U.S NUCLEAR REGULATORY COMMISSION
DIVISION OF WASTE MANAGEMENT

SALT CONCEPTUAL MODEL UPDATE

Salt Repository Project
Subtask 3.4

Prepared by

Daniel B. Stephens and Associates

for

Nuclear Waste Consultants

TECHNICAL ASSISTANCE IN HYDROGEOLOGY
PROJECT B - ANALYSIS
RS-NMS-85-009

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DANIEL B. STEPHENS & ASSOCIATES, INC.
CONSULTANTS IN GROUND-WATER HYDROLOGY

• GROUND-WATER CONTAMINATION • UNSATURATED ZONE INVESTIGATIONS • WATER SUPPLY DEVELOPMENT •

JUN 01 1987

May 27, 1987

Mr. Mark Logsdon
Project Manager
Nuclear Waste Consultants, Inc.
8341 S. Sangre de Cristo Rd
Littleton, CO 80127

Re: Conceptual Model Evaluation Update Report, Subtask 3.4

Dear Mark:

The attached document serves as the update report for Subtask 3.4, Conceptual Model Evaluation. The report describes and comments on issues raised in the initial Conceptual Model Evaluation Report which have subsequently been or are currently being numerically evaluated. Recommendations for additional work to reduce uncertainty in flow system conceptualization and assess data needs are also presented.

Please do not hesitate to call if you should have any questions regarding this report.

Very truly yours,

Daniel B. Stephens & Associates, Inc.

Jeffrie D. Minier

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Project Manager

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Enclosure

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CONCEPTUAL MODEL EVALUATION UPDATE REPORT

DEAF SMITH COUNTY SITE, PALO DURO BASIN

Prepared For

Nuclear Waste Consultants, Inc.
And
U.S. Nuclear Regulatory Commission

Subtask 3.4

Technical Assistance In Hydrogeology
Project B - Analysis
RS-NMS-85-009

May, 1987

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INTRODUCTION

The initial Conceptual Model Evaluation Report (Stephens & Associates, 1986a) described and compared several conceptualizations of the Palo Duro Basin flow system. Most conceptual models identify three hydrostratigraphic units (HSU) in the Palo Duro Basin: 1) the shallow fresh-water aquifer (HSU-A), 2) the Permian evaporite aquitard (HSU-B), and 3) the deep-basin brine aquifer (HSU-C). A brief description of a general conceptual model for the Palo Duro Basin has been presented in the first Subtask 3.4 Update Report (Stephens & Associates, 1986b). The initial Subtask 3.4 Report (Stephens & Associates, 1986a) also identified areas of uncertainty in existing conceptual models. Data needs and work plans for numerical evaluation of the conceptual models were also discussed in the initial report.

This subtask 3.4 Update Report will review progress to date in evaluating conceptual model issues. Numerical analyses which have been completed or are currently in progress are briefly discussed. The report concludes with recommendations for additional work which should reduce uncertainty in flow system conceptualization and assess data needs.

PROGRESS IN EVALUATING CONCEPTUAL MODEL ISSUES

Fifteen areas of uncertainty concerning data needs and conceptualization were identified and discussed in the initial Subtask 3.4 report (Stephens & Associates, 1986a):

1. Fluid Density Effects
2. Thermal Effects
3. Unsaturated Flow in the Evaporite Aquitard
4. Areal Extent of Conceptual Model
5. Spatial Variability and Scale
6. Anisotropy
7. Ogallala and Dockum Interconnection
8. Evaporite-Aquitard Permeability
9. Fracture and Matrix Interaction
10. Choice of Boundary Conditions
11. Caprock Retreat
12. Inundation of Interior Basins
13. Ground-water Discharge
14. Local Head Anomalies
15. Hydrochemical Responses

While many of these areas of uncertainty may be addressed with relatively simple computational analyses, evaluation of some of the areas will require numerical simulation (for example, 5. Spatial Variability and Scale). Furthermore, because of the heterogeneous nature of the Palo Duro Basin, numerical evaluations which apply analytical solutions to a highly simplified flow system often result in ambiguous results. Therefore, many of the recommended work plans incorporate numerical codes which can simulate heterogeneous systems.

