FINAL REPORT
Project Activity ORD-FY04-018
Groundwater Flow and Thermal Modeling to Support a Preferred Conceptual Model for the Large Hydraulic Gradient North of Yucca Mountain

Project Activity ORD-FY04-018 was initially identified by DOE as a quality affecting task under Cooperative Agreement DE-FC28-04RW12232. However, the Cooperative Agreement has been downgraded by the Department of Energy to *Unqualified* in accordance with amendment M029 of DE-FC28-04RW12232. Therefore, this final report has been produced as an unqualified document. Although the technical work presented in this report was conducted in full compliance with the approved NSHE QA Program, and the report has successfully completed an independent technical review, the report has not completed quality assurance reviews and therefore should not be used for quality affecting purposes.

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FINAL TECHNICAL REPORT

Title:
Groundwater Flow and Thermal Modeling to Support a Preferred Conceptual Model for the Large Hydraulic Gradient North of Yucca Mountain

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2.0 PURPOSE

The purpose of this study is to report on the results of a preliminary modeling framework to investigate the causes of the large hydraulic gradient north of Yucca Mountain. This study builds on the Saturated Zone Site-Scale Flow and Transport Model (referenced herein as the Site-scale model (Zyvoloski, 2004a), which is a three-dimensional saturated zone model of the Yucca Mountain area. Groundwater flow was simulated under natural conditions. The model framework and grid design describe the geologic layering and the calibration parameters describe the hydrogeology. The Site-scale model is calibrated to hydraulic heads, fluid temperature, and groundwater flowpaths.

One area of interest in the Site-scale model represents the large hydraulic gradient north of Yucca Mountain. Nearby water levels suggest over 200 meters of hydraulic head difference in less than 1,000 meters horizontal distance. Given the geologic conceptual models defined by various hydrogeologic reports (Faunt, 2000, 2001; Zyvoloski, 2004b), no definitive explanation has been found for the cause of the large hydraulic gradient.

Luckey et al. (1996) presents several possible explanations for the large hydraulic gradient as provided below:

The gradient is simply the result of flow through the upper volcanic confining unit, which is nearly 300 meters thick near the large gradient.

The gradient represents a semi-perched system in which flow in the upper and lower aquifers is predominantly horizontal, whereas flow in the upper confining unit would be predominantly vertical.

The gradient represents a drain down a buried fault from the volcanic aquifers to the lower Carbonate Aquifer.

The gradient represents a spillway in which a fault marks the effective northern limit of the lower volcanic aquifer.

The large gradient results from the presence at depth of the Eleana Formation, a part of the Paleozoic upper confining unit, which overlies the lower Carbonate Aquifer in much of the Death Valley region. The Eleana Formation is absent at borehole UE-25 p#1 at Yucca Mountain, which penetrated the lower Carbonate Aquifer directly beneath the lower volcanic confining unit.

The Site-scale model uses an area of very low permeability, referenced as the east-west barrier, to simulate the large hydraulic gradient. The Site-scale model is further refined in this study to provide a base-case model for exploring the geologic causes of the large hydraulic gradient.

2.1 Scope

The scope of this report includes documentation of the study's purpose, methods, results, recommendations, and intended use.

2.2 Limitations of Use

The results of this study should be used as a starting point for further investigation. Its purpose is to provide the grid and input files for use with alternate geologic interpretations or boundary fluxes to investigate the high-gradient area. The model parameters are taken from the saturated zone model and no model calibration was performed to observe hydraulic heads or groundwater temperatures.

3.0 QUALITY ASSURANCE

This report is written in accordance with the Nevada System of Higher Education (NSHE) Quality Assurance Program. No conclusions of this report are based on unqualified data. All work was performed in full compliance with the quality assurance program that has been developed and implemented to ensure that work conducted under the NSHE cooperative agreement DE-FC28-03RW12232 meets the Office of Civilian Radioactive Waste Management (OCRWM), Quality Assurance Requirements, and Description (QARD) requirements for quality-affecting work.

