(16)

United States Department of the Interior

GEOLOGICAL SURVEY
BOX 25046 M.S. 416
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY REFER TO:

September 9, 1983-01

Mr. Seth Coplan
High-Level Waste Management
Development Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

WM DOCKET CONTROL CENTER
'83 SEP 12 A11:12

Dear Seth:

Enclosed is a set of documents that is being made available to you and your staff prior to the NNWSI Hydrology Briefing, September 20-21, 1983, in Golden, Colorado.

Also enclosed is a list of these references plus others that are being made available for inspection only at the office of John B. Robertson, Office of Hazardous Waste Hydrology, USGS, Reston, Virginia. All references will also be available at my office prior to and during the briefing.

Very truly yours

William E. Wilson

William E. Wilson

Enclosure

cc: W. W. Dudley, USGS Coordinator for NNWSI
J. B. Robertson, Chief, OHWH

WM Record File 102

WM Project 11
Docket No.
PDR ✓
LPDR ✓

Distribution:
SCOPLAN

(Return to WM, 623-SS) 15

8311280031 830909
PDR WASTE
WM-11 PDR

H
NV83/669

00073

United States Department of the Interior
GEOLOGICAL SURVEY
BOX 25046 M.S. 416
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY REFER TO:

September 9, 1983

Memorandum

To: George Dinwiddie

From: William E. Wilson

Subject: MEETINGS--reference materials for inspection by NRC prior to NNWSI Hydrology Briefing

Enclosed is a set of reference materials that is to be made available for inspection only to the staff of the Nuclear Regulatory Commission prior to the NNWSI Hydrology Briefing, September 20-21, Golden, Colorado.

Also enclosed is a list of these references plus others that have been made directly available to NRC.

Please make the enclosed materials conveniently available for inspection.

William E. Wilson

William E. Wilson

Enclosure

cc: W. W. Dudley, USGS Coordinator for NNWSI
Seth Coplan, NRC

Background References
for
NNWSI HYDROLOGY BRIEFING FOR NRC
September 20-21, 1983
Golden, Colorado

(Items marked with an asterisk (*) are draft interpretive reports or information not yet approved by the Geological Survey for release; they will be made available for inspection only. Items not marked with an asterisk do not require further approval and are being provided to NRC directly for advance inspection. Reference items provided in January 1983 are not included in this list.)

Ref.
No.

1. Letter, Dudley to Vieth (8-19-83)--Summary of hydrogeologic conceptual model and calculations of ground-water flow times.

2. Report--Rush, F. E., Thordarson, William, and Bruckheimer, Laura, 1983, Geohydrologic and drill-hole data for test well USW H-1, adjacent to Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Open-File Report 83-141, 38 p.

3. Report--Scott, R. B., Spengler, R. W., Diehl, S., Lappin, A. R., and Chornack, M. P., 1983, Geologic character of tuffs in the unsaturated zone at Yucca Mountain, southern Nevada, in Role of the unsaturated zone in radioactive and hazardous waste disposal, Mercer, J. W., Roo, P. S. C., and Marine, I. W., eds.: Ann Arbor Science Publishers, Ann Arbor, Mich., p. 289-335.

4. Report--Waddell, R. K., 1982, Two-dimensional steady-state model of ground-water flow, Nevada Test Site and vicinity, Nevada-California: U.S. Geological Survey Water-Resources Investigations Report 82-4085, 72 p.

*5. Manuscript--Draft test proposals (hydrology) for the NNWSI Exploratory Shaft.

*6. Manuscript--Bentley, C. B., 1983, Geohydrologic data for well USW G-4, Yucca Mountain area, Nye County, Nevada: U.S. Geological Survey Open-File Report (in review).

*7. Manuscript--Bentley, C. B., Robison, J. H., and Spengler, R. W., 1983, Geohydrologic data for well USW H-5, Yucca Mountain area, Nye County, Nevada: U.S. Geological Survey Open-File Report (in review).

*8. Manuscript--Claassen, H. C., 1983, Sources and mechanisms of recharge for ground water in the west-central Amargosa Desert, Nevada--a geochemical interpretation: U.S. Geological Survey Open-File Report 83-542.

*9. Manuscript--Craig, R. W., Reed, R. L., and Spengler, R. W., 1983, Geohydrologic data for well USW H-6, Yucca Mountain area, Nye County, Nevada: U.S. Geological Survey Open-File Report (in review).

