Title

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CALCULATION OF DRIFT SEEPAGE FOR ALTERNATIVE EMPLACEMENT DESIGNS

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PURPOSE

The calculations presented in this report are performed to obtain seepage rates into drift and boreholes for two alternative designs of drift and waste emplacement at Yucca Mountain. The two designs are defined according to the Scope of Work 14012021M1, activity 399621, drafted October 6, 1998, and further refined in a conference telephone call on October 13, 1998, between Mark Balady, Jim Blink, Rob Howard and Chin-Fu Tsang. The two designs considered are described below.

Design A: Horizontal boreholes 1.0 m in diameter on both sides of the drift, with each borehole 8 m long and inclined to the drift axis by 30 degrees. The pillar between boreholes, measured parallel to the drift axis, is 3.3 m. In the current calculations, a simplified model of an isolated horizontal borehole 8 m long will be simulated. The horizontal borehole will be located in a heterogeneous fracture continuum representing the repository layer. Three different realizations will be taken from the heterogeneous field, representing three different locations in the rock. Seepage for each realization is calculated as a function of the percolation flux.

Design B: Vertical boreholes, 1.0 m in diameter and 8.0 m deep, drilled from the bottom of an excavated 8.0 m diameter drift. Again, the drift with the vertical borehole will be assumed to be located in a heterogeneous fracture continuum, representing the rock at the repository horizon. Two realizations are considered, and seepage is calculated for the 8-m drift with and without the vertical 1-m borehole at its bottom.

METHOD

The approach and method are fully described in the Level 4 Milestone Report SP331DM4: "Drift Scale Modeling: Studies of Seepage into a Drift" by Tsang et al., September, 1997; pp. 4-9, section 2 (DTN: LB970901233129.001). The report also gives data sources and references. This is the method used for subsequent detailed drift seepage calculations whose results were used in the TSPA-VA document. To summarize very briefly and qualitatively:

- a heterogeneous field was constructed from air permeability data in the ESF and Detailed Line Survey along the ESF;
- a drift is assumed to be located in the heterogeneous field, with the drift wall represented by a capillary barrier;
- for a series of percolation flux values entering the domain at the upper boundary, calculations were made to obtain the seepage locations and flow rates.

It turns out that seepage depends strongly on flow channeling and local ponding (both of which are results of rock permeability heterogeneity). Seepage occurs at percolation fluxes one or two orders of magnitude earlier (smaller) than that to be expected for a homogeneous medium.

ASSUMPTIONS

The assumptions employed are fully described in the Level 4 Milestone Report SP331DM4: "Drift Scale Modeling: Studies of Seepage into a Drift" by Tsang et al., September, 1997; pp. 7-12, 27-28 (DTN: LB970901233129.001). Key assumptions are as follows:

- The drift or borehole represents a capillary barrier.
- The fractures around the drift or borehole can be represented by a fracture continuum.
- The van Genuchten characteristic relationships can be used to describe the unsaturated flow.
- For the 1-m horizontal borehole calculations (Design A), the calculational mesh with grid size of 0.125 m is of sufficient accuracy.
- For the 8-m drift with 1-m vertical borehole (Design B), a calculational mesh with grid size of 0.5 m is of sufficient accuracy.

- Percolation in the mountain is constant over time; no episodic events are considered.
- The heterogeneity field based on air permeability tests in the ESF is a good representation of the fracture system at the site. The mean fracture continuum permeability k, used in the calculations, is 10^{-13} m^2, with σ (ln k) = 2.01, and the permeability spatial correlation length is 2 m, and the resolution for the generated heterogeneous field is 0.5 m.

COMPUTER SOFTWARE USED

The calculations presented in this report used the qualified baseline software ITOUGH2 Version 3.2_drift.

CALCULATIONS

Input parameters are presented in Table 1. They are same as the base case described in the Level 4 Milestone Report SLX01LB4: "Abstraction of Drift Scale Model for TSPA: Evaluation of Seepage into Drifts." April, 1998, by Tsang et al.; p. 15, Table 1, "Sept. 97" column (DTN: LB980412541195.001; DTN: LB980412541195.002). The report presents drift scale seepage results that were used in the TSPA-VA.

The calculational mesh for Design A is shown in Figures 1a, 1b, and 1c for the three different realizations of the heterogeneous permeability field, and the mesh for Design B is shown in Figures 2a and 2b for two permeability realizations. For Design B, computer runs were made twice for each case, once with the vertical 1-m borehole as shown in Figures 2a and 2b, and again without the vertical borehole. Comparison of these companion runs shows the changes in saturation and flows in the two cases and distinguishes the seepage into the drift from that into the vertical borehole.

The cases considered are listed in Tables 2 and 3 for Design A and Design B, respectively. In each of the cases for both designs, a series of percolation flux values were used, ranging from 10 mm/yr to 1000 mm/yr.

RESULTS AND DISCUSSIONS

As one can see from Table 2, not much seepage is expected for Design A. Because the diameter of the horizontal boreholes is relatively small, flow can easily go around it under gravity. Also, because the spatial heterogeneity correlation scale is 2 m, larger than the borehole diameter, the rock in the neighborhood of the borehole has similar permeability values. Thus the medium is approximately homogeneous near the borehole and the channeling effects are not significant. Then the ease with which liquid flows around the drift depends on the permeability values in the neighborhood of the borehole. Among all the cases run, there is the case of Realization 2 (see Figure 1b) where the borehole is in a relatively low-permeability region and in this case seepage occurs (Table 2). Even in this case, seepage starts to occur at a relatively large percolation flux, 50 mm/yr, and the seepage percentage, defined as the total seepage flow rate into the borehole divided by the total flux over the footprint of the 8-m borehole, is only 0.13%. When the percolation flux is 100 mm/yr, the seepage percentage is calculated to be 0.39%. The liquid saturation profile for this last case is shown in Figure 3. More common are the cases where there is no seepage, even for percolation flux values up to 500 mm/yr. Figures 4 and 5 show the liquid saturation profile for one of these cases (Realization 3 in Table 2) for percolation flux of 100 and 500 mm/yr respectively.