Several completed technical reports have been discussed in the previous Subtask 3.4 Update Report (Stephens & Associates, 1986b) and thus will not be addressed in this report. Those technical reports (Stephens & Associates, 1986c) evaluate the following topics:

1. Unsaturated Flow in HSU B
2. Vertical Permeability in HSU B
3. Horizontal Permeability in HSU B
4. Horizontal Permeability in HSU C
5. Natural Geothermal Convection

Technical reports which have been completed since the previous Subtask 3.4 Update Report are now presented.

Induced Thermal Convection-Plume Type

Radioactive waste stored in the repository will generate heat during decay processes. Thermal expansion and the accompanying density decrease of water near the repository may result in a thermal plume of ascending ground water. The objective of this analysis is to determine whether the thermal plume could possibly be a significant mechanism for transporting waste to the accessible environment. This change in the local flow system near the repository has been investigated using a simplified, analytical solution (Turcotte and Schubert, 1982).

Results of the analyses performed by Stephens & Associates (1987a) suggest that specific discharges due to the thermal plume occurring in very permeable materials (for example, karst limestone or fractured rock) may be on the order of 1 m/y. These results suggest that significant specific discharges associated with a thermal plume may also occur in the Permian aquitard. Because of the simplifying assumptions required to obtain the analytical solution, the results for low permeable materials are of limited usefulness. Therefore, an additional analysis (discussed below) for two-dimensional cellular convection (resulting from radiogenic heating of the repository) has been pursued.

Induced Thermal Convection - Cellular Type

Ground-water convection cells (Donaldson, 1962), which will include upward flow paths, may be generated in saturated sediments between the repository and the ground surface if the repository temperature exceeds some critical value. At the critical temperature bouyancy forces (due to thermal expansion of water) overcome the viscous resistance to flow of the ground water. Because the greatest expected permeability for HSU B is less than 10 md (DOE, 1986), the minimum repository temperature required for convection is estimated to be greater than 1000°C. Therefore, because the expected repository temperature is less than 250°C (DOE, 1986), thermal ground-water convection is not likely to be induced (Stephens & Associates, in preparation).

Molecular Diffusion

The migration of radionuclides by molecular diffusion is limited to relatively short distances and therefore is generally not considered to be a significant transport mechanism. However, the presence of permeable interbeds above or below the repository with horizontal hydraulic gradients may promote radionuclide transport through a combination of vertical molecular diffusion and lateral advection. The flux of radionuclides into the interbed will be proportional to the concentration gradient at the contact between the host horizon and the interbed.

A simple analytical solution for molecular diffusion (Stephens & Associates, 1987a) has been used to estimate the radionuclide concentration gradient. The results of our analysis suggest that significant concentration gradients may develop several meters from the repository but require relatively long time periods to do so. Molecular diffusion will not be an important radionuclide transport mechanism unless a permeable interbed is located within a few meters of the repository.

Aquitard Diffusion

Horizontal hydraulic gradients have been observed in HSU B (for example Dutton, 1983). Permeable interbeds adjacent to or intersecting the repository may provide an important radionuclide transport pathway. A previous analysis considered molecular diffusion of radionuclides from the repository to a nearby, permeable zone where the radionuclides could then be transported to the accessible environment by lateral advection (Stephens & Associates, 1987a). This analysis examines the effect of aquitard diffusion on radionuclide concentrations and transport during lateral advection. Diffusion of radionuclides into the bounding aquitard during horizontal transport should decrease the amount of radionuclides being transported through the interbed. The analytical solution (Sudicky and Frind, 1981) used in this analysis predicts radionuclide concentrations in the interbed and accounts for radionuclide losses due to diffusion into the bounding aquitard and radioactive decay. The combined effects of aquitard diffusion and radioactive decay cause the concentration of many, but not all, of the radionuclides in the interbed to be significantly reduced at a distance of a few kilometers down gradient from the repository (Stephens & Associates, in preparation).

CONCEPTUAL MODEL ASSESSMENTS IN PROGRESS

Ponding in Wolfcamp Recharge Area

The significance of ponding in the recharge area on the lateral hydraulic gradient in the Wolfcamp aquifer is currently being investigated. Geologic evidence indicates that basins in the outcrop area for the Permian section in New Mexico were previously occupied by lakes in geologically recent times (Bachhuber, 1982). The effect of ponding in the recharge area on ground-water travel time and flux near the repository is being estimated by Stephens & Associates (in preparation).