*10. Manuscript--Lobmeyer, D. H., Whitfield, M. S., Jr., Lahoud, R. R., and Bruckheimer, L., 1983, Geohydrologic data for test well UE-25b#1H, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Open-File Report (in review).

*11. Manuscript--Benson, L. V., Robison, J. H., Blankennagel, R. K., and Ogard, A. E., 1983, Chemical composition of ground water and the locations of permeable zones in the Yucca Mountain area, Nevada: U.S. Geological Survey Open-File Report (in review).

*12. Manuscript--Rush, F. E., Thordarson, W., and Pyles, D. G., 1983, Results of hydraulic tests in well USW H-1, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report (in review).

*13. Manuscript--Spaulding, W. G., 1983, Vegetation and climates of the last 45,000 years in the vicinity of the Nevada Test Site, south-central Nevada: U.S. Geological Survey Open-File Report 83-535, 205 p. (pending U.S. Geological Survey Professional Paper.)

*14. Manuscript--Thordarson, W., 1983, Geohydrologic data and test results from well J-13, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 83-4171.

*15. Manuscript--Waddell, R. K., Jr., 1983, Geohydrologic and drill-hole data for test wells UE-29a#1 and UE-29a#2, Fortymile Canyon, Nevada Test Site: U.S. Geological Survey Open-File Report (in review).

(1)

August 19, 1983

D. L. Vieth, Director
Waste Management Project Office
U.S. Department of Energy
Nevada Operations Office
P.O. Box 14100
Las Vegas, Nevada 89114

Dear Don:

The way that water moves within and is controlled by the geologic framework is very important to evaluations of Yucca Mountain as a possible repository for nuclear waste. Therefore, for your information and to aid in any evaluations, described below is the current conceptual model of the geohydrologic framework that was favored by Geological Survey representatives as well as attendees from Sandia National Laboratories, Lawrence Livermore National Laboratory, and Los Alamos National Laboratory at a meeting in Las Vegas on July 26, 1983.

Figure 1 shows the conceptual geologic framework of Yucca Mountain. Rock units are defined on the basis of their hydrologic properties rather than geologic origin.

A. Hydrostratigraphy

That portion of the Yucca Mountain site that would contain the repository consists of the following units in increasing order of depth.

1. Surficial units. Densely to moderately welded tuff of the Tiva Canyon Member of the Paintbrush Tuff forms a caprock of this portion of Yucca Mountain and dips from 5 to 8 degrees eastward, resulting in a relatively planar eastward-sloping land surface. Dissection of the caprock by channel erosion is essentially absent at the western (topographically higher) part of the area, but the planar surface becomes increasingly dissected eastward. Channel cutting has removed part of the Tiva Canyon Member along upstream reaches, and all of the Member along main channels in the

eastern part of the area. Alluvium and discontinuous remnants of the Rainier Mesa Member of the Timber Mountain Tuff overlie dissected portions of the Tiva Canyon outcrop/subcrop area. The Tiva Canyon Member is sufficiently fractured that ground-water movement is considered to occur through fracture flow; porous flow is presumed to be dominant in the poorly consolidated alluvium and other surficial materials. Direct evidence of recharge rates or infiltration capacities has not been obtained, but the surficial materials are considered to be moderately permeable and capable of accepting recharge at flux rates commensurate with those estimated by water-budget studies in the southern Great Basin or with those evident from independent measurements or estimates of flux in the ground-water system. The surficial units are above the water table.

2. Upper clastic unit. This unit consists of bedded and nonwelded tuffs of the Pah Canyon and Yucca Mountain Members of the Paintbrush Tuff. The unit occurs beneath the Tiva Canyon Member where it is present and beneath alluvium where the Tiva Canyon has been removed by erosion. The tuffs of this unit are vitric, highly porous, and poorly indurated. Although specific data are not available, the upper clastic unit is considered by inspection to have a moderately high matrix permeability and thus not to limit the prevailing recharge flux; flow is presumed to occur principally through the matrix pore space. The unit is above the water table.

3. Densely welded unit. This unit consists of a thin upper vitrophyre, a thick central zone comprising several densely welded ash-flow sheets, and a thin lower vitrophyre, all within the Topopah Spring Member of the Paintbrush Tuff. The unit is above the water table at the proposed repository location. The matrix of the densely welded unit is very low in permeability (Ref. 1) but the rock is pervasively fractured. Based on characteristics of cores, fluid losses during drilling, and the productivity of wells that penetrate it beneath the water table elsewhere, the densely welded unit is presumed to have a high fracture permeability and not to limit the prevailing recharge flux.