4.0 INTRODUCTION

A large hydraulic gradient is observed in the saturated zone north of Yucca Mountain. Geologic representations of the area do not explain the cause of this large gradient. This feature has been conceptualized as alternative configurations combining zones of high and low permeability within horizontal and vertical features. In the current Site-scale model, the large hydraulic gradient is simulated as a thin, vertical flow barrier extending east-west and affecting the entire saturated thickness of the model. Though the existence of this feature in the model improves model results, there is no direct evidence of such a geologic feature at this location.

In this study, we used the Site-scale model to develop an abstracted model with a refined grid and smaller domain. The geologic and hydrogeologic representations are the same as that described in the Site-scale model. Boundary fluxes were extracted from Site-scale model and applied to constant-head or constant-flux boundaries. Because of this effort, there now exists a baseline-refined, two-dimensional groundwater model to use in future studies to investigate the large hydraulic gradient. The Site-scale saturated zone model is the basis for the refined model described below.

5.0 METHODS

5.1 Summary of Site-scale Saturated Zone Model

The Site-scale saturated zone model is a large and complex model. A complete description of the conceptual model, computational model, and results are given in the Site-scale Saturated Zone Flow Model report (Zyvoloski, 2004a). The purpose of the Site-scale model was to describe the steady-state flow of groundwater and thermal transport of the area of large hydraulic gradient. This model is the basis for the refined groundwater flow and thermal transport described later in this report.

5.1.1 Domain

The Site-scale model extends east-west from UTM (NAD 1927) coordinates 533,340 meters to 563,340 meters and north-south from UTM coordinates 4,046,780 meters to 4,091,780 meters. The total aerial extent of the model is 1,350 square kilometers. The model extends vertically from -2,200 meters below sea level to an elevation of 1,200 meters.

The domain was chosen to encompass the following components that affect flow and transport: the Solitario Canyon Fault, recharge on Yucca Mountain, the Crater Flat Tuff hydrogeologic units, the shallow alluvial aquifer of Fortymile Wash, and the regional carbonate aquifer.

5.1.2 Geology

The Site-scale model encompasses 19 hydrostratigraphic units. The extents of each unit are defined in DTN: GS030208312332.001 [163087]. They were developed to characterize a three-dimensional model of the site base-case hydrologic flow model. The geologic units extend vertically from the interpolated groundwater table to the base of the regional groundwater flow model.

Fault zones near the large hydraulic gradient include the Claim Canyon, Calico Hills, Shoshone Mountain fault zones, and the east-west barrier (Zyvoloski, 2004b). The east-west barrier is simply a narrow low-permeability zone whose purpose is to separate the high heads in the north from the lower heads near Yucca Mountain.

5.1.3 Recharge

Recharge in the Site-scale model is compiled from three sources: the Site-scale unsaturated zone model, the regional saturated zone model, and Fortymile Wash. These sources were interpolated to the Site-scale grid while preserving total flux. The output from the unsaturated zone model was used directly as the recharge input to the saturated zone model. No unsaturated modeling was performed. The total recharge for the site-scale saturated zone model is 1,550,000 m^3/year.

5.1.4 Boundaries

The lateral boundary conditions for the Site-scale model were taken from the regional water level and head data and extrapolated to the site-scale grid. No vertical gradient was specified on these boundaries, even though vertical gradients were observed near well UE-25 p#1. A constant recharge flux at the water table (coincident with the top of the grid) was applied as described above. A no-flow boundary was applied to the bottom of the model at elevation -2,200 meters. It is assumed that this boundary is deep enough to have little impact on flow and transport in the area of interest.