With Design B, for the two realizations calculated and for all the percolation flux values used, total seepage rates are the same with or without the 1-m borehole at the bottom of the drift (see Table 3). This means that all seepage occurs in the drift and not in the borehole, which is confirmed by detailed study of the calculational results. Figures 6, 7a and 7b show the saturation profiles for the case of a very large percolation flux of 2000 mm/yr, with and without the 1-m vertical boreholes. They are quite similar, indicating that the 8-m drift acts as a very effective "umbrella" over the 1-m borehole, reducing the probability of seepage into the vertical boreholes. Thus, this is a very effective system as far as seepage into the borehole is concerned. The issue then becomes how well one can prevent the water that has seeped into the 8-m drift from entering into the vertical boreholes at the connection on the floor of the drift. Seepage percentages into the 8-m drift as a function of incoming percolation flux values are shown in Figure 8. Overall, these are much larger than those for the 1-m horizontal borehole cases in Design A. They are comparable to the results for the 5-m drift case used in TSPA-VA studies (See Level 4 Milestone Report SLX01LB4: "Abstraction of Drift Scale Model for TSPA: Evaluation of Seepage into Drifts." April

1998, by Tsang et al.; p. 51, Figure 16 (DTN: LB980412541195.001; DTN: LB980412541195.002). Normally we expect that, for homogeneous medium, the larger the drift diameter, the more difficult it is for the liquid to flow around it without being trapped by possible local ponding at the drift walls. However it appears that for heterogeneous medium, flow is dominated by channeled flow and local ponding and the seepage percentage would be about the same for different drift diameters if they are all significantly larger than the spatial heterogeneity correlation length.

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REFERENCES

Tsang, C. F., Birkholzer, J., Li, G. and Tsang, Y W., September, 1997. "Drift Scale Modeling: Studies of Seepage into a Drift." Level 4 Milestone SP331DM4, DTN: LB970901233129.001.

Tsang, C. F., Birkholzer, J., Li, G. and Tsang, Y W., April, 1998. "Abstraction of Drift Scale Model for TSPA: Evaluation of Seepage into Drifts." . Level 4 Milestone SLX01LB4, DTN: LB980412541195.001, DTN: LB980412541195.002

Table 1. Base case parameter sets used for the fracture continuum in the drift scale modeling (Tsang, et al., April 1998).

Permeability* (horizontal)	1.00×10^{-13} m^2
Permeability* (vertical)	1.00×10^{-13} m^2
σ (ln k)	2.01
vG α - value	9.73×10^{-4} 1/Pa
vG n - value	2.70
Residual Sat.	0.01

* **Values represent geometric mean of fracture permeability fields**

Table 2. Rate of seepage into drift for different percolation fluxes of design A. The seepage rate is given as percentage (%) of percolation flux over the borehole footprint. "No" is used for no seepage. DTN LB981101233129.001

Scenarios(mm/yr)	10	20	50	100	200	500
Realization 1	No	No	No	No	No	No
Realization 2	No	No	0.134	0.390	---	---
Realization 3	No	No	No	No	No	No

Table 3. Rate of seepage into drift for different percolation fluxes of design B. The seepage rate is given as percentage (%) of percolation flux over the drift footprint. "No" is used for no seepage. DTN LB981101233129.001

Scenarios(mm/yr)	Realization 1		Realization 2	
	8-m diameter main drift	8-m drift with a 1-m diameter extension	8-m diameter main drift	8-m drift with a 1-m diameter extension
10	No	No	No	No
20	3.419	3.419	No	No
50	6.356	6.356	1.154	1.154
100	10.906	10.906	6.017	6.017
200	19.397	19.397	18.365	18.365
500	32.684	32.684	38.315	38.315
1000	53.199	53.199	58.923	58.923
2000	70.148	70.148	77.549	77.549

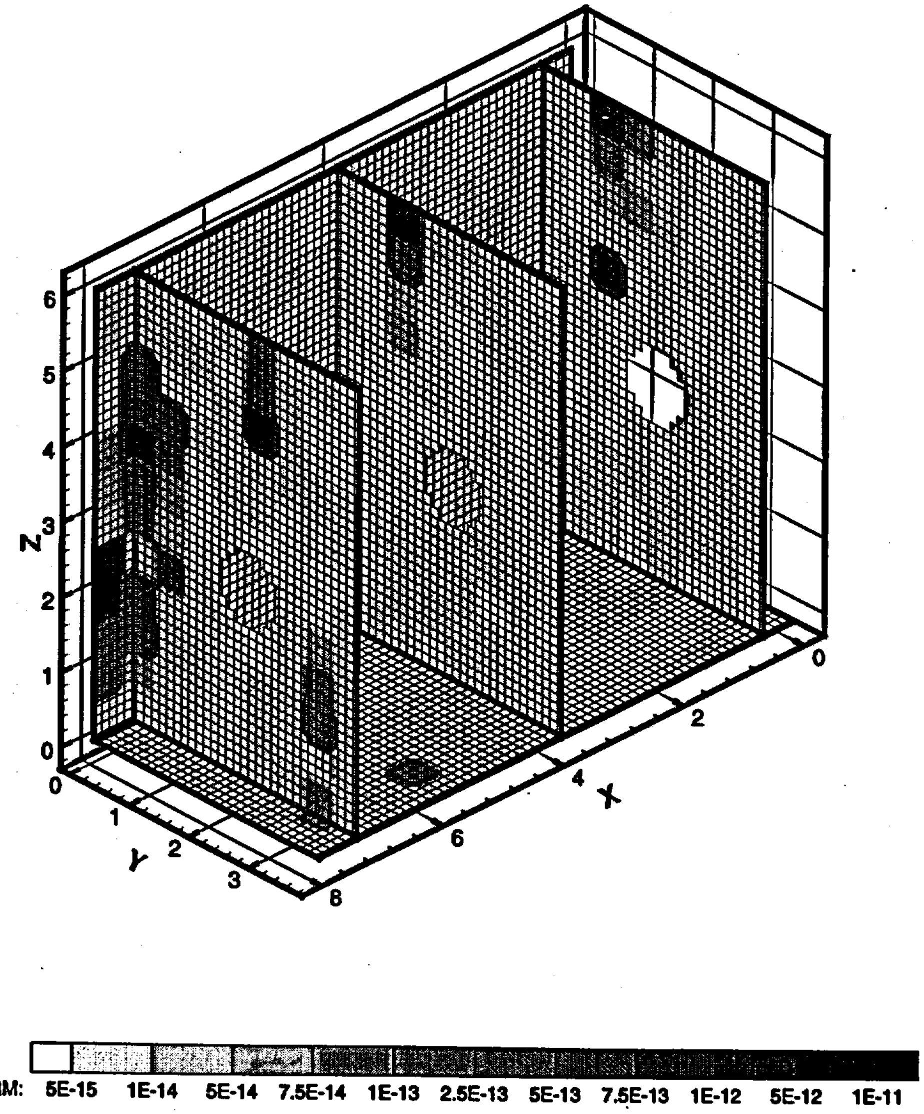

Figure 1a. Heterogeneous fracture permeability field for vertical planes in realization 1 of Design A, with permeability in units of m^2. The grid shown is the calculation grid with 0.125-m resolution. Note that the resolution for heterogeneous field is 0.5-m. DTN LB981101233129.001