   (The proposed repository at Yucca Mountain is in the lower half of the densely welded unit. It is reasonably expected that the lateral, upper, and lower boundaries of the disturbed zone will also be contained within the unit.)

4. Lower clastic unit. A series of nonwelded ash-flow, ash-fall, and reworked tuffs comprises a hydrostratigraphic unit that includes the lowermost part of the Topopah Spring Member and the tuffs of Calico Hills (informal name). This

unit is above the water table beneath the western part of the disturbed zone and partly below the water table beneath the eastern extent of the repository. Near the eastern and northern boundaries the unit is pervasively zeolitized and argillized (Ref. 2), at the southwestern corner it is vitric (Ref. 3).

Both the vitric and zeolitic facies of the unit are highly porous, based on available measurements of core samples (Ref. 4); 30 percent by volume is probably a conservatively low value. Measured values for the saturated hydraulic conductivity of zeolitic samples from two core holes at Yucca Mountain comprise a unimodal distribution with a most frequent value of about 5×10^{-2} m/yr. Values for vitric samples comprise a bimodal distribution with most frequent values of about 1×10^{-4} m/yr and 1×10^{-1} m/yr. Porous flow is believed to dominate in the unsaturated zone, where the value of saturated hydraulic conductivity is greater than the value of prevailing downward flux.

5. <u>Older volcanics</u>. Rocks older than the Calico Hills tuffs occur partly above the water table beneath the western half of the disturbed zone and below the water table there and to the east. Nonwelded to moderately welded tuffs predominate over thinner intervals of densely welded ash-flow tuff, bedded ash-fall tuff, and dacitic lava and flow breccia. The rocks are commonly zeolitized and argillized (Ref. 4) where they have been sampled. Hydraulic testing, (Ref. 5) including flow surveys while pumping, has shown the rocks to be moderately to highly transmissive with fracture premeability dominating. Bulk transmissivity is variable from place to place, and flow surveys demonstrate that there is no clear stratigraphic control on the locations of permeable zones. Hydraulic tests show that an average hydraulic conductivity of 1 m/day characterizes this unit where it is highly fractured. Although matrix porosities are commonly in the range of 20 to 30 percent, (Ref. 6) field tests have not yet been done to determine effective porosity. Assuming that flow paths will pass through a variety of both highly and minimally fractured rocks, an effective porosity of 2 percent is selected for computations.

6. <u>Pre-Tertiary rocks</u>. Carbonate rocks have been encountered beneath the Tertiary volcanic sequence at a depth of about 1250 m in only one drill hole, UE25p#1, located about 2.5 km east of the proposed repository. These consist of fractured and brecciated dolomites of probable Silurian age. Recent testing shows that they are highly permeable with fracture flow predominating, but values of hydraulic conductivity and effective porosity are not available. Geophysical evidence

(Ref. 7) indicates that Paleozoic rocks are either not present beneath Yucca Mountain itself or else occur at great depth (> 3,000 m) beneath the thick section of volcanic rocks.

B. Structural Flowpaths

The area of principal interest, informally termed the "central block," is bounded on the west by a fault, topographically expressed by Solitario Canyon, that significantly offsets the target horizon; on the north by a probable fracture zone topographically expressed by Drillhole Wash; on the east by several small faults; and on the south by an area of closely spaced small faults and fracture zones (Ref. 8). Minor faults of small displacement also occur within the central block; hydraulic characteristics of these faults remain to be determined.

For the purpose of geohydrologic evaluation, it is assumed that fracture and fault zones are preferential pathways for flow in rocks that have insufficient matrix permeability to allow passage of the prevailing flux under the prevailing hydraulic gradient. It is further assumed that the repository would be within only the central block. (Information that is presently available, however, does not preclude expansion beneath Drillhole Wash to the northern block.) No multiple-well test data are available (though tests are planned) to either show the degree of hydraulic continuity and interconnectivity of the fracture and fault zones, or the resultant anisotropy of bulk transmissivity. Hence, the hydraulic conductivity (1 m/day) chosen (A.4 above) for calculation of ground-water velocity in the saturated zone to the accessible environment is that determined from tests (Ref. 9) in Well J-13 east of the site and in UE25b#1, a hole that penetrates the fracture zone beneath Drillhole Wash; also conservative is the assumption that this and other potential pathways are hydraulically continuous to the accessible environment along a straight-line flow path.

