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Hydrogeology • Mineral Resources Waste Management • Geological Engineering • Mine Hydrology

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May 8, 1986

Dr. Dick Codell
U.S. Nuclear Regualtory Commission
Division of Waste Management
7915 Eastern Avenue
Silver Spring, Maryland 20910

Dear Dick:

I am enclosing the following document reviews for your perusal.

1. Parvis Montazer and W.E. Wilson, 1984, Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada. U.S. Geological Survey, Water Resources Investigations Report 84-4345.

2. L.A. Monde, B.L. Baker, R.L. Eaton, July 1985, Vadose Water Flow Around A Backfilled Drift Located in Tuff. Sandia National Laboratory, Albuquerque, NM, SAND84-0369.

Please contact me if you have any questions or comments.

Sincerely,

Roy Williams/sl

Roy E. Williams

REW:sl

enclosures

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WM Project 10, 11, 16
Docket No.
PDR ✓
LPDR ✓B, N, S

Distribution:

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WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: USGS-WRI-84-4345

DOCUMENT: Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada. Parviz Montazer and W.E. Wilson, U.S. Geological Survey, Water Resources Investigations Report 84-4345

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: April 30, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The report presents a conceptual model of the unsaturated zone at Yucca Mountain, which considers the various geologic formations; the product is an estimate of the flux through each layer that results from natural infiltration. The model includes so-called capillary barriers which are said to retard and divert the flow around the repository location. We note that for the purposes of the objective pursued herein capillary barriers would be valid only for the case of transient flow conditions; the moisture content of the upper material in the "barrier" would increase eventually to the point that water would move down through the lower material, thereby destroying the "barrier."

Air permeability measurements were made in various boreholes using barometric pressure variations as the driving force. The authors do not point out that this method would be in error due to the portion of the pore volume that is filled with water. The actual value measured would be the effective conductivity to air at a particular level of water saturation and not the saturated value of conductivity.

Vapor flux estimates in the conceptual model are not substantiated by data; they are questionable, as are some of the liquid flux estimates. Some of the values through various layers appear to violate continuity or conservation of mass.

The authors' model boundaries are not validated by data. The assumption of flow through structural features is not substantiated by data nor is the occurrence of a perched water table at some interfaces between hydrostratigraphic units. The validity of the assumption of lateral flow along hydrostratigraphic unit interfaces is dependent on the existence of the perched water tables.

The authors point out correctly that several aspects of their conceptual model should be investigated experimentally.

BRIEF SUMMARY OF DOCUMENT:

A summary of the conceptual model is as follows. A hypothetical model is proposed for flow through the various layers of tuff beneath Yucca Mountain. In this model flow through fractures may occur at almost all stages of saturation, but the flux magnitude in fractures is a function of the contrast between the hydraulic properties of the matrix and fractures and the magnitude of the flux through the entire profile. Downward flux is assumed to be retarded by capillary barriers that occur at the contacts between non welded and welded tuff units. These barriers are suggested to produce lateral flow. Water infiltrates into the Tiva Canyon welded tuff unit as well as into the alluvium, into the Paintbrush non welded tuff unit, and into the Topopah Spring welded tuff unit wherever these hydrostratigraphic units are exposed at land surface. Eastward lateral flow is conceptualized as occurring at the upper contact with the Paintbrush non welded tuff unit; this eastward flow is assumed to be intercepted by structural features which transmit most of the infiltrated water downward to the water table along pathways located "alongside" the repository.

Paintbrush Non Welded Tuff

Vertical flux in the Paintbrush non welded tuff unit may vary from .1 to 98 mm/yr and the lateral flux may be 100 mm/yr. The authors of the report under review believe that the ratio of vertical to lateral fluxes depends on the effectiveness of the capillary barrier at the lower contact of the unit. Downward flux is portrayed as occurring in the matrix of the Topopah Spring unit, but the probable net flux is believed to be about 1 to 2 mm/yr upward. There is little explanation of this apparent contradiction in the report.

We do not agree with many factors in this conceptual model. These issues will be pointed out in detail in the comments that follow. Throughout this report the concept of a capillary barrier is used to explain that water may not flow downward from an upper hydrostratigraphic unit to the unit immediately beneath it. The condition which would bring about this capillary barrier consists of material with fine pores occupying the upper layer with a material with large pores or fractures constituting the lower layer. A capillary barrier such as this would be effective only for a short time under a transient condition because the moisture content in the upper material would increase to the point that water would move into, and ultimately through, the larger pores or fractures of the lower layer. A capillary barrier may be effective on a short term basis in a small area such as over a tunnel or drift which has sufficient cross-sectional area in a horizontal plane in the porous matrix for the flow to pass around the drift. However in the case of an entire hydrostratigraphic unit of large areal extent the water has no alternative flow path to follow that would not increase the moisture content of the lower hydrostratigraphic unit. Flow then would occur into, and ultimately through, the large pores of the lower hydrostratigraphic unit. On the basis of this reasoning we reject the concept that the capillary barrier would prevent water from moving into the lower hydrostratigraphic unit that comprises the so-called capillary barrier.