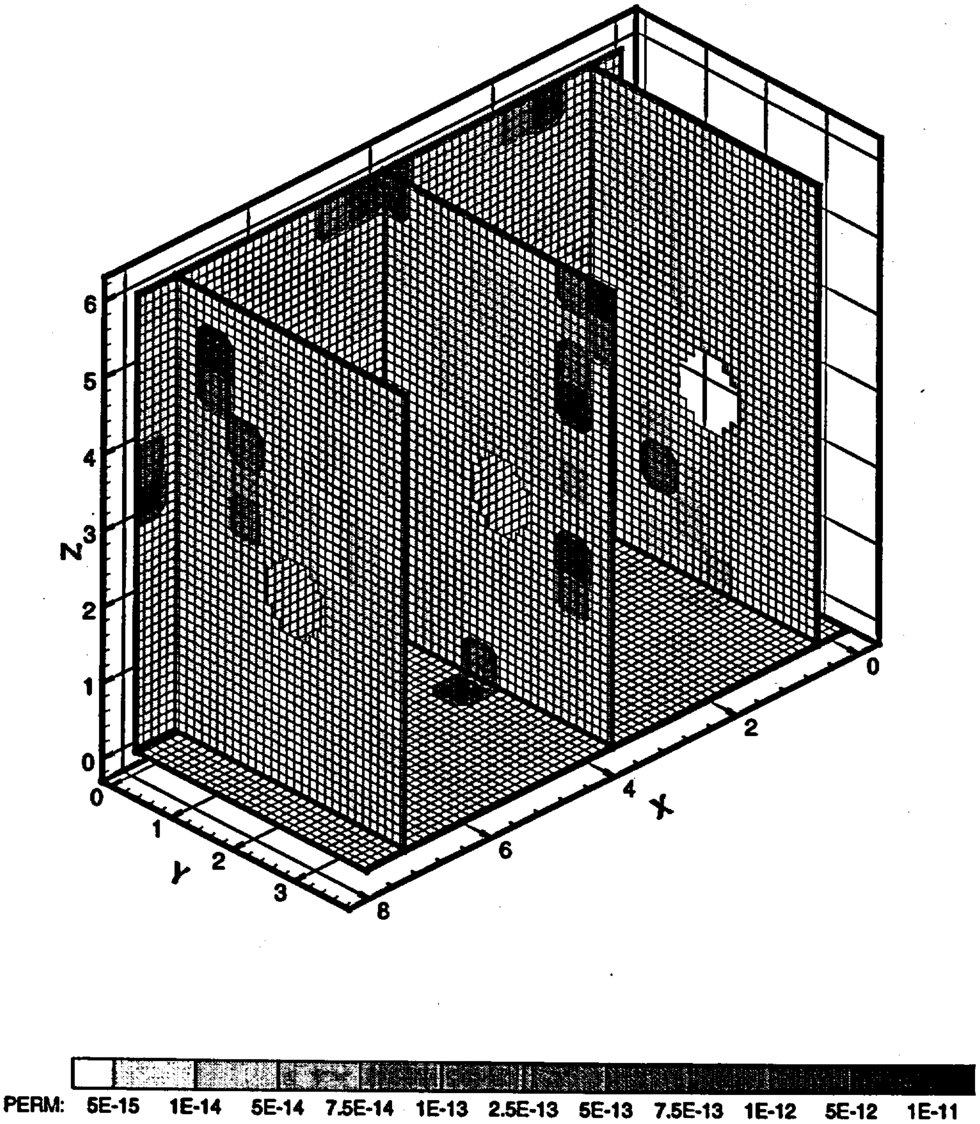

Figure 1b. Heterogeneous fracture permeability field for vertical planes in realization 2 of Design A, with permeability in units of m^2. The grid shown is the calculation grid with 0.125-m resolution. Note that the resolution for heterogeneous field is 0.5-m. DTN LB981101233129.001

