SIMULATION OF SPRING FLOWS SOUTH OF YUCCA MOUNTAIN, NEVADA, FOLLOWING A POTENTIAL FUTURE WATER TABLE RISE

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ABSTRACT

The Center for Nuclear Waste Regulatory Analyses (CNWRA) developed an independent, three-dimensional saturated-zone flow model for the Yucca Mountain region using the MODFLOW code (Harbaugh, et al., 2000). This model has proven useful as an independent means of evaluating the parameter uncertainties and alternative interpretations of hydrogeologic conditions. This report shows the results of analyses used to evaluate the effects of water table rise during potential wetter climate conditions. Water table rise was included in the model by increasing potentiometric head values at the model side boundaries by a fixed percentage and doubling the rate of surface recharge. A 5-percent increase in boundary heads from the estimated present-day values caused the calculated water table elevation to first reach the land surface in an area coincident with evaporite deposits that indicate the past occurrence of spring flows. To model their effect on flow paths, spring discharges were simulated using the MODFLOW DRAIN package, total spring discharge was varied by using different values for drain conductance and elevation. Particle-tracking analyses of flow paths from beneath Yucca Mountain were then performed for different spring discharge rates using the MODPATH code (Pollack, 1994). The modeling analysis included maximum spring discharge in excess of 10,000 m^3/d [3,000 acre-ft/yr] from the area of observed evaporite deposits. Results suggest that calculated flow paths from beneath Yucca Mountain do not change appreciably as a result of spring discharges at this location. Reverse particle tracking indicated that simulated spring discharges at this location originate from the Crater Flat area, west of Yucca Mountain.

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: No original data were generated from the analyses presented in this report.

ANALYSES AND CODES: The MODFLOW 2000 groundwater flow modeling code and the MODPATH particle-tracking code were used to perform the calculations presented in this report. The Groundwater Modeling System (GMS) Version 5.1 graphical interface was used to execute these codes and view the results. The MODFLOW-2000, MODPATH codes and the GMS software package have been validated in accordance with CNWRA Technical Operating Procedure (TOP)–18. The Modeling activities reported herein are documented in CNWRA Scientific Notebook 480E.

1 INTRODUCTION

The Center for Nuclear Waste Regulatory Analyses (CNWRA) three-dimensional, site-scale saturated-zone flow model for the Yucca Mountain region was developed as a tool to assist the U.S. Nuclear Regulatory Commission (NRC) with evaluating the potential effects of parameter and conceptual uncertainties on estimated flow paths and groundwater fluxes near Yucca Mountain, Nevada, the site of a potential high-level waste repository.

The CNWRA site-scale saturated zone flow model previously has been used to evaluate the potential effects on flow paths of a higher water table that might result from future wetter climate conditions (Winterle, 2003). During that exercise, a higher water table was simulated by increasing the constant-head model boundary values by five percent. This approach was successful in predicting that a rising water table would first intersect the land surface in an area where thick evaporite mineral deposits are present. These mineral deposits are the result of evaporating spring flows that occurred when the water table intersected the land surface in the past. This previous work suggested that the modeled increase in water table elevation resulted in increased hydraulic gradients, but did not significantly affect flow paths from beneath Yucca Mountain. A limitation of the analysis by Winterle (2003), however, is that spring discharge was included in the model at only a single model cell with a spring discharge rate of only 0.3 m^3/d [10^{-4} cfs]. In this report, the effect of potential spring flows that occur over a larger area and at higher flow rates is explored.