5.1.5 Grid

Grid nodes in the Site-scale model were placed coincident with the nodes in the regional-scale model. The entire grid contains 142,853 orthogonal hexahedral (6-sided) elements. The shape of the elements was chosen to allow for the use of the particle tracking capability in the Finite Element Heat and Mass transfer code (FEHM). Grid elements are 500 meters by 500 meters in the horizontal direction. Grid zones are 550 meters thick at the bottom of the grid and between 10 and 50 meters thick near the top. Each zone is further divided into between one and six layers. A finer resolution was required near the water table to better capture the geometry of the geologic units.

5.1.6 Numerical Code

The FEHM application, version 2.20, was used to simulate flow and transport through the porous media. FEHM simulates water, air, heat, and contaminants in three-dimensional saturated/unsaturated heterogeneous porous media. This application is also capable of modeling reactive geochemistry and particle tracking and can simulate discrete fracture, dual porosity, or dual permeability conditions.

5.2 Development of an Abstracted Saturated Zone Model with Refined Grid

The purpose of the model developed for this study is to allow further exploration of the large hydraulic gradient in the area north of Yucca Mountain. Specifically, this model can be used to test alternative geologic conceptual models that may better simulate the water levels and groundwater temperatures associated with the large hydraulic gradient. An abstracted and refined model was developed from the Site-scale model to serve as a thorough compilation of the hydrologic features (including geology, recharge, water levels, and thermal properties) and as a starting point for further groundwater models.

5.2.1 Domain

The Site-scale model horizontal domain is a rectangular region 30 kilometers by 45 kilometers. The refined model domain developed for this study is a rectangular region 5 kilometers by 20 kilometers, or 100 square kilometers. Universal Transverse Mercator (UTM) (NAD 1927) coordinates range from 545,000 to 550,000 meters in the east-west direction and 4,071,000 to 4,091,000 meters in the north-south direction. Vertically, the refined model extends to elevations ranging from 1,200 meters to -1,000 meters.

The domain was chosen to maintain a computationally feasible number of grid cells, while still placing model boundaries at distance from the area of interest.

5.2.2 Geology

The refined model consists of the same geologic framework used to develop the Site-scale model. Because of this model's smaller domain, many geologic units that exist in the Site-scale model do not exist within the domain of the refined model. The units listed below, including the zone number used in the Site-scale model, are found within the refined model's domain:

Carbonate east-west barrier [56]

Claim Canyon Caldera (west) [61]

Claim Canyon Caldera (east) [62]

Solitario Canyon Fault splay [73]

Northern Zone (entire Claim Canyon, Calico Hills, Shoshone Mtn.) [81]

Imbricate Fault Zone [91]

Though the model domain only encompasses the six geologic units listed above, all 19 units are presented in the refined model input files. Though these units appear in the input files they are not used because the FEHM code discards any data falling outside of the model domain.

5.2.3 Recharge

Recharge in the refined model was taken from the Site-scale model. Values for the refined model were copied from the value of the nearest node in the Site-scale model. No interpolation was performed to develop the recharge data set.

5.2.4 Boundaries

In the area north of Yucca Mountain, flow is approximately north-south. Therefore, no-flow boundaries in the north-south direction are appropriate. This effectively reduces the three-dimensional model to computationally a two-dimensional model. The initial head values for each node on the lateral no-flow boundaries were extracted from that of the nearest node in the Site-scale model.

The upstream hydraulic head boundary was fixed at 1,200 meters and the downstream hydraulic head boundary was fixed at 750 meters. These values were taken from the Site-scale model and should be re-evaluated for appropriateness in future applications of the refined model. However, they proved sufficient for the purpose of developing a working model with a refined grid.

A no-flow boundary was applied to the bottom of the model at elevation -2,200 meters. As in the Site-scale model, it is assumed that this boundary is deep enough to have little impact on flow and transport in the area of interest.