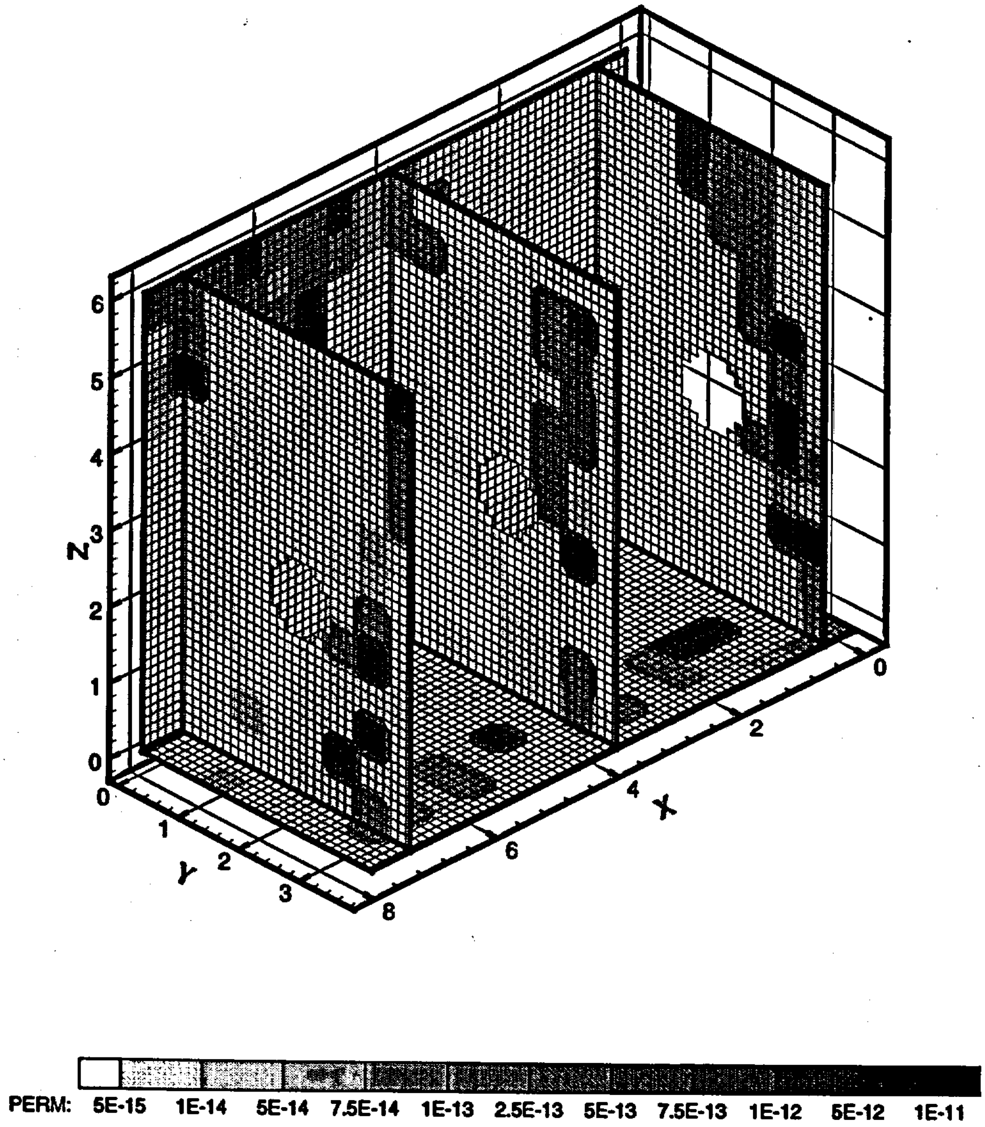

Figure 1c. Heterogeneous fracture permeability field for vertical planes in realization 3 of Design A, with permeability in units of m^2. The grid shown is the calculation grid with 0.125-m resolution. Note that the resolution for heterogeneous field is 0.5-m. DTN LB981101233129.001

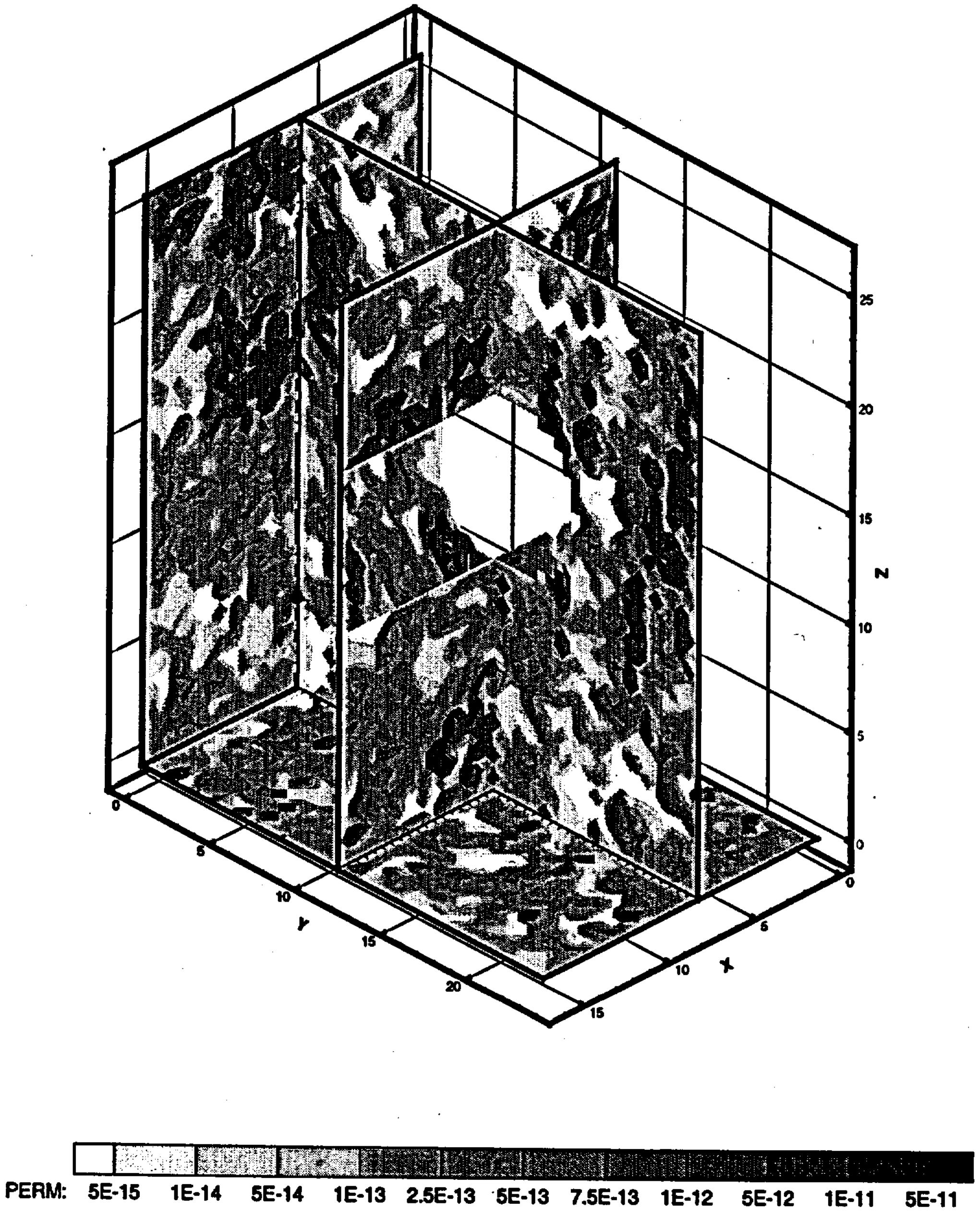

Figure 2a. Heterogeneous fracture permeability field for vertical planes in realization 1 of Design B. Permeability is in units of m^2. DTN LB981101233129.001