Programmatic Relevance of Work

Figure 1 shows the location of observed evaporite deposits in relation to the general direction of groundwater flow from beneath Yucca Mountain, as modeled by Winterle (2003). A concern that prompted the modeling analysis in this report is whether high rates of spring discharges within the area represented by these spring deposits could either capture groundwater flow paths from beneath Yucca Mountain or at least divert the flow paths farther to the west. A more westerly flow path would tend to travel a greater distance in volcanic tuff rock and less distance in valley fill alluvium before reaching the compliance boundary specified in 10 CFR Part 63, approximately 18-km [11-mi] south of the potential repository area. Risk insights developed by NRC identify retardation of radionuclides in saturated alluvium as being of high significance to waste isolation for a potential repository. Hence, this relatively easy analysis of the effects of spring discharges on flow paths from Yucca Mountain is justified by the risk significance of potentially shorter flow paths in alluvium.

2 MODEL DESCRIPTION

The CNWRA saturated zone flow model for Yucca Mountain was developed by Winterle, et al. (2002). The computational grid covers a 28.5 × 41.4-km [17.7 × 25.7-mi] area surrounding Yucca Mountain, as shown in Figure 1. The model domain extends vertically from 1,200 m [3,940 ft] above mean sea level to 1,500 m [4,920 ft] below mean sea level. There are 30 horizontal layers in the numerical grid, which vary in thickness from 50 m [164 ft] to 200 m [656 ft], with the thinnest grid layers assigned at and below the water table where flow paths from Yucca Mountain might occur. Each of the 30 layers is uniformly divided into 300-m [900-ft] square horizontal grid blocks for a total of 393,300 computational cells. The model was originally developed using Groundwater Modeling System (GMS) Version 3.1 for model grid development, and MODFLOW-96 (Harbaugh and McDonald, 1996) for execution of the

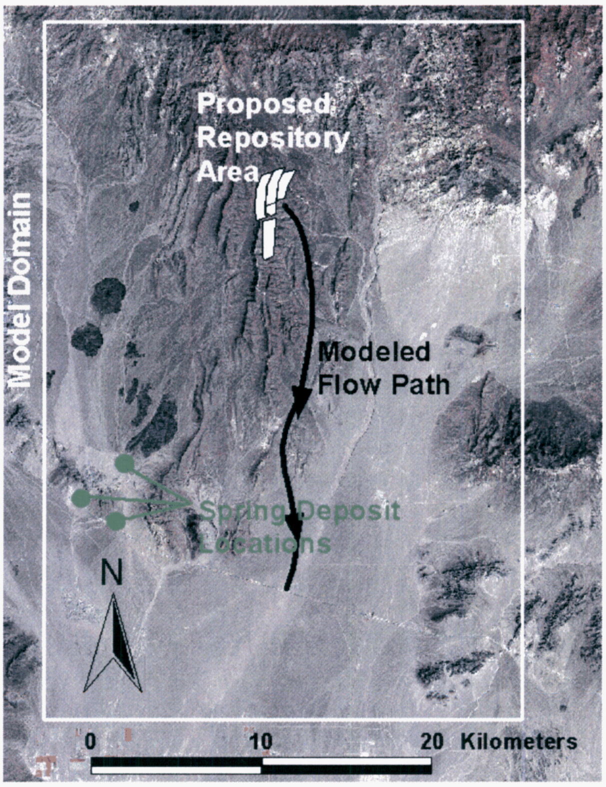

Figure 1. Locations of Spring Evaporite Mineral Deposits in Relation to Flow Path from Beneath the Proposed Design Area for the Potential Repository (Winterle, 2003). Plan View of the CNWRA Site-Scale Saturated Flow Model Used in this Analysis Also Is Shown.

groundwater flow model. For the analyses in this report, the CNWRA model was updated to run with the newer GMS Version 5 and MODFLOW-2000 (Harbaugh, et al., 2000). The MODPATH Version 3 particle-tracking code was used for evaluating flow paths.