Air permeability tests were conducted in test well UE-25A#4 using barometric pressure changes as a driving force. This test is not described in detail, but the authors should realize that air permeability is dependent on the amount of pore space that is filled with air as opposed to water. The degree of saturation (moisture content) is defined poorly in the report under review; in addition, it is doubtful that one air permeability test would produce reliable data. Insitu air permeability tests are limited by the fact that if considerable moisture exists in the material, the permeability measured with air is not the same permeability that would be measured if the material were filled completely with one fluid.

Topopah Spring Unit

Air permeability tests also were conducted on the Topopah Spring Unit using barometric pressure as a driving force. The authors point out that permeability values determined by flow of air through fractured rocks could be greater than the intrinsic permeability because of the slip flow phenomena (Klinkenburg effect). This assertion is correct, but, for the reasons just mentioned the permeability of the rock to air also could be less than the saturated hydraulic conductivity value.

Flow Through Fractured Rocks

In this section the authors develop a conceptual model of flow through the fractures. Points of contact in the fractures are hypothesized around which pendular rings of water exist under unsaturated conditions. Hypothetical curves of effective permeability to water versus matric potential then are presented. These curves are discussed in great detail, both for the fracture and the porous matrix flow. Even though these curves are completely hypothetical considerable detail is presented concerning the magnitude of the difference between the fracture flow and the matrix flow. This discussion is inappropriate because the curves are completely hypothetical and are not based on any experimental calculations or data.

In this section considerable discussion of the effect of rate of wetting on hysteresis also is presented. The authors of this report believe that the concept of hysteresis is insignificant within Yucca Mountain. Since hysteresis is dependent on changes from the wetting cycle to the drying cycle, it would occur only under unsteady flow conditions. The authors assume that the flow through the majority of Yucca Mountain is essentially steady state.

Capillary Barriers

This section begins with the statement that "Capillary barriers occur in unsaturated zones at the contact where a unit containing relatively fine pores or fractures overlies a unit containing relatively coarse pores or fractures. Such capillary barriers probably exist at Yucca Mountain and could serve to retard the rate of percolation." The validity of this statement is very questionable. The coarse material underneath the fine material would tend to retard flow early in the process of a recharge when flow is transient. Under steady state conditions of downward flow, the same flux would traverse the coarse material as the fine material. As water moves along its downward directed flow path, the moisture content will increase in the upper or finer material until water begins to move into the larger pores. After flow is established in the larger pores of the lower layer the same flux rate will be established through the coarse material as through the fine material.

Equations 1 and 2 on page 28 are incorrect. The denominator should include the radius of the tube rather than the diameter of the tube. In this discussion of various tube sizes and fracture sizes, the authors fail to mention that the critical height in the two tubes will always be attained under steady state downward flow conditions because water is being supplied to the smaller tube; the pressure will attain the value necessary to produce flow into the coarse material.

The authors describe further the effect of coarse material over fine material and point out the difference in the effective conductivity curves of the two materials. This difference is reflected in the fact that at lower moisture contents the fine-grained material will attain a higher effective conductivity than a coarse-grained material. This assertion is correct. However, the authors do not point out that the matric potential in the two materials will adjust such that the same effective conductivity develops in each of the materials even though the process occurs at different matric potentials in the two materials. The authors also discuss the effect of the curves of the two materials not intersecting. This effect is not relevant to downward flow because the two materials still will develop the same effective conductivity but at different matric potentials.

Page 31. The authors cite Palmquist and Johnson (1962) and Hillel and Talpaz (1977) to support their concept of the capillary barrier. These authors evidently show that the fine-grained material above a coarse-grained material will be substantially wetter than the coarse-grained material. We have discussed this phenomenon above (i.e., that the degree of saturation will increase until water traverses the coarse material at the same rate that it traverses the finer material).

Page 34. The authors discuss two instances in which water has been shown to move very rapidly to depths of several tens of meters through fractures within a few days after rapid snow melt. The first of these examples (Montazer, 1982) was in metamorphic rocks which have insignificant matrix conductivity; therefore all flow would occur in fractures. The second of these (Thordarson, 1965) is in Rainer Mesa in which the matrix is reported to be completely saturated.