C. Recharge

Recharge is estimated by two independent techniques. The first is derived from perturbations of the geothermal heat flow by the downward flux of water in the unsaturated zone and in the uppermost saturated zone. Calculations published to date (Ref. 10) indicate a Darcian flux of 1-10 mm/yr. Further analyses that are underway indicate that the upper limit will probably be adjusted downward as more data and analyses become available; therefore the assumed value of 8 mm/yr is considered to be conservative.

The second technique utilizes relationships among recharge, altitude zone, and precipitation that have been developed by the U.S. Geological Survey in water-budget studies in cooperation with the Nevada

Department of Conservation and Natural Resources (Ref. 11). For the Yucca Mountain area and altitude zone, the annual precipitation is 150 mm to 200 mm (Ref. 12) and the part of that estimated to recharge the ground-water system is 3 percent (Ref. 13). The resulting value of 4.5 to 6 mm/yr Darcian flux compares favorably with the 10 mm/yr or less estimated by the heat-flow analysis.

Within the local setting, the persistent soil-moisture deficiency indicates that only major, runoff-producing precipitation events are likely to produce recharge. This local recharge is probably concentrated areally in the major ephemeral washes that define the boundaries of the central block at Yucca Mountain. The actual recharge in the interchannel and undissected areas overlying the proposed repository is probably less than the 4.5 to 10 mm/yr range established above. A value of 8 mm/yr selected for travel-time calculations is believed to be conservative, perhaps highly so.

D. Conceptual Flow Model and Travel Time

Figure 2 shows schematically the various segments of the flow paths discussed below.

1. Unsaturated Zone

Infiltration that descends beneath the surficial zone of evaporation and upward vapor transport moves downward through fractures or alluvium to the upper clastic unit, which is unsaturated. The hydraulic potential of water in the matrix is less than atmospheric, and the permeability is moderately high; because the unit is stratified, the lateral permeability is probably higher than the vertical. Large lateral hydraulic gradients exist from rocks having a higher degree of saturation to those with lower degrees of saturation, resulting in the probable dominance of lateral flow until matric potentials (fluid tension) are nearly equalized through the rock mass. Therefore, nonuniformly distributed recharge becomes more uniform both areally and in time. Under a vertical hydraulic gradient of unity, the unsaturated flux moves by porous flow downward to the densely welded unit, where the significant fracture permeability can easily transmit an 8 mm/yr flux. The interconnecting, nonvertical fractures vary in aperture and therefore in moisture tension as well, further dispersing and attenuating the flow. Travel time from the disturbed zone to the top of the lower clastic unit is not considered in the analysis.

Assume first that the upper range of the bimodally distributed permeability predominates areally in the vitric tuff of the lower clastic unit. Under the unit hydraulic gradient ($i=1$) in the unsaturated tuffs, the maximum flux (q_{max})

that can be transmitted without at least partial rejection is equal to the saturated hydraulic conductivity (k_s):

$$q_{max} = (k_s)\ (i) = 100\ mm/yr$$

Similarly, for the zeolitic tuff, q_{max} = 50 mm/yr. Therefore, both tuff facies can readily transmit the conservatively high recharge flux of 8 mm/yr.

There are not yet sufficient data to estimate the velocity of unsaturated flow through the lower clastic unit by rigorous methods relating the dependency of hydraulic conductivity and effective porosity to ambient moisture content, flux, and pore geometry. However, the few measurements that are available indicates near-saturation (95%) and low matric tension (1 bar) in the clastic tuffs. Therefore, a reasonable prediction of average velocity can be obtained by the relation,

$$v_s = \left(\frac{q}{q\ max}\right) \frac{k_s}{n} = \frac{q}{n} = \frac{.008\ m/yr}{.30} = 0.0267\ m/yr.$$

The thickness of the lower clastic unit ranges from about 70 m at the southern end of the central block to about 150 meters at the northern end (Refs 2, 3, 4, 14). Dividing this range by the seepage velocity results in calculated travel times of 2,600 to 5,600 years.

Alternatively, if the lower range of permeability measured in the vitric tuff is stratigraphically continuous (which is not known to be the case), the recharge could be rejected and diverted eastward and northward to the zeolitic facies. Again, conservatively estimating that all of the recharge might flow through only half of the cross-sectional area, where the lower clastic unit is at least 100 m thick, the calculated travel time is 1,900 years.