5.2.5 Grid

The purpose of this study is to analyze the large hydraulic gradient with a refined grid. As stated above, the principal flow direction is north-south. Therefore, few nodes are necessary in the east-west direction. Though FEHM is capable of simulating a true two-dimensional domain, three dimensions were used for this study. The grid used for the refined model is a rectangular grid with 17,600 orthogonal hexahedral elements and 27,135 nodes. The grid has three nodes in the east-west direction, 201 nodes in the north-south direction, and 45 nodes vertically. The volume of each grid element is 12,500,000 cubic meters. The grid for the refined model essentially consists of subdividing the grid used within the Site-scale model. The model grid is illustrated in Figure 1.

The water table elevation was taken from the Site-scale model. Nodes above the observed water table were effectively removed from the model by setting the porosity to 0.0 in the input file. Removing unsaturated nodes shortens computation time in FEHM.

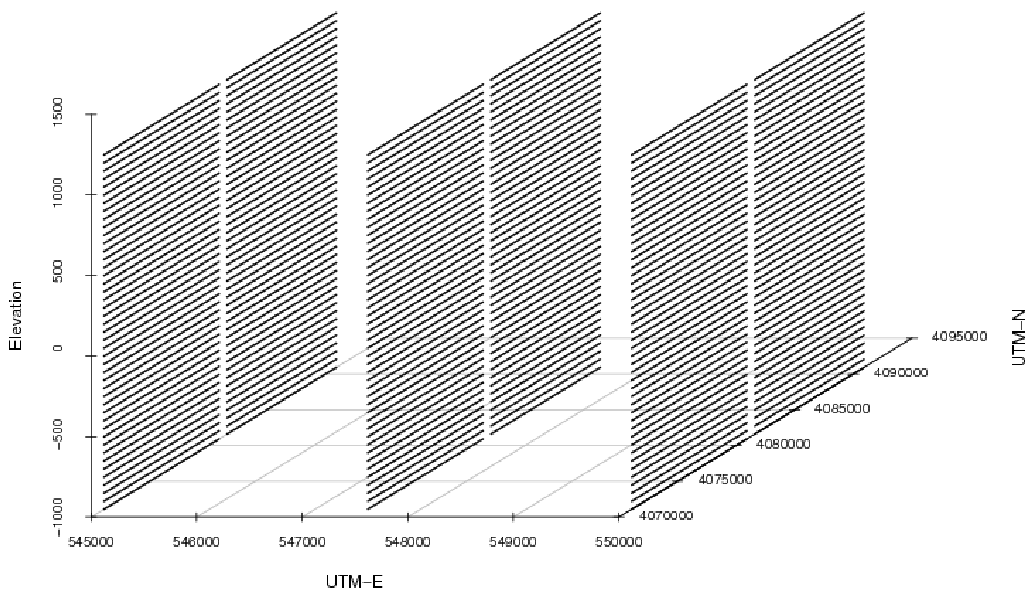

Figure 1. The grid for the refined model.

5.2.6 Numerical Code

The groundwater code FEHM V 2.20 (LANL, 2003) [161725] STN: 10086-2.20-00 was operated on a Dell Precision 650 under LINUX Red Hat was used for the refined model.

6.0 ASSUMPTIONS

The assumptions for formulating the refined model are essentially equivalent to the assumptions of the Site-scale model. The only unique assumption is that groundwater flow follows a path along the model grid and that lateral variations in groundwater flow are insignificant in evaluating possible geologic configurations of the large hydraulic gradient.

7.0 DISCUSSION/CONCLUSIONS

7.1 Results

Figure 2 illustrates a cross section of the results of one model run using the refined model. The large hydraulic gradient is illustrated in Figure 2 as the abrupt change in water level at approximately 4,081,000 meters north.

Groundwater temperature was also modeled. The temperature of the recharge boundary flux was simulated as a constant value, resulting in the final temperature of the steady-state solution for all nodes equal to that of the recharge boundary. The model is prepared for future temperature simulations, with the calibrated rock properties of the Site-scale model.