The model boundary conditions and hydrologic properties used for this analysis are the same as those described in Winterle (2003) as Case 4, which was created to evaluate the potential effects of a future water table rise combined with increased recharge. The Case 4 model was created beginning with a model calibrated to present-day water level observations; constant head boundary values on the vertical sides of the model were then increased by a factor of 1.05. This factor is somewhat arbitrary, but is based on the amount of increase necessary for the water table to begin intersecting the land surface. Recharge was assumed to double in the northern portion of the model area and in the Yucca Mountain area, and recharge of 200 mm/yr [7.9 in/yr] was added to the incised channel of Fortymile Wash. Modeled recharge areas and recharge rates are shown in Figure 2. The hydrologic properties assigned to this model are discussed in detail by Winterle (2003) and are not repeated here.

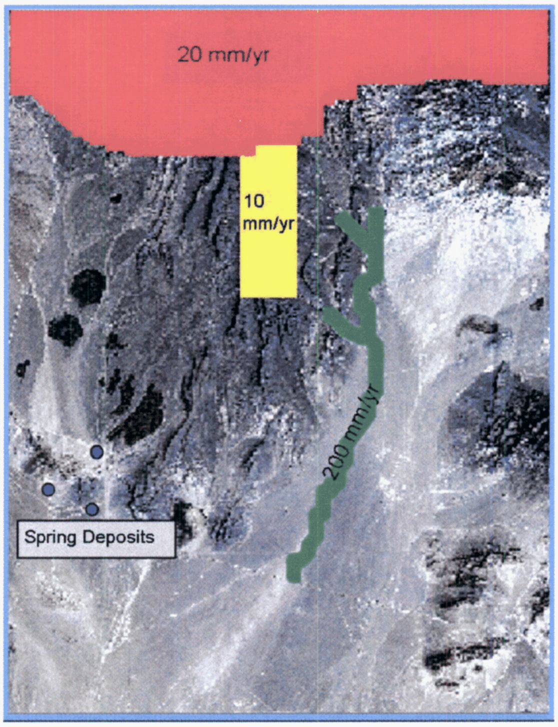

Figure 2. Map of Vertical Surface Recharge Areas Included in the Flow Model. For Scale, Refer to the Model Domain Shown in Figure 1. [1 mm = 0.039 in]

3 POTENTIAL SPRING FLOW LOCATIONS

The first step in evaluating the effects of potential future spring flows on flow paths from Yucca Mountain is to establish the model cell locations that should be treated as spring locations. As previously mentioned, this analysis begins with the Case 4 model of Winterle (2003). The first change made to this model was to activate all model cells designated as above land surface cells in the MODFLOW model grid that were inactive in the original Case 4 model. These are cells in which the elevation of the cell center is above the land surface defined in the hydrogeologic framework model of the Amargosa Valley region (Sims, et al., 1999). The initial hydraulic head values in all variable-head cells (i.e., cells not defined as constant-head boundary cells) were then set to arbitrary values greater than the elevation of the tops of the cells. The model was then run to achieve a steady-state solution with the top seven grid layers of the model set to use the confined/unconfined solution scheme of MODFLOW-2000. With the confined/unconfined solution, the MODFLOW code automatically inactivates any cell in which the computed hydraulic head falls below the elevation of the bottom cell face. In this manner, the high initial head values were allowed to decrease until the model was in steady-state equilibrium with the specified constant-head and recharge boundary conditions.

After initially running the model as described above, only a few of the above land surface cells remained active. The locations of these cells are shown in Figure 3. It must be noted that the above land surface designation is based on cell center elevations and that cells in the grid