2. Saturated Zone

Measurements of hydraulic, potential, temperature and depths of permeable zones in boreholes indicate that flow patsh in the older volcanics beneath the water table are tortuous, preferentially following fractures where they are open and favorably oriented. Permeable fractures occur with the greatest frequency in the upper 500 m of the saturated zone. That fracture properties vary in space is indicated by the fact that transmissivity or storage coefficients appear to change during hydraulic testing, as the zone of influence of the test expands from the borehole

The water table to the north and west of the proposed repository site, and beneath the western part of the central block, is higher than that further south and east by several tens of meters. Data are sufficient to indicate, though not yet to demonstrate conclusively, that the Solitario Canyon fault is not a major pathway for southward flow despite its favorable orientation with respect to the regional southward direction of flow.

Beneath the eastern half of the disturbed zone and to both the east and south, the water table is nearly flat and is difficult to characterize. Tentative results of an ongoing drilling program suggest that, from the southern end of the disturbed zone, flow is southward but that, from the central and northern parts, flow is generally eastward. The general southward direction of regional flow is well documented (Refs. 12a, 13, 15) and constrains this eastward flow from the central block of Yucca Mountain. The most probable pathway is eastward or southeastward to a position beneath Fortymile Wash, about 7 km east of Yucca Mountain and then south-southeastward following the trend of the wash. Such a curvilinear path would increase the actual distance of flow to the accessible environment to more than 10 km. For purposes of the calculations that follow, it is conservatively assumed that neither curvilinear nor tortous flow paths significantly increase the 10-kilometer distance.

Similarly, no credit is taken for transit times beneath the lower clastic unit under the disturbed zone, although most of the flux through the disturbed zone will be significantly delayed in this segment of the total pathway.

The calculation of flow time to the accessible environment is as follows:

Hydraulic conductivity, k = 1 m/day or 365 m/yr (See A.5 above), for a unit hydraulic gradient.

Hydraulic gradient, $i = 1.6 \times 10^{-4}$ (Distance-weighted average of gradients between UE25b#1 and Well J-13 and between Well J-13 and Well J-12, based on measured hydraulic heads and distances. The first segment has a gradient of 2.0×10^{-4} over a distance of 6.4 km; the second has a gradient of 1.1×10^{-4} over a distance of 4.7 km).

Effective porosity, $n_e = 0.02$ (See A.5 above.)

Average velocity along flow path,

$$v = \frac{(k_s i)}{(n_e)} = \frac{(365)\ (1.6 \times 10^{-4})}{0.02} = 2.9 \text{ m/yr}$$

Travel time for 10 km,

$$t = \frac{10,000}{2.9} = 3,400 \text{ years}$$

Regional investigations provide checks on the reasonableness of the calculations. Hydraulic analyses of Pahute Mesa, which is comprised of similar rock types, provide a probable velocity on the order of 5 m/yr (Ref. 16). Carbon-14 ages of ground water in the vicinity of Yucca Mountain are in the ragne of 10,000 to 13,000 years (Ref. 17). If it is assumed that these waters are derived from the head of the regional system at Pahute Mesa, 65 km to the north, the calculated <u>maximum</u> ground-water velocities are 5 to 7 m/yr. Addition of recharge between the basin extremity and Yucca Mountain would result in lower calculated velocities. Hence, a saturated-zone velocity of about 3 m/yr and a 10-km travel time in excess of 3,000 years are reasonably expected from both site-specific and regional information.

References

1. a. Winograd, I. J., and Thordarson, William, 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with a special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

b. Thordarson, Wiliam, Geohydrologic data and test results from well J-13, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 83-4171 (in preparation).

c. Borg, I. Y., Stone, R., Levy, H. B., and Ramspott, L. D., 1976, Information pertinent to the migration of radionuclides in ground water at the Nevada Test Site: Part 1--Review and analysis of existing information: Lawrence Livermore Laboratory Report UCRL-52078, 216 p.

2. a. Spengler, R. W., Byers, F. M., Jr., and Warner, J. B., 1981, Stratigraphy and structure of volcanic rocks in drill hole USWG1, Yucca Mountain, Nye County, Nevada: U.S. Geological Survey Open-File Report 81-1349, 50 p.

b. Spengler, R. W., Muller, D. C., and Livermoe, R. B, 1979, Preliminary report on the geology and geophysics of drill hole UE25a-1, Yucca Mountain, Nevada Test Site: U.S. Geological Survey Open-File Report 79-1244, 43 p.

3. a. Scott, R. B., and Castellanos, Mayra, Preliminary report on the geologic character of drill holes USW GU-3 and USW G-3: U.S. Geological Survey Open-File Report (in preparation).

b. Spengler, R. W., written communication, 1982.