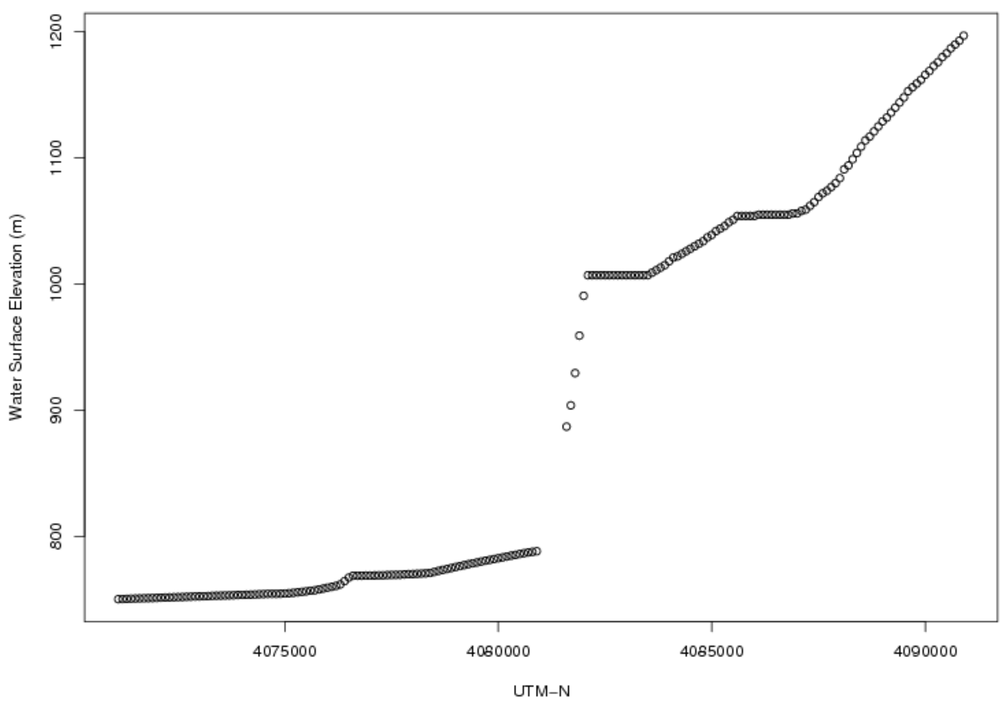

Figure 2. Water surface elevation near the large hydraulic gradient.

7.2 Conclusions Based Only on Q Data

The purpose of this study is to prepare a groundwater model suitable for simulating heads and temperature in the area of the large hydraulic gradient north of Yucca Mountain. The refined model is based strictly on the Site-scale saturated model and uses the same calibrated hydrogeologic parameters. In the primary direction of flow, the grid in the refined model is five times more detailed than the grid in the Site-scale model. This level of grid resolution is necessary to represent alternative geologic representations on the large hydraulic gradient.

New geologic conceptual models, with the intent of providing a better explanation of the large hydraulic gradient, can be represented in this refined model.

7.3 Recommendations

The refined model should be applied to alternative conceptual representations of the large hydraulic gradient.

7.4 Restrictions for Use of Information

There are no restrictions on the use of the information contained in this report.

8.0 INPUTS AND REFERENCES

Faunt, C., 2000, Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, December 2000, ANL-NBS-HS-000034, REV 00, ICN 01.

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Zyvoloski, G.A., 2004a, Site-Scale Saturated Zone Model, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, January 2004, MDL-NBS-HS-000011, Rev 01.

Zyvoloski, G.A., 2004b, Calibration of the Site-scale Saturated Zone Model, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, January 2004, MDL-NBS-HS-000011, Rev 01.

9.0 SOFTWARE

The groundwater code FEHM V 2.20 LANL (2003) [161725] STN: 10086-2.20-00, operated on a Dell Precision 650 under LINUX Red Hat was used for the refined model. The code was obtained from the Bechtel-SAIC Company according to QA requirements and installed and validated by running all of the test cases.