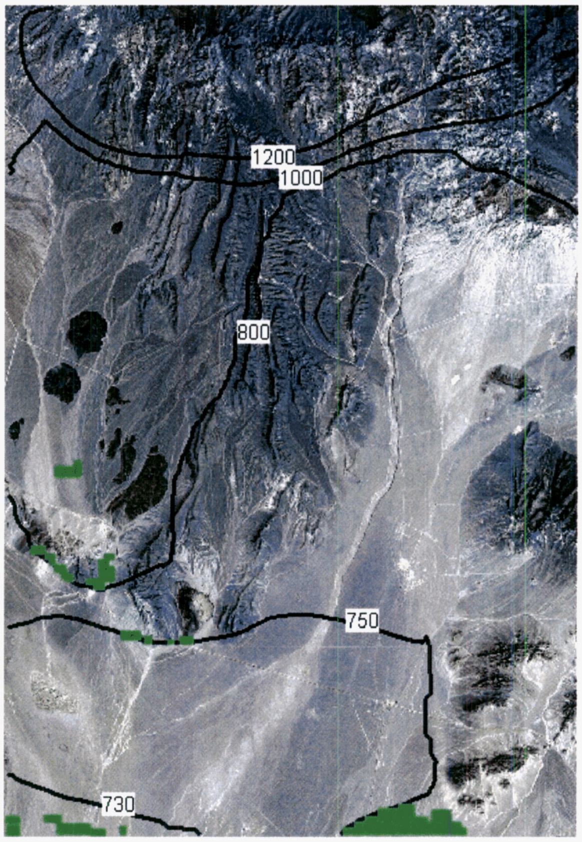

Figure 3. Map Showing Locations Where Computed Water Table Elevations in the Initial Model Run Intersect Model Cells Designated as Above Land Surface. Contour Lines Indicate Computed Hydraulic Heads, in Meters, for Model Grid Layer 7. Map Shows Entire Model Domain. For Scale, Refer to the Model Domain Shown in Figure 1. [1 m = 3.281 ft]

layers of interest are 50-m [165-ft] thick. Consequently, it is possible that the actual land surface elevation could be as much as 25 m [82 ft] above the bottom elevation of these cells designated as being above land surface. Further screening is therefore necessary to determine which of the above land surface cells should be considered as potential spring discharge locations.

Figure 4 illustrates the conceptual approach for considering which above land surface cells should be included in the model as spring locations. It can be seen that, while the centers of cells are above land surface, the water table can still be below the actual land surface in cases where the computed water table elevation is not higher than the cell center. It is not practical to cross check actual land surface elevations at every above land surface model cell. Consequently, judgment was used to determine that above land surface cells should not be treated as potential spring flow locations unless the computed water table is at least 5 m [16 ft] above the cell bottom elevation. Although this criterion is arbitrary, it results in numerous potential spring locations, which is consistent with the desire to evaluate high spring discharge