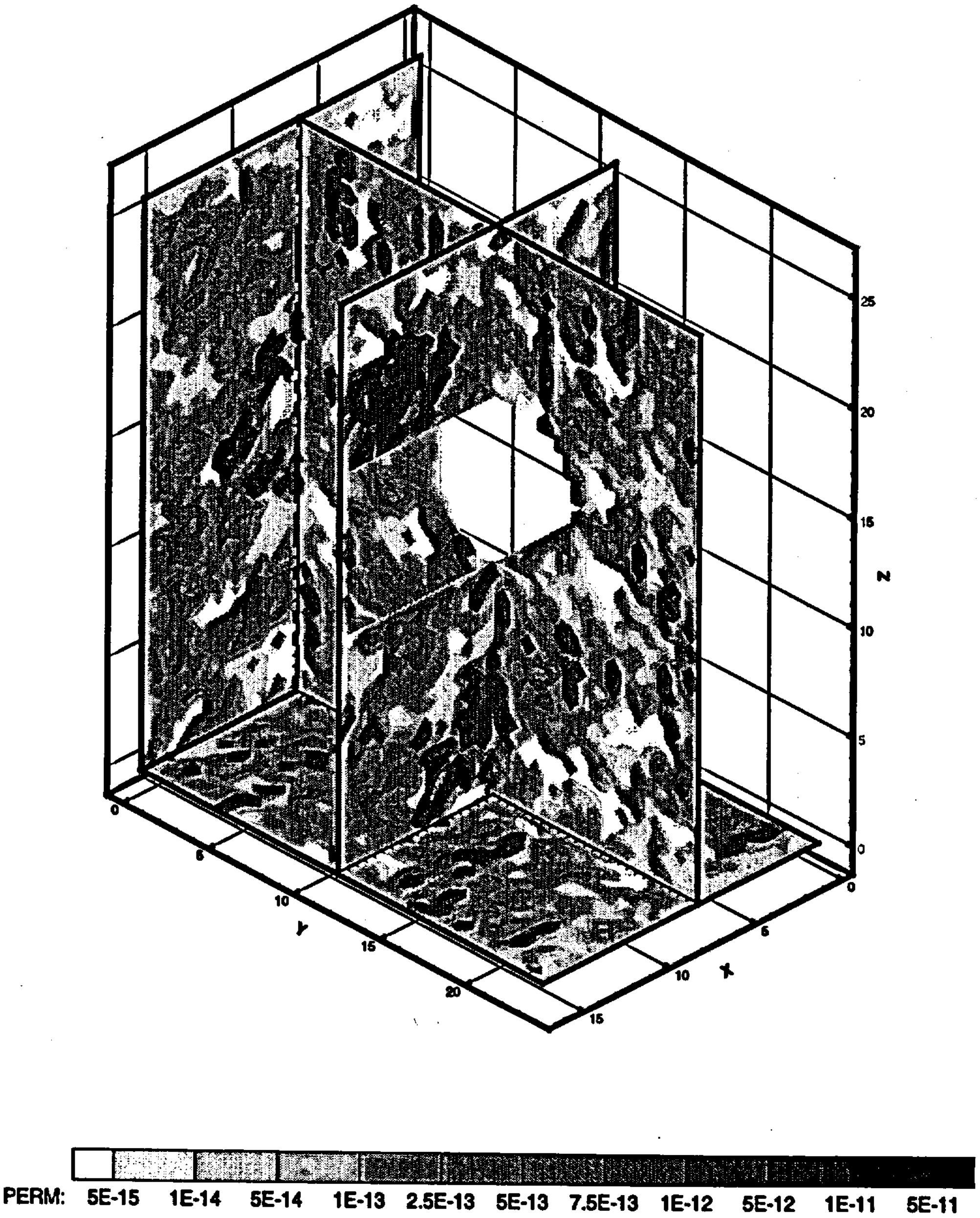

Figure 2b. Heterogeneous fracture permeability field for vertical planes in realization 2 of Design B. Permeability is in units of m^2. DTN LB981101233129.001

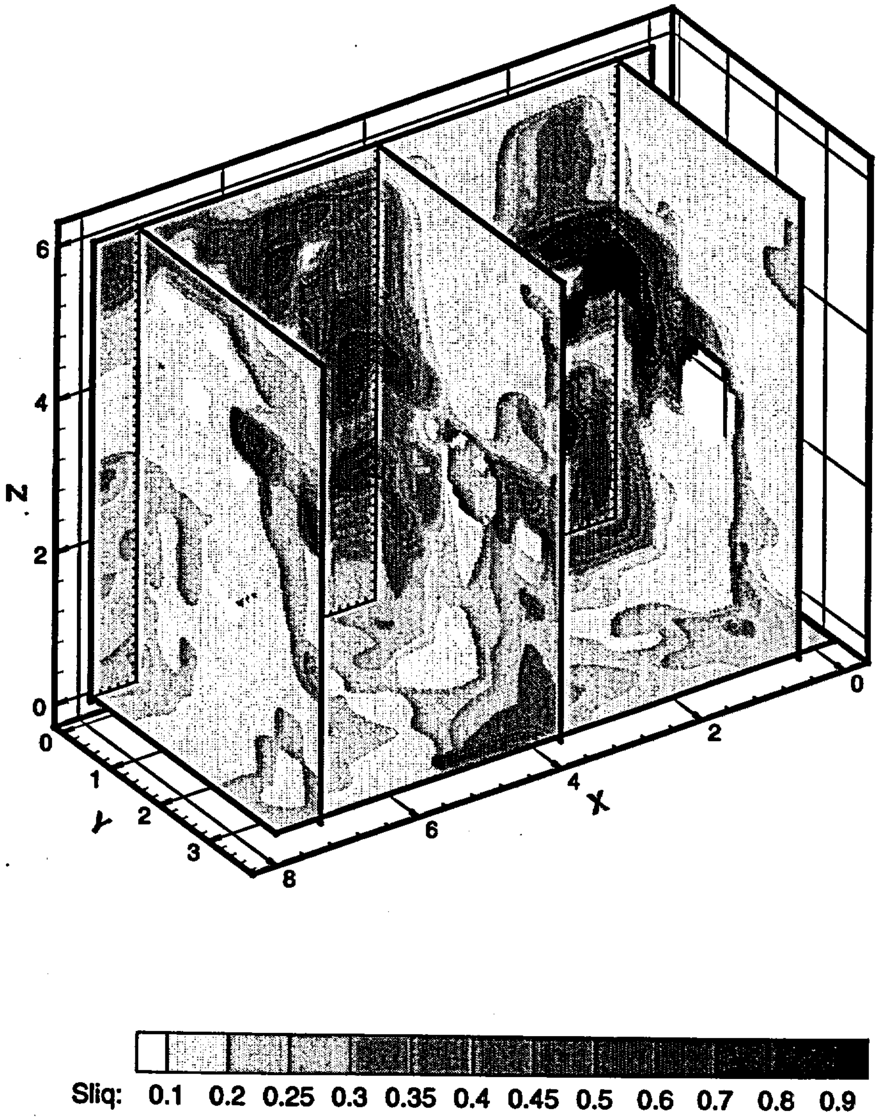

Figure 3. Saturation contours in fracture continuum on vertical plates in realization 2 of Design A for percolation flux 100 mm/yr. DTN LB981101233129.001

