably has more than one contributing fracture. However, the method to define the flowing interval spacing parameter as presented here is a step toward determining a more realistic description of contaminant transport in fractured media.

Acknowledgements

This work was supported by the Yucca Mountain Site Characterization Office as part of the Civilian Radioactive Waste Management Program, which is managed by the U.S. Department of Energy, Yucca Mountain Site Characterization Project. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

References

1. CRWMS M&O 1997. *Analysis of Flow Rate Logs from Borehole UE-25c#3 of the Site Saturated-Zone Groundwater Flow System at the Yucca Mountain, Nevada*. BAA000000-01717-5000-002 REV 00. Las Vegas, Nevada.

2. CRWMS M&O 2000. *Probability Distribution for Flow Interval Spacing.* ANL-NBS-MD-000003. Las Vegas, Nevada.

3. Terzaghi, R.D. 1966. "Sources of Error in Joint Surveys." *Geotechnique, 11 to 15,* 287-304. London, England: Institution of Civil Engineers. TIC: 239078.

4. StatSoft 1995. *Statistica. Volume 1, General Conventions and Statistics I.* Tulsa, Oklahoma: Statsoft. TIC: 239795.

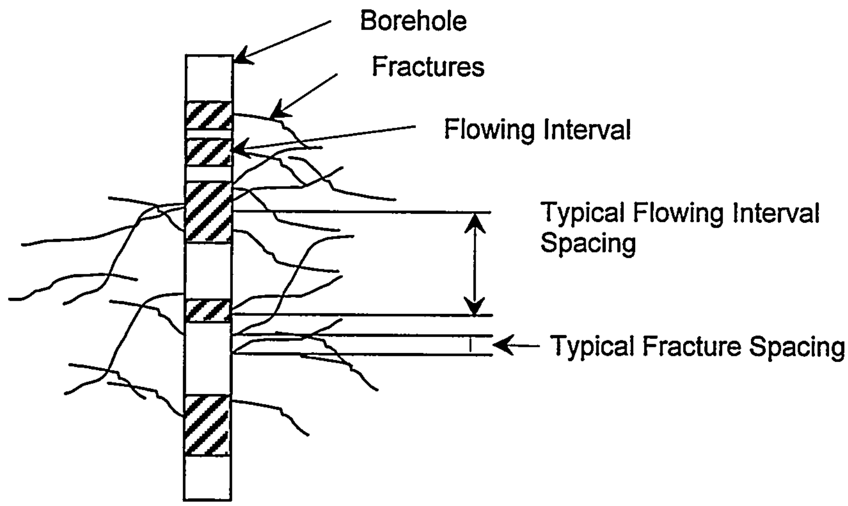
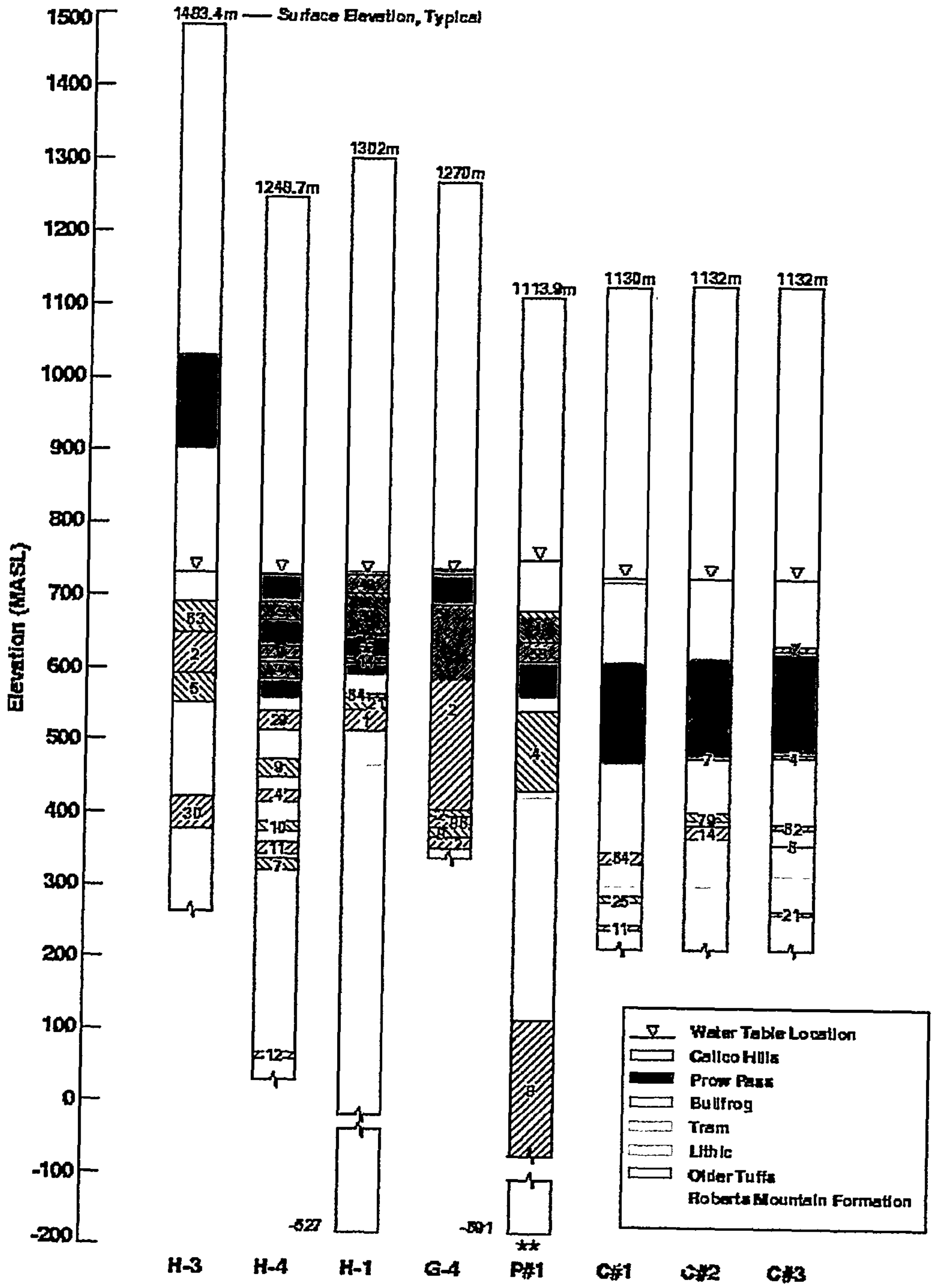