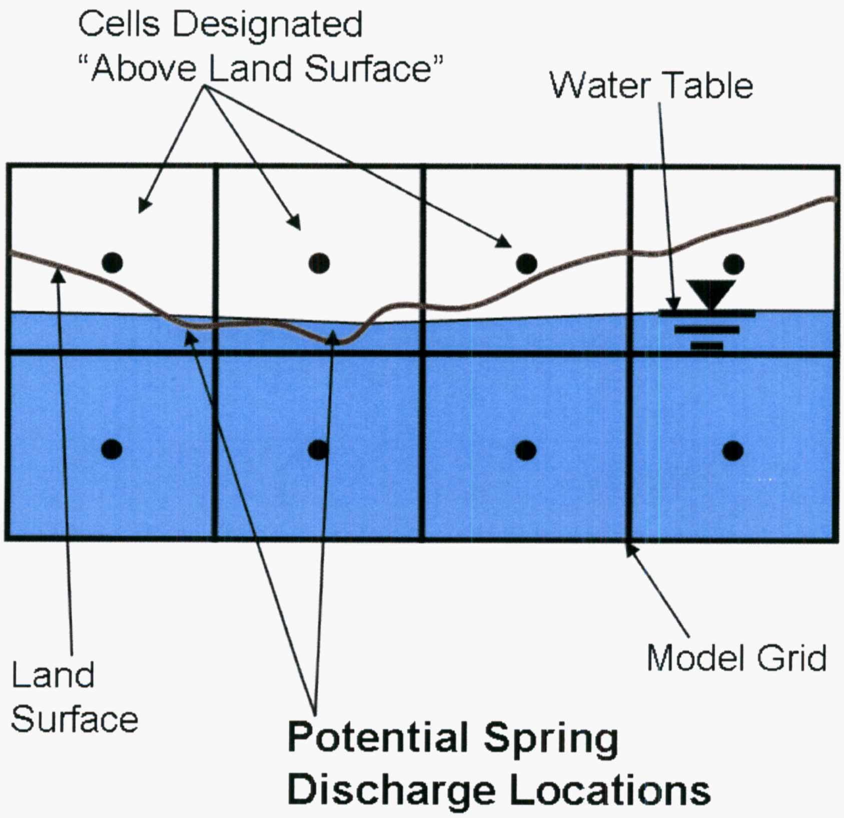

Figure 4. Illustration of Conceptual Approach Used to Evaluate Cells Designated as Above Land Surface That Should Be Considered as Potential Spring Flow Locations

rates. Additionally, groups of active above land surface cells that are directly adjacent to constant-head model boundaries are also ruled out as potential spring locations because the activation of these cells was an artifact of the assigned boundary conditions. Accordingly, none of the active above land surface cells adjacent to the southern model boundary (see Figure 3) are considered as potential spring flow locations.

After screening the active above land surface cells, 23 locations were identified where computed water table elevations were more than 5 m [16 ft] above the cell bottom location and where the cells were not in close proximity to a constant-head model boundary. The locations of these cells are shown in Figure 5. It is especially important to note that these locations are in close proximity to the areas of observed paleo-spring evaporite deposits.

4 EVALUATING THE EFFECTS OF SPRING FLOWS

To simulate the effects of spring flow, the 23 cell locations identified in the model as potential spring locations were assigned as drain cells using the DRAIN package of the MODFLOW-2000 code (Harbaugh, et al., 2000). Drain cells act as sinks for groundwater discharge from the model. Discharge rates for drain cells are proportional to the specified