The effect of the fairly high degree of saturation (high moisture content) on air movement in Yucca Mountain seldom has been discussed. A high degree of saturation would allow relatively little movement of air; but this factor should be evaluated by studying the air permeability of the material as affected by water saturation.

Unsaturated Zone Flux

The authors list many sources of information on recharge in the general area of Yucca Mountain but few data are available on recharge at Yucca Mountain itself. The estimates vary from .5 mm/yr by Czarnecki (1984) to 4.5 mm/yr by Rush (1970). Sass and Lachenbruch (1982) estimate a vertical water flux of 1 to 10 mm/yr from geothermal data. Sass and others (1980) used heat flow data and showed a negative (upward) water flux of more than 150 mm/yr in the saturated zone. The authors of the report under review state that if the method of Sass and Lachenbruch (1982) is used to calculate the upward flux of water vapor saturated air in the Topopah Spring welded tuff unit, a flux of about 1.5 mm/yr was obtained. Their calculations are not shown. It also is not clear how the method of Sass and Lachenbruch (1982) could be used for the unsaturated zone; they can assume specifically that the porous matrix is saturated. Sass and Lachenbruch state that they can say specifically that no movement of water occurs up and down the borehole outside the casing in only one of the boreholes. They also state that the drilling mud may well have been a source of heat to the rocks. The authors summary statement is that in the unsaturated zone at Yucca Mountain thermal flux is complicated by movement in both liquid and vapor phases, by heterogeneity of the hydrogeologic system, and by possible lateral flow. Both upward water vapor movement in the fractures and downward liquid flow in the matrix may occur. It is our feeling that this analysis of vapor movement is highly speculative and that very few data exist to support their assumptions.

The authors also list several other references and values for the flux; the values range from 1×10^{-7} to 30 mm/yr in both upward and downward directions. It is difficult to understand why upward flow would occur in the liquid phase; any method that suggests the occurrence of upward flow is very questionable. The authors state that data from borehole USW UZ-1 show that a large lateral component of flow must be assumed in order to explain the distribution of the matric potentials measured in the Paintbrush non welded tuff unit. The authors investigate the possibility of lateral flow further; but it is not clear whether the continuity equation is satisfied because no statement is provided concerning the ultimate disposition of flow after it moves laterally. Mathematical models of various cross-sections has not produced any indication of lateral flow.

In summary the reasoning presented in the report under review attempts to show that:

1) "From .1 to 98.6 mm/yr of vertical flux may be occurring in the Paintbrush non welded unit; but the magnitude of vertical flux depends on the effectiveness of the so-called capillary barrier at the lower contact of this unit." This statement does not make sense. Even if the capillary barrier at the bottom was effective, it would have no effect on the vertical flux through the Paintbrush non welded unit. In addition, as explained previously herein, the capillary barrier is not a valid concept in this case.

2) "The capacity to transmit flow laterally in the Paintbrush non welded tuff unit is more than 100 mm/yr or about twice the maximum estimated infiltrated water."

3) "From 10^{-7} to .2 mm/yr flux could be occurring in the matrix of the Topopah Spring welded unit. Flux in the fractures is unknown."

4) "Flux in the Calico Hills non welded unit is variable but probably is limited to .006 mm/yr in the downward direction." From the continuity equation if the downward flux in Calico Hills is only .006 mm/yr then that also would be the downward flux in all the other formations.

5) "Results of analyses of the geothermal heat flux data show that about 1 to 2 mm/yr of upward net flux occurs in the Topopah Spring welded unit possibly as a result of upward moving air saturated with water vapor; but the results are uncertain because of possible alternative interpretations of the data." This conclusion is highly speculative and the references given do not justify the 1 to 2 mm/yr upward net flux.

Flow System Boundaries

Boundaries to the flow regions are shown in figure 1. Lateral flow downdip at contacts between hydrostratigraphic units is shown even though there is no indication that such flow actually occurs. Perched water tables also are shown near the fault zones but there is no indication that these actually exist.

Page 49. The authors make the statement, "The upper contact of the unit and upward component of flux from the matrix of the Calico Hills non welded unit into the matrix of the Topopah Spring welded unit may develop because of differences in the capillary pressures." This statement is questionable because some driving force must cause upward flow. Capillary pressures will not bring about upward flow unless some phenomenon such as evaporation creates the capillary pressure difference.