Figure 1. Example of Flowing Interval Spacing and Fracture Spacing as Identified from Borehole Flow Meter Survey Data. (CRWMS M&O 2000)



* Top of second survey. Two surveys were conducted in this borehole

** Note 28% of flow moved past lowest measurable station

Figure 2. Comparison of the Flow Meter Survey Borehole Information Used in this Analysis (CRWMS M&O 2000). Note: The shaded areas indicate flowing intervals and the number within the flowing interval represents the percentage of total flow within that interval.

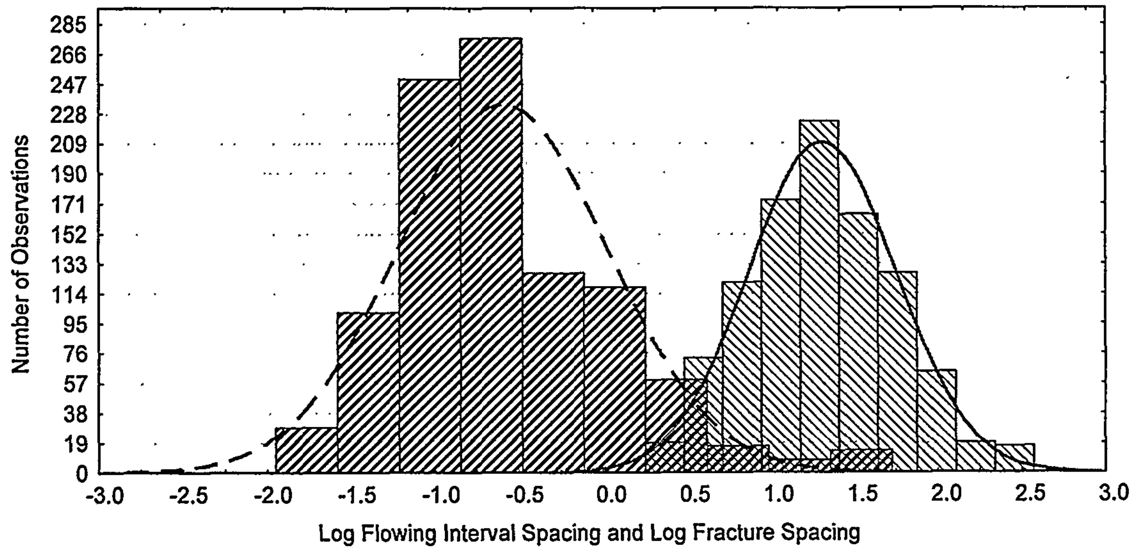


Figure 3. Comparison of the Probability Distributions of the Log_{10} of Corrected Flowing Interval Spacing and Fractures Spacing. Note: the solid line corresponds to the normal distribution fit to the log_{10} of the flowing interval spacing (log-normal distribution) and the dashed line corresponds to the normal distribution fit to the log_{10} of the fracture spacing (log-normal distribution).