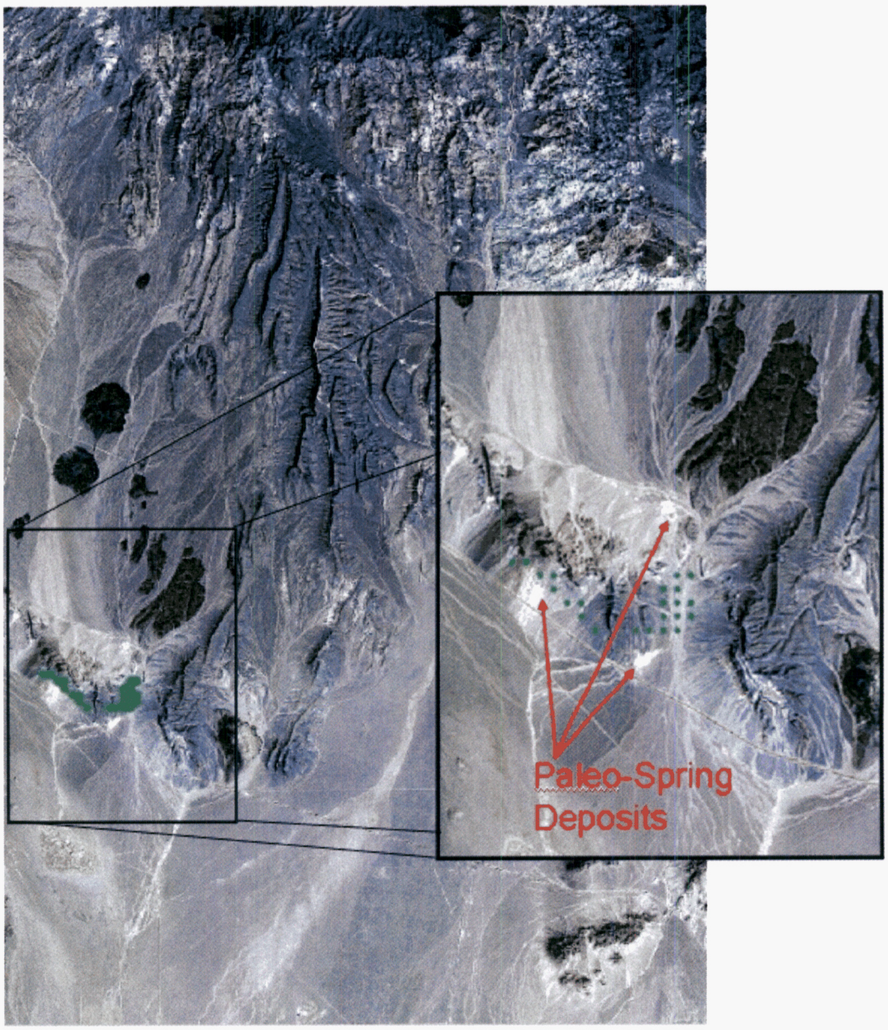

Figure 5. Larger Map View of Model Domain Shows Locations of MODFLOW DRAIN Cells Used to Account for Spring Discharge. For Scale, Refer to the Model Domain Shown in Figure 1. Inset Shows a Close-Up View to Illustrate Relationship of Modeled Spring Locations to Observed Evaporite Mineral Deposits.

conductance of the cell and the difference between the specified drain elevation and the computed water table elevation. In this analysis, drain elevations were fixed at the cell bottom, and the drain conductances were arbitrarily manipulated to obtain a total spring discharge rate in excess of 10,000 m^3/d [3,000 acre-ft/yr]. This rate of discharge is much greater than is evidenced by evaporite deposits, which are indicative of relatively low spring flows. It is desired, however, to conduct this analysis using discharge rates that are high enough to bound the potential effects of spring flows at these locations on flow paths from beneath the potential Yucca Mountain repository.

Figure 6 shows a comparison of flow paths from beneath the Yucca Mountain area for scenarios with and without the inclusion of spring discharge in the CNWRA site-scale flow model. The

a. Flow paths without simulated spring discharge

b. Flow paths with 10,800 m^3/d spring discharge

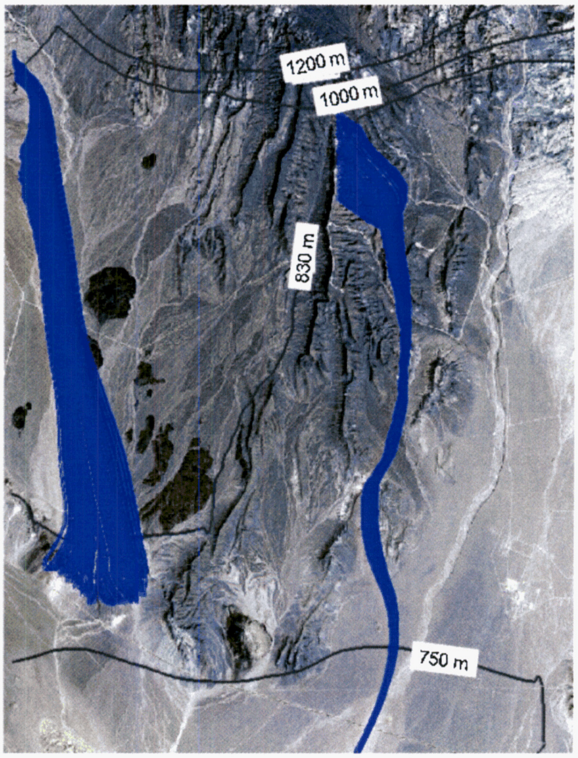

Figure 6. (a) MODPATH Simulation of Forward Flow Paths from Beneath Yucca Mountain with No Spring Discharges Included in the Model and (b) Forward Flow Paths from Beneath Yucca Mountain with Spring Discharge Included. Also Shown Are Reverse Particle Tracks from MODFLOW DRAIN Cell Locations. Contour Lines Indicate Computed Hydraulic Heads, in Meters, for Model Grid Layer 7. Maps Show Entire Model Domain. For Scale, Refer to the Model Domain Shown in Figure 1. [1 m = 3.281 ft]