In summary, the authors state (page 51) that

> "most of the infiltrated water is transmitted downward to the water table along structural features. Some matrix to matrix flow occurs from the Paintbrush non welded unit into the underlying Topopah Spring welded unit. A capillary barrier retards flow into the fractures of the Topopah Spring welded unit. Percolation rates are variable or even negative in the Topopah Spring welded unit except along completely penetrating, very conductive structural features."

This is not substantiated by data. Again quoting on page 51,

> "Therefore pulses of infiltration may cause rapid percolation down through the Tiva Canyon welded unit and into the Paintbrush non welded unit. Hysteresis effects may occur in the upper part of the Paintbrush unit and result in rejection of downward percolating water much sooner that would be predicted by drainage curves."

No evidence has been presented to the NRC that would substantiate this analysis. This report continues, "Fracture flow into the Topopah Spring welded unit is retarded by the capillary barrier that exists between the Paintbrush non welded unit and this welded unit." No evidence has been presented to the NRC that would substantiate this statement. The concept of a long term capillary barrier in this case is invalid.

> "Considering the potential for vapor transport under geothermal gradients, the net flux in parts of the Topopah Spring welded unit even may be negative (upward). Of the conservatively estimated 4.5 mm/yr net infiltration probably only a maximum of 1 mm/yr (equivalent to saturated hydraulic conductivity of the unit) is transmitted through the Topopah Spring unit. The excess net infiltration probably flows laterally into the structural features."

Again no evidence has been presented to the NRC that would support this conclusion.

Page 52. The authors suggest the following additional work that should be done. Such investigations could include evaluations of:

1) "Flux in shallow hydrogeologic units to identify more directly the net infiltration rate." Such a study would be very valuable. Experiments should be conducted on the application of water to the ground surface to determine rates of flow into the rock and whether infiltrating water flows downward into fractures or into the matrix.

2) "Flux in the major structural features in the central block to assess the significance of such features and similar ones that might exist or develop in the central block."

3) "The presence or absence of perched water tables to assess the impact on repository construction and integrity." This type of study definitely should be pursued; the present model assumes that perched water tables will form near the structural features. Perhaps drilling in fault areas should be implemented to determine whether perched water tables exist.

4) "Two-phase flux in the Topopah Spring unit to evaluate the potential for upward moving water."

5) "The assumptions made in developing the conceptual model to assess the appropriateness of the model to provide a basis for its revision." We agree that the aforementioned topics of work are important to determine the validity of any conceptual model that may be used.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

A well verified conceptual model is a prerequisite to the evaluation of the movement of water through the unsaturated zone at the repository site. Such a model probably will lead to a defensible analysis for time of travel to the accessible environment. This report is a first draft of such a model. But as it exists presently much of it is very speculative.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The concept of a long term capillary barrier is used incorrectly in the report. Such a barrier is not a valid reason for diversion of water around the repository site. Several portions of the conceptual model, such as interfaces between hydrogeologic units, should be simulated with a two dimensional model in order to investigate the effect of a sloping contact. Movement of water around backfilled drifts and movement of water into the tuff immediately below the ground surface should be evaluated also.

REFERENCES CITED

Czarnecki, J.B., 1984, Simulated Effects of Increased Recharge on the Ground-Water Flow System of Yucca Mountain and Vicinity, Nevada-California. U.S. Geological Survey Water-Resources Investigations Report 84-4344, 33 p.

Hillel, Daniel, and Talpaz, H., 1977, Simulation of Soil Water Dynamics in Layered Soils. Soil Science, v. 123, no. 1, p. 54-62.

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Rush, F.E., 1970, Regional Ground-Water System in the Nevada Test Site Area, Nye, Lincoln, and Clark Counties, Nevada. Nevada Department of Conservation and Natural Resources Reconnaissance Series Report 54, 25 p.

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Thordarson, William, 1965, Perched Ground Water in Zeolitized-bedded Tuff, Rainier Mesa and Vicinity, Nevada Test Site, Nevada. U.S. Geological Survey Trace Elements Investigative Report TEI-862, 90 p.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND84-0369

DOCUMENT: Vadose Water Flow Around A Backfilled Drift Located in Tuff. L.A. Monde, B.L. Baker, R.L. Eaton, Sandia National Laboratory, Albuquerque, New Mexico, July 1985.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: April 30, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The computer program SAGUARO is used to model flow around vertically emplaced waste containers in tuff. The authors had severe numerical instability problems due to the low values of hydraulic conductivity used for the sand backfill. In our review, however, we suggest that incorrect hydraulic conductivity values were used in the model which may have been part of the problem. The principle recommendation of our review is that the hydraulic properties of the material to be used for backfill be measured and the modeling be repeated with correct properties used as input.