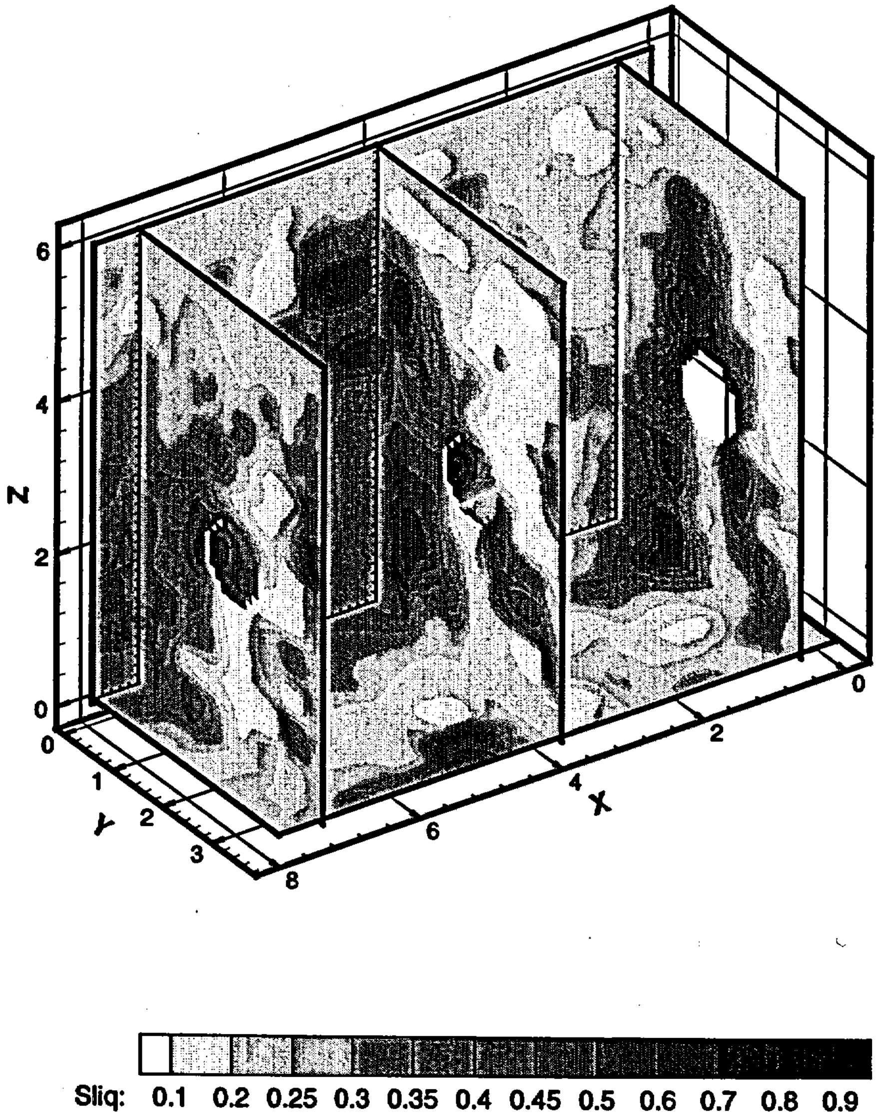

Figure 4. Saturation contours in fracture continuum on vertical plates in realization 3 of Design A for percolation flux 100 mm/yr. DTN LB981101233129.001

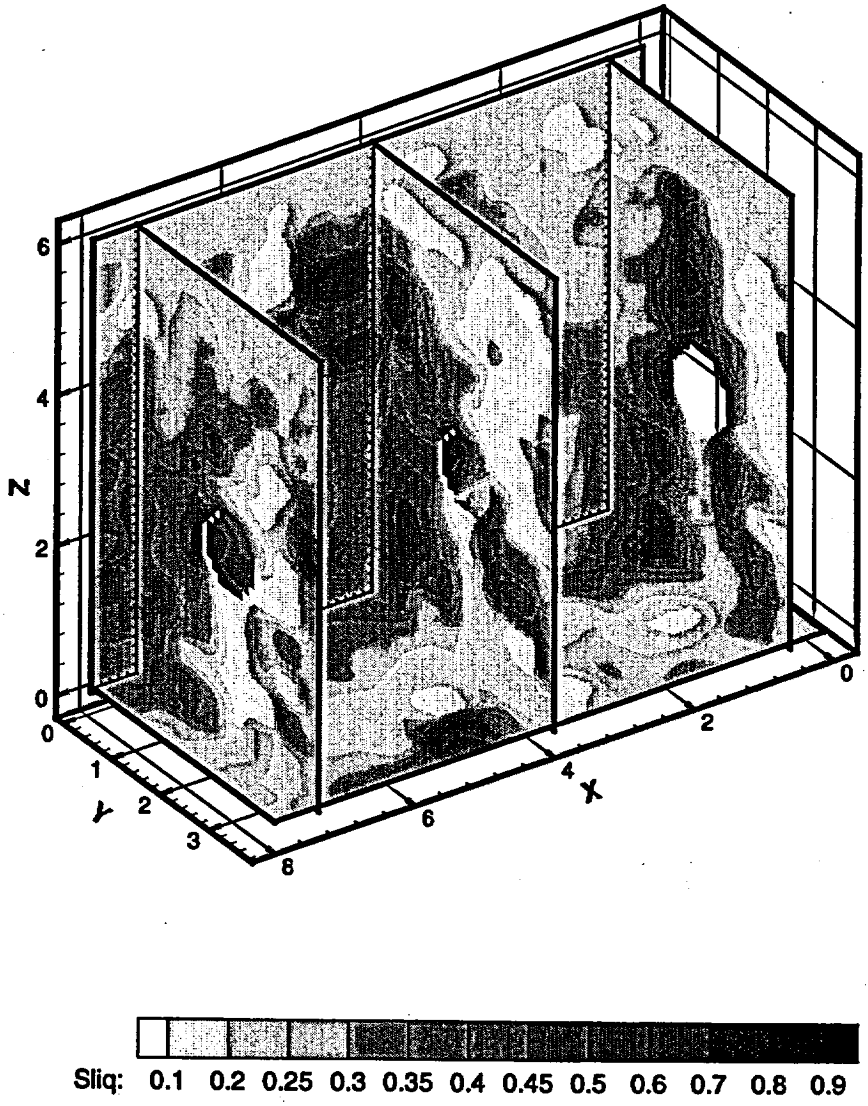

Figure 5. Saturation contours in fracture continuum on vertical plates in realization 3 of Design A for percolation flux 500 mm/yr. DTN LB981101233129.001