flow paths shown in Figure 6 were simulated with the MODPATH particle tracking code (Pollack, 1994) using steady-state cell-to-cell fluxes calculated by MODFLOW-2000. Figure 6a shows forward flow trajectories for a line of particles running north-south beneath the potential repository area for the case with no spring discharges included in the model.

Figure 6b shows two sets of flow trajectories for the model simulation with 10,800 m^3/d [3,200 acre-ft/yr, or 4.5 cfs] discharging from the spring locations shown in Figure 5. The first set is a group of forward trajectories for the same particle-starting locations simulated in Figure 6a. It is difficult to discern any difference between these simulated flow paths and those for the case with no spring discharge. A close inspection of model results suggests that the trajectories for the case with the high spring discharge are pulled slightly toward the area of spring discharge, but not more than a few tens of meters.

The second set of trajectories shown in Figure 6b is a backward particle tracking analysis to evaluate the source of groundwater discharge from the simulated spring locations. For the model conditions considered in this analysis, it can be seen that the simulated spring flow originates from the northwest corner of the model boundary, more than 10 km [6.2 mi] west of Yucca Mountain.

5 DISCUSSION OF RESULTS

The preceding analysis was a relatively simple exercise focused on the specific question of whether flow paths from beneath Yucca Mountain might be susceptible to capture by potential spring flows during future, wetter climate conditions. The following key points can be drawn from this analysis.

A simulation of a potential water table rise by assuming a uniform five percent increase in model boundary heads resulted in the simulated water table intersecting the land surface in areas where paleospring deposits suggest spring flows have occurred in the past. This result lends confidence to the analysis because the modeled locations of potential future spring flows are entirely consistent with locations where spring flows are known to have occurred in the past.

A simulation of spring flows as high as 10,800 m^3/day [4.4 cfs] in the area of these spring deposits had a nearly negligible effect on the simulated particle tracks of flow paths from beneath Yucca Mountain. To put this simulated rate of spring flow into perspective, this discharge rate would be sufficient to produce one or more perennial streams that would flow into the Amargosa River channel. Conversely, the evaporite mineral deposits cited as evidence of previous spring flows suggest much lower discharge rates because evaporite deposits form where water evaporates before it can run off and carry away its cargo of dissolved minerals. It should, therefore, be noted that the spring flow rates simulated in this analysis are intended to be bounding rather than realistic estimates. Because these bounding rates of spring flow had negligible effects on flow paths from beneath Yucca Mountain, it can be concluded that lower flow rates would also have a negligible effects.

A final result of this analysis is that the groundwater flow system beneath Crater Flat, west of Yucca Mountain, would be the likely source of groundwater if spring flows occurred at the locations considered in this analysis.

6 CONCLUSION

Based on the results of this analysis, there is no indication that flow paths from beneath Yucca Mountain could be significantly affected by initiating future spring flows in the areas where evaporite deposits indicate past spring flows. This negative result suggests there is no need to further consider this process in performance assessments or other analyses that may be used to evaluate waste isolation capability or environmental impacts of a potential Yucca Mountain repository.

As a concluding note, the analysis presented in this report was conducted with a relatively low level of effort because the CNWRA site-scale saturated zone flow model already exists and can be easily adapted to consider alternative conceptualizations of hydrologic processes in the Yucca Mountain area. Although initiating spring flows had not been identified previously as a risk significant process, the low level of effort expended on this activity is certainly justified by the improved understanding of flow processes at Yucca Mountain and the improved confidence that such spring flows do not need to be explicitly considered.

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