4. a. Rush, F. E., Thordarson, William, and Pyles, D. G., Results of hydraulic tests in U.S. Department of Energy's well USW H-1, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report (in preparation).

b. Spengler, R. W., Muller, D. C., and Livermoe, R. B, 1979, Preliminary report on the geology and geophysics of drill hole UE25a-1, Yucca Mountain, Nevada Test Site: U.S. Geological Survey Open-File Report 79-1244, 43 p.

c. Scott, R. B., and Castellanos, Mayra, Preliminary report on the geologic character of drill holes USW GU-3 and USW G-3: U.S. Geological Survey Open-File Report (in preparation).

5. Rush, F. E., Thordarson, William, and Pyles, D. G., Results of hydraulic tests in U.S. Department of Energy's well USW H-1, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report (in preparation).

6. a. Rush, F. E., Thordarson, William, and Pyles, D. G., Results of hydraulic tests in U.S. Department of Energy's well USW H-1, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report (in preparation).

b. Daniels, W. R., Wolfsberg, K., Rundberg, R. S., Ogard, A. E., Kerrisk, J. F., and others, 1982, Summary report on the geochemistry of Yucca Mountain and environs: Los Alamos National Laboratory Report LA-9328-MS, 364 p.

c. Spengler, R. W., Muller, D. C., and Livermoe, R. B, 1979, Preliminary report on the geology and geophysics of drill hole UE25a-1, Yucca Mountain, Nevada Test Site: U.S. Geological Survey Open-File Report 79-1244, 43 p.

7. Snyder, D. B., and Carr, W. J., 1982, Prelininary results of gravity investigations at Yucca Mountain and vicinity, southern Nye County, Nevada: U.S. Geological Survey Open-File Report 82-701, 36 p.

8. Scott, R. B., Spengler, R. W., Diehl, Sharon, Lappin, A. R., and Chornack, M. P., 1983, Geologic character of the unsaturated zone in ash-flow tuff at Yucca Mountain, southwestern Nevada, in Role of the unsaturated zone in radioactive and hazardous waste disposal: Ann Arbor, Ann Arbor Science, p. 289-335.

9. a. Thordarson, William, Geohydrologic data and test results from well J-13, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 83-4171 (in preparation).

b. Lahoud and Lobmeyer (written communication, 1983).

10. Sass, J. H., and Lachenbruch, A. H., 1982, Preliminary interpretation of thermal data from the Nevada Test Site: U.S. Geological Survey Open-File Report 82-973, 30 p.

11. a. Eakin, T. E., Maxey, G. B., Robinson, T. W., Fredericks, J. C., and Loeltz, O. J., 1951, Estimated annual increment to ground water, in Contributions to the hydrology of eastern Nevada: Nevada State Engineer, Water Resources Bulletin 12, p. 26-27.

b. Malmberg, G. T., and Eakin, T. E., 1962, Ground-water appraisal of Sarcobatus Flat and Oasis Valley, Nye and Esmeralda Counties, Nevada: Nevada Department of Conservation and Natural Resources, Ground-Water Resources--Reconnaissance Series Report 10, 39 p.

12. Winograd, I. J., and Thordarson, William, 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with a special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

13. Rush, F. E., 1970, Regional ground-water systems in the Nevada Test Site area, Nye, Lincoln, and Clark Counties, Nevada: Nevada Department of Conservation and Natural Resources, Division of Water Resources, Water Resources Reconnaissance Series Report 54, 25 p.

14. Scott, R. B., Spengler, R. W., Diehl, Sharon, Lappin, A. R., and Chornack, M. P., 1983, Geologic character of the

unsaturated zone in ash-flow tuff at Yucca Mountain, southwestern Nevada, in Role of the unsaturated zone in radioactive and hazardous waste disposal: Ann Arbor, Ann Arbor Science, p. 289-335.

15. Waddell, R. K., 1982, Two-dimensional, steady-state model of ground-water flow, Nevada Test Site and vicinity, Nevada-California: U.S. Geological Survey Water-Resources Investigations Report 82-4085, 72 p.

16. Blankennagel, R. K., and Weir, J. E., Jr., 1973, Geohydrology of the eastern part of Pahute Mesa, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Professional Paper 712-B, 35 p.

17. Benson, L. V., Robison, J. H., Blankennagel, R. K., and Ogard, A. L., Chemical composition of ground water and the locations of permeable zones in the Yucca Mountain area, Nevada: U.S. Geological Survey Open-File Report (in preparation).