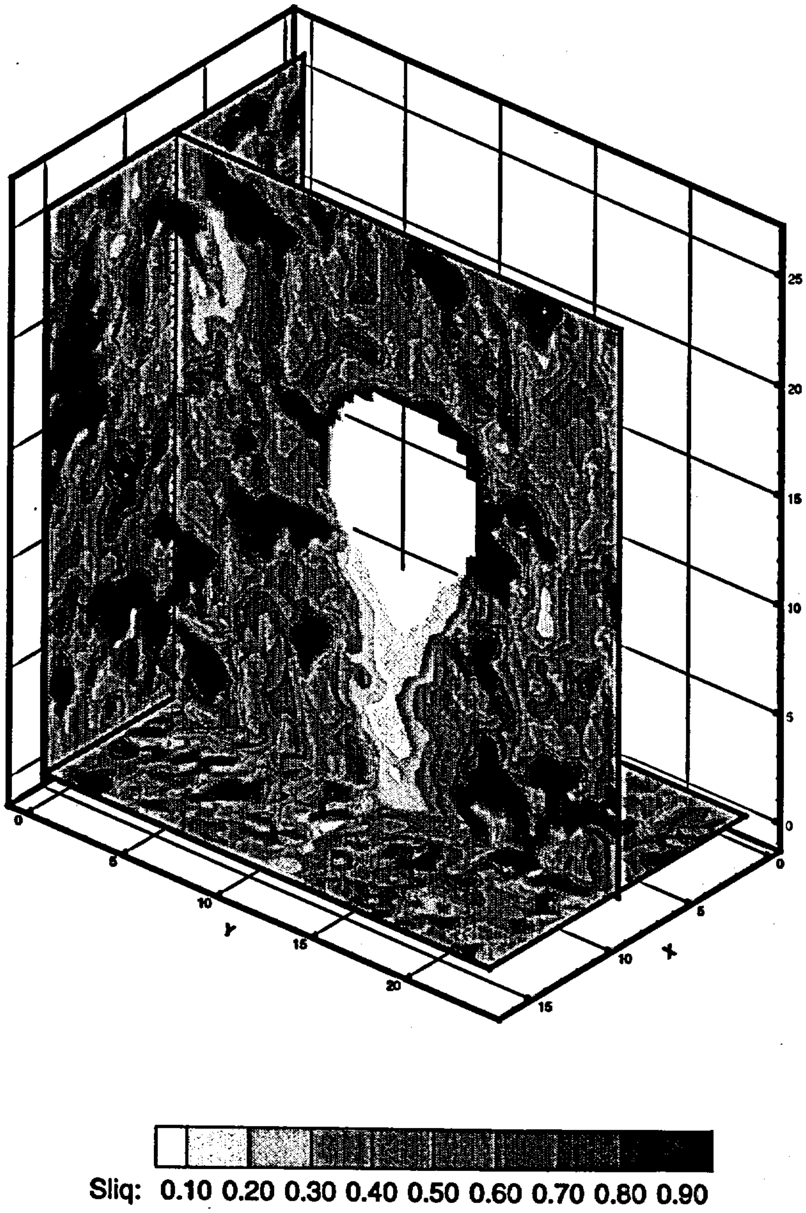

Figure 6. Saturation contours in fracture continuum on vertical plates in realization 1 of Design B without the vertical 1-m borehole for percolation flux 2000 mm/yr. DTN LB981101233129.001

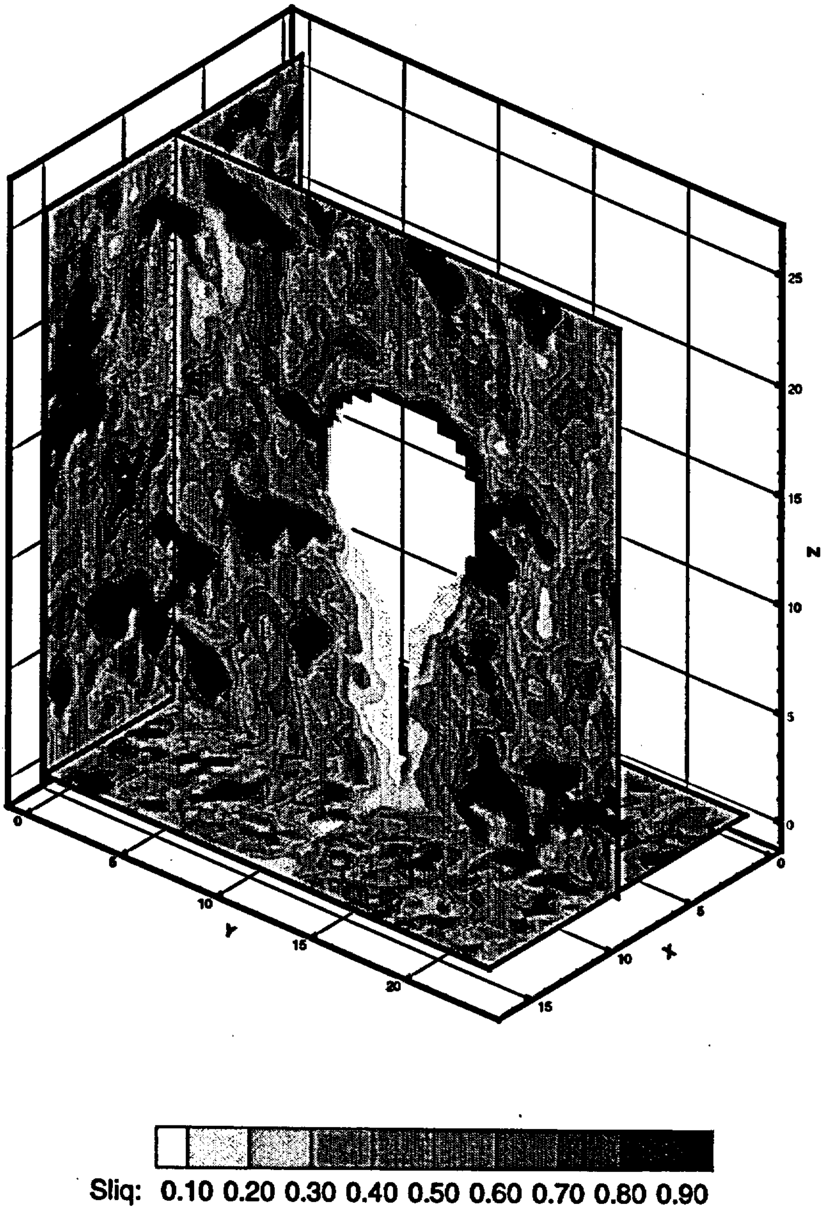

Figure 7a. Saturation contours in fracture continuum on a vertical plate along y-direction in realization 1 of Design B with the vertical 1-m borehole for percolation flux 2000 mm/yr. DTN LB981101233129.001