Numerical Simulation of Unsaturated Flow

Results of a previous technical report (Stephens & Associates, 1986c) suggest that unsaturated conditions may exist within the Permian aquitard. A numerical model incorporating detailed hydrostratigraphic data may identify the most probable units where unsaturated flow could occur. The implications of unsaturated flow on existing conceptual models of the hydrogeologic system may be significant in terms of likely ground-water flow paths, travel time, and flux. A numerical analysis of unsaturated flow has been initiated by Stephens & Associates. Additional effort to complete this task will continue pending approval by the NRC staff.

Noble Gas Isotopes

Data for the concentrations and isotope ratios of noble gases for the deep-basin brines and aquifer rocks may be interpreted to obtain residence times and flow paths of ground water in the Palo Duro Basin (Zaikowski and others, 1987). Because they are independent of hydrodynamic data, interpretations based on geochemical data can have significant potential to reduce uncertainty in flow system conceptulization.

Characteristic Permeability

The statistical distribution of permeability data may be used to estimate confidence intervals for HSU B and HSU C. Confidence intervals should indicate a likely range of permeability, at a given probability level, which will be representative of the hydrostratigraphic unit. Statistical tests may be used to estimate from the current data the probability that the mean permeability of the hydrostratigraphic unit will be greater than a given value (Dixon and Massey, 1983). The results of these analyses may then be combined with Darcy's Law to estimate uncertainty in ground-water travel time predictions.

Vertical Fracture Zones

Geologic data suggest that vertical fracture zones may act as preferred pathways for ground-water movement and accelerated salt dissolution in some areas of the Palo Duro Basin (Gustavson and Budnik, 1985). A numerical simulation to investigate the effect of a fracture zone on fluid flow and radionuclide transport is being pursued (Stephens & Associates, in preparation).

Parameter Estimation Analysis

A flow-net analysis is being applied to existing potentiometric surface maps to determine the relative magnitudes of transmissivity along stream tubes (Hunt, 1976). The results of this analysis may be used to estimate spatial variations in permeability and thus may also provide useful information for ground-water travel time calculations and uncertainty estimates. It is expected that variations in transmissivity along a stream tube will reflect first-order facies changes across the basin.

RECOMMENDATIONS

Under the current contract, conceptual model evaluation shall include discussion of areas of uncertainty and additional data needs. The contract also requires that the need for alternate conceptual models be determined. In order to fulfill these requirements, Stephens & Associates recommend that a hydrochemical conceptualization of the Palo Duro Basin flow system and a stochastic analysis of uncertainty be pursued. Work plans for these topics, briefly discussed below, have been submitted for NRC staff approval (Task Descriptive Summaries, Stephens & Associates, 1987b).

Hydrochemical Conceptualization

A three phase hydrochemical conceptualization of the Palo Duro Basin flow system has been recommended (Stephens & Associates, 1987b, 1987c). The first phase (Phase I) of this task will identify hydrochemical methods for reducing uncertainty in the conceptual model of the Palo Duro Basin flow system. Phase II of this task will consist of hydrochemical technical analyses and reports which have been recommended in the Phase I letter report. Ths Phase III report will summarize and integrate the results of the Phase II technical reports and make a final assessment of hydrochemical data needs.

Uncertainty Analysis

A three phase task has been proposed to analyze uncertainty in prediction of ground-water travel path and travel time (Yeh and Stephens & Associates, 1986; Stephens & Associates, 1987b). The objectives of the three phases are:

I. To evaluate the importance of using a stochastic approach to characterize the uncertainty in the prediction of ground-water travel time and radionuclide flux.

II. To assess the ability of using deterministic simulations to address the uncertainties in predicting ground-water travel time.

III. To investigate the relevance of using a stochastic approach to address uncertainties in predicting ground-water travel time and radionuclide transport.

This task will compare deterministic and stochastic methods of analysis of ground-water flow and solute transport. An introduction to the stochastic method will also be included. Discussion of the results will focus on which parameters should be measured, where parameters should be measured, over what scale parameters should be determined and the data density that is needed to adequately characterize the uncertainties in predictions of ground-water travel and radionuclide flux.