18. a. Daniels, W. R., Wolfsberg, K., Rundberg, R. S., Ogard, A. E., Kerrisk, J. F., and others, 1982, Summary report on the geochemistry of Yucca Mountain and environs: Los Alamos National Laboratory REport LA-9328-MS, 364 p.

b. Borg, I. Y., Stone, R., Levy, H. B., and Ramspott, L. D., 1976, Information pertinent to the migration of radionuclides in ground water at the Nevada Test Site: Part 1--Review and analysis of existing information: Lawrence Livermore Laboratory Report UCRL-52078, 216 p.

Sincerely,

james h. robison, for

W. W. Dudley, Jr.
USGS Technical Project Officer

Copy to:
LANL D. T. Oakley
LLNL L. D. Ramspott
SNL T. O. Hunter
W A. R. Hakl
USGS W. W. Dudley

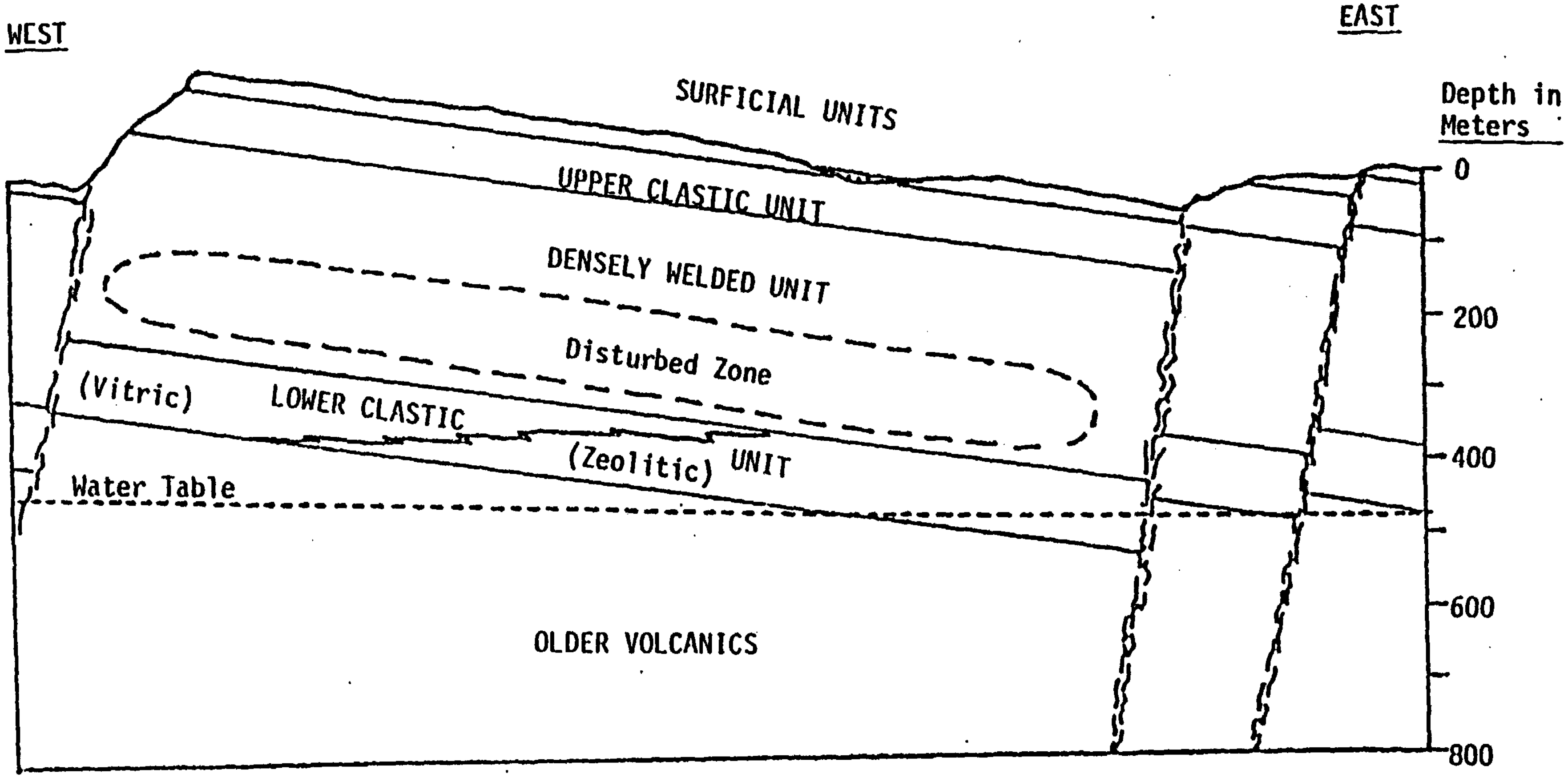

Figure 1. Hydrogeologic model of proposed Yucca Mountain repository site. Vertical exaggeration is about 1.5.