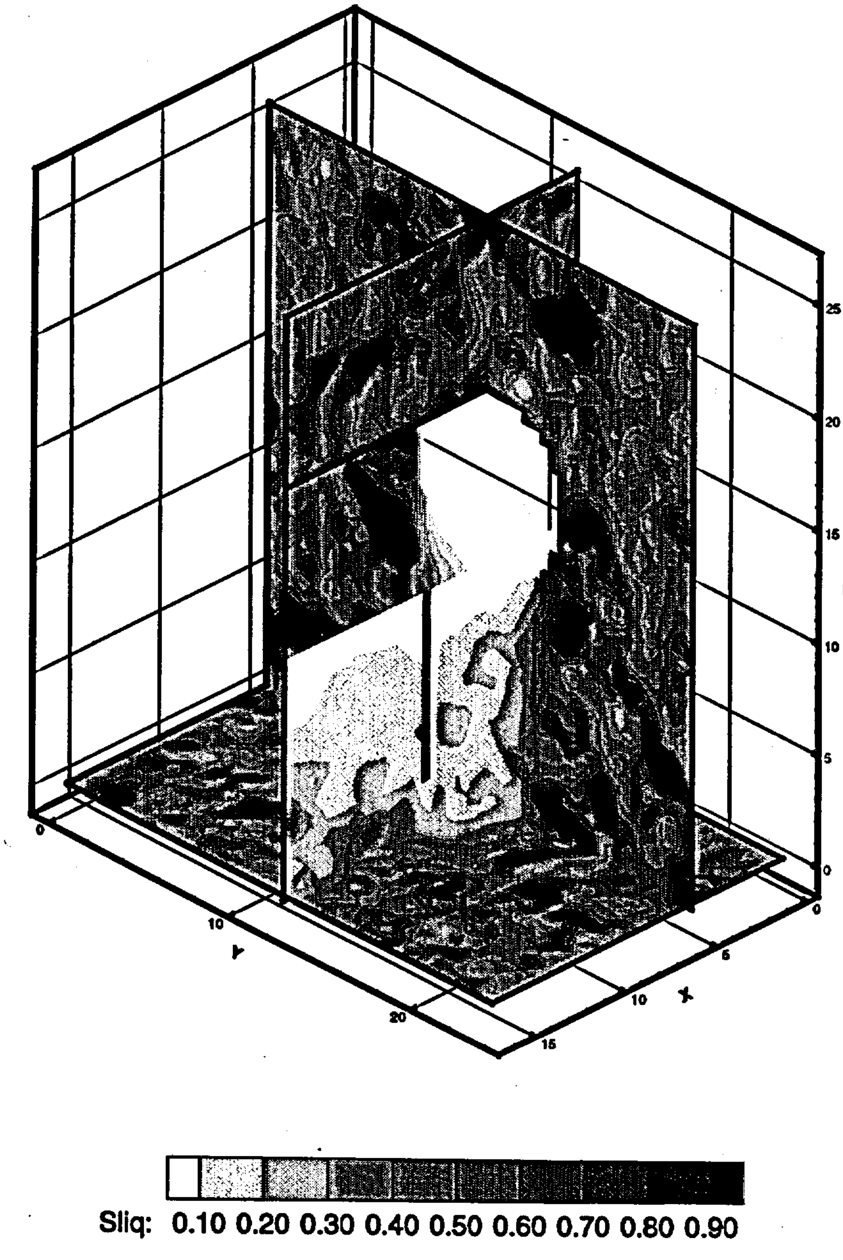

Figure 7b. Saturation contours in fracture continuum on a vertical plate along x-direction in realization 1 of Design B with the vertical 1-m borehole for percolation flux 2000 mm/yr. DTN LB981101233129.001

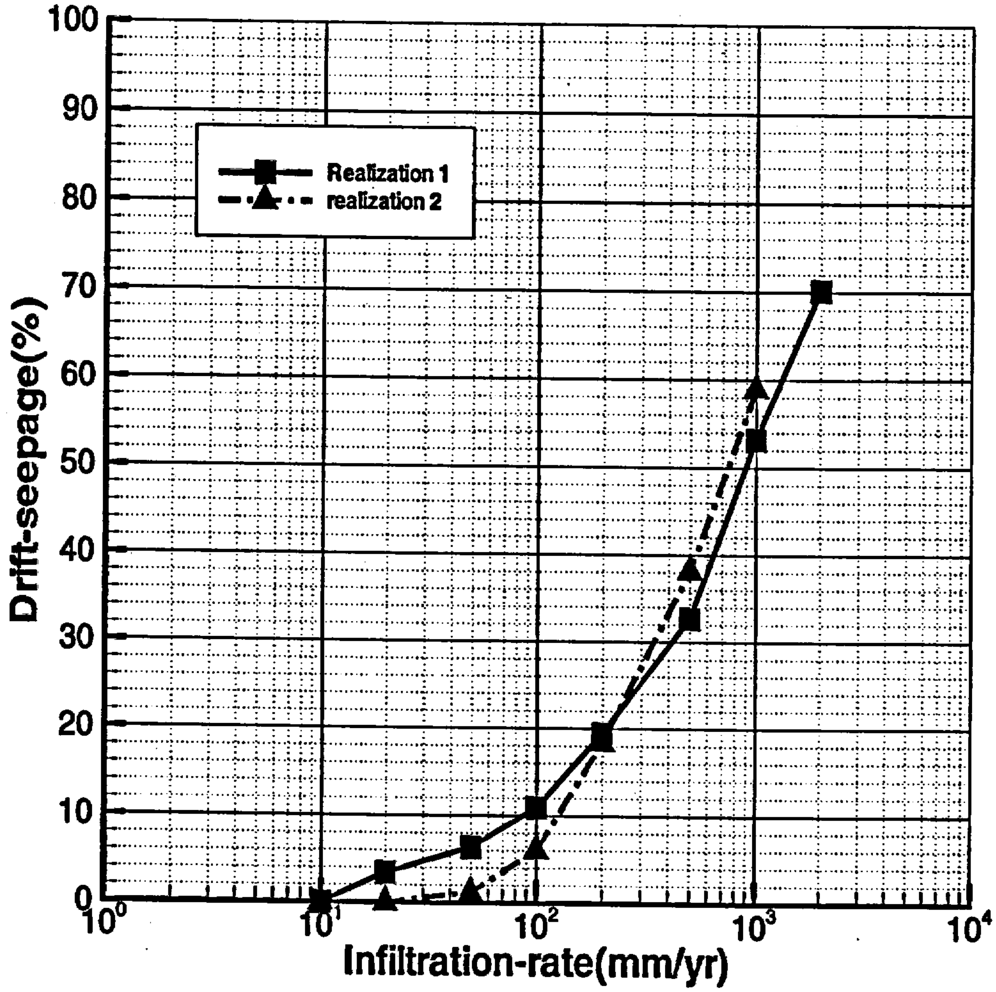

Figure 8. Rate of seepage into drift as a function of percolation fluxes for realization 1 and 2 of Design B. DTN LB981101233129.001