BRIEF SUMMARY OF DOCUMENT:

The computer code SAGUARO for unsaturated flow is used to model flow around vertically emplaced waste containers beneath a drift in tuff. The modeling simulated either sand or clay backfill in the drift. The authors conclude that backfilling a drift does not provide a significant reduction of flow in the vicinity of a vertically emplaced waste package. The proposed tunnels or drifts in the repository will be approximately 5 m wide and 6 m high. The vertical emplacement would consist of a shaft approximately 7-1/2 m long and 1 m in diameter, excavated in the bottom of the drift. The waste canister would fill approximately the bottom 4 m of the hole. The remainder of the shaft would be filled with an impermeable isolating plug. The work under review here was done to determine the effect of backfilling of the drift on the flow past the waste canister. This flow was modeled in a two-dimensional mode using the computer code SAGUARO, recently developed at Sandia Laboratory. A finite element mesh consisting of 234 node points was used for the simulation. The size of the mesh was 15 m across by 135 m in height. The left boundary was at the plane of symmetry through the waste package while the right boundary was through the plane of symmetry between two adjacent waste packages.

Material properties used in the simulation were taken from Mualem (1976) for the clay and sand, and from Gee (1985) for the tuff. The values of saturated conductivity used for the clay and sand are incorrect. The value used for clay was 3.92×10^{-14} m^2 while that for sand was 1.93×10^{-13} m^2. Checking of these values in Mualem shows that the correct values are 2.3×10^{-14} m^2 for clay and 1.31×10^{-11} m^2 for sand. The error in saturated hydraulic conductivity was nearly two orders of magnitude for each material.

There also are errors in the determination of unsaturated flow characteristics. The actual procedure used for calculation of such values is not described but the values of relative conductivity presented differ by as much as six orders of magnitude from comparable values determined by the Brooks-Corey relationships. The Brooks-Corey values of unsaturated flow characteristics for these materials have been verified with laboratory data (King, 1964). These errors may be the reason for problems that were encountered in maintaining a stable numerical solution when sand was used in the drift. Usually sand does not cause numerical instabilities that are as severe as those produced when a material such as clay is used. In the report under review, the numerical difficulty was encountered with the sand because of its low permeability. In a portion of the simulation a fictitious value was used for the conductivity of the sand at high capillary pressures in order to bring about a stable solution. With such gross errors in the input values of conductivity of these materials it is questionable whether the results of the experiment are valid.

The authors state on page 23, "We feel that refining the mesh is the least effective way to overcome the numerical instabilities because the sand permeability can change over seven orders of magnitude with a change of .1 m in pressure head and because the number of elements allowed in SAGUARO is limited to 1,000." This statement is incorrect. The probable intended meaning is that a change in pressure head of one order of magnitude produces a seven order of magnitude change in permeability. Use of the proper values for the hydraulic conductivity of sand probably would have reduced the numerical difficulties.

On page 25, the velocity in the sand is calculated as approximately 1.7×10^{-15} m/sec downward. This calculation is incorrect because the flux rate was not divided by either the moisture content or the degree of saturation multiplied by porosity. Assuming the moisture content is about .1, the velocity should be about 1.7×10^{-14} m/sec.

Several plots of the pressures in the flow field around the drift and waste emplacement area are presented. Plots of velocity in the flow region are presented also. Although the actual values are suspect due to the problems discussed above it is doubtful that correct values of conductivity for sand and clay would change the flow patterns significantly. We recommend, however, that the actual material to be used for backfill, such as finely crushed tuff or coarsely crushed tuff, be compacted and tested in the laboratory to determine the correct hydraulic characteristics for these materials. The current experiment (modeling) could then be repeated with correct hydraulic characteristic values; this procedure would increase the credibility of the experiment (modeling).

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The water flux through the actual waste canister should be determined to facilitate the prediction of post emplacement travel times to the accessible environment. Modeling of unsaturated flow around the canister is the first step in the determination of flux. This determination is required for evaluation of compliance with the EPA standard (40CFR191).

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The most serious problem with the work under review is the erroneous values of hydraulic conductivity used for simulating pressure distribution in and flow through the backfill material. These errors probably produce the severe numerical instabilities encountered during the simulation.

SUGGESTED FOLLOW-UP ACTIVITIES:

This experiment should be repeated using correct hydrogeologic parameter values, after experiments have been conducted to obtain defensible properties of backfill materials.

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