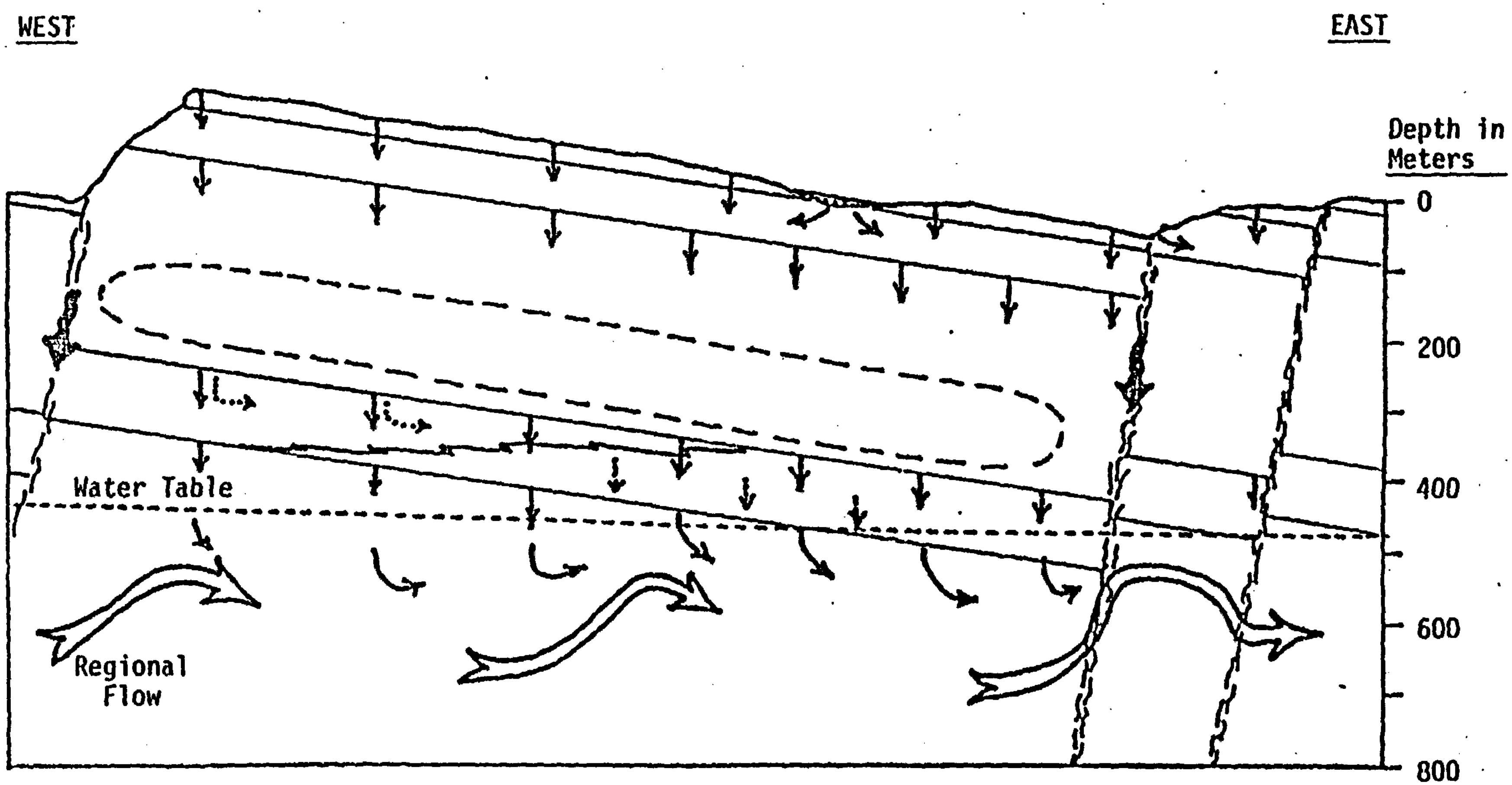

Figure 2. Conceptual flow model. See Fig. 1 for identification of hydrogeologic units. Dashed flow arrows in the lower clastic unit depict the possible rejection of flow by the vitric facies and resulting concentration in the zeolitic facies.