Additional Topics

Additional topics which have previously been identified as subjects of future technical reports include the following (Stephens & Associates, 1986a):

1. There is considerable variability in the concentration of total dissolved solids (TDS) in the ground water of the Palo Duro Basin (DOE, 1986). Fluid density effects due to spatial variation of TDS concentration may affect ground-water circulation between the deep and shallow aquifers. A variable density numerical model may be used to investigate the effect of variable density on ground-water flow paths and travel time.

2. Predictions of ground-water travel time and flow paths are often obtained from numerical models of the flow system. The predicted travel time will depend to some extent on the location and nature of the boundary conditions specified for the numerical model. The importance of the choice of the nature and location of model boundaries on the resultant flow field could be addressed with sensitivity studies.

3. Recent structural deformation in the Palo Duro Basin is related to salt dissolution. Reeves and Temple (1986) suggest that breccia pipes resulting from salt dissolution may locally provide zones of recharge.

They concluded that point-source dissolution of salt beds may adversely affect the ability of the repository to isolate waste. Performance assessment calculations regarding salt dissolution should be calculated on the point-source dissolution areas near the proposed repository location rather than on the more distant salt dissolution fronts on the periphery of the basin.

4. Anomalous hydraulic head data have been culled in order to obtain smooth potentiometric surface maps. The anomalous data are generally assumed to reflect poor quality drill stem tests or hydrocarbon production. However, anomalously high head values may also result from local hydrodynamic or hydrochemical processes (for example fractures or osmotic-pressure effects). Relatively simple models may be used to identify the likelihood that anomalous head data are due to local hydrologic processes. The significance of the anomalous head data on ground-water travel time predictions can also be investigated.

5. Many conceptual models of the Palo Duro Basin flow system consider that the Ogallala and Dockum aquifers are hydraulically interconnected. However, other studies suggest that recharge to the Dockum from the Ogallala may be negligible (Dutton and Simpkins,

1985). The degree of interconnection strongly influences flux through the Permian aquitard and thus will affect ground-water travel time and flow paths. Evaluations of the degree of interconnection may yield important implications for ground-water flow paths and chemical data.

SUMMARY

In order to evaluate conceptual models of the Palo Duro Basin flow system, Stephens & Associates (1987a; in preparation) have performed several numerical analyses. Two recently completed analyses have investigated thermal convection of ground water induced by radiogenic heating of the waste repository. Because the expected repository temperature and HSU B permeability are both relatively low values, induced thermal ground-water convection is not likely to occur. Two additional recently completed analyses examined the significance of molecular diffusion on radionuclide transport. The first diffusion analysis considered molecular diffusion of radionuclides from the repository to a nearby zone of advective transport. This transport mechanism will be significant only if the zone of advective transport is located within a few meters of the repository. Because of the relatively slow movement by diffusion, migration of radionuclides to greater distances requires relatively long time periods. The second diffusion analysis estimated the amount of radionuclides which diffuse into the bounding aquitard during horizontal advection through a relatively permeable HSU B interbed. The amounts of some, but not all, radionuclides being advected through the permeable interbed are significantly reduced by diffusive losses to the aquitard.

Evaluation of the Palo Duro Basin flow system continues with several numerical analyses currently in progress at Stephens & Associates. Areas currently being investigated include ponding in the recharge area of the Wolfcamp aquifer, numerical simulation of unsaturated flow in HSU B, use of noble gas isotope data to obtain residence times and flow paths of ground water, statistical consideration of characteristic permeability of HSU B and HSU C, the effect of vertical fracture zones on fluid flow and radionuclide transport, and a flow-net analysis applied to existing potentiometric surface data.

Stephens & Associates recommend several additional topics to be investigated. Perhaps the two most important recommendations are:

1. The development of a hydrochemical conceptualization of the Palo Duro Basin flow system to complement the hydrodynamic models and reduce uncertainty in flow system conceptualization.
2. A stochastic uncertainty analysis
    - i) to address uncertainty in ground-water travel time/travel path predictions
    - ii) to assess data needs for site characterization.

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