4. SUMMARY AND CONCLUSIONS

This technical basis document presents technical data, related analyses, and models that form the conceptual basis for the understanding of saturated zone flow and transport processes relevant to the postclosure performance of the Yucca Mountain repository. The various data sets (including geologic, hydrogeologic, and geochemical data) assist in constraining the groundwater flow directions and rates between Yucca Mountain and the accessible environment. Field and laboratory data related to radionuclide transport have been used to constrain the advective transport times between the repository and the accessible environment for nonsorbing and sorbing radionuclides. Nonsorbing advective transport times and velocities have been corroborated using naturally occurring ^{14}C tracers. In situ field transport tests using surrogates to radionuclides and colloids of importance to repository performance have been used to build confidence in the radionuclide transport conceptual models and to develop transport properties for use in evaluating the performance of the saturated zone barrier. Finally, laboratory tests of the sorption behavior of radionuclides of importance to performance have been conducted to develop the sorption characteristics of these radionuclides in the saturated zone.

The saturated zone flow and transport processes described in this technical basis document are represented by different conceptual and numerical models that are used to predict the expected behavior of the saturated zone barrier as it relates to the performance of the Yucca Mountain repository system. These include models of groundwater flow at the regional and site scales, plus models of radionuclide transport. The models were constructed using parameter values generated using in situ field observations, field tests, laboratory tests, expert elicitation, and the literature. The parameters that most affect the predicted performance of the saturated zone barrier are:

- Hydraulic gradient
- Hydraulic conductivity
- Recharge and discharge
- Specific discharge
- Flowing interval spacing
- Flow path length in fractured tuff and alluvium
- Effective porosity of fractured tuff and porous alluvium
- Dispersivity
- Effective mass transfer
- Sorption.

Uncertainty in these parameters has been considered in the development of the uncertainty in the radionuclide transport travel times from the base of the unsaturated zone to the point of compliance.

All of the information presented here was used to develop the conceptual basis of the behavior of the saturated zone barrier. In each aspect important to postclosure repository performance, uncertainty in the flow and transport properties has been considered. This uncertainty is reflected in the projection of the performance of the saturated zone flow and transport barrier. It reflects data and parameter uncertainty as well as uncertainty in the conceptual representation.

This uncertainty results in a wide range of possible advective transport times for all of the important radionuclides potentially affecting repository performance.

The following sections summarize the understanding of the saturated zone and the relevance of this understanding to repository performance.

4.1 SUMMARY OF SATURATED ZONE FLOW PROCESSES AND RELEVANCE TO REPOSITORY PERFORMANCE

Saturated zone flow processes control the direction and rate of groundwater flow. The groundwater flow direction determines the location where radionuclides released from the repository may be intercepted by a hypothetical well located along the compliance boundary. In addition, between the point where radionuclides enter the saturated zone (generally beneath the repository) and the point where saturated zone water is extracted by the hypothetical well, the hydrogeologic units and geochemical environments along the flow path affect flow and transport characteristics. The rate of groundwater flow (the advective flux through the saturated zone) affects the transport velocity when flow porosity is considered.

The groundwater flow direction from Yucca Mountain downgradient to the point of compliance has been determined based on observations of hydraulic head and hydraulic conductivity near Yucca Mountain. Although the observed hydraulic head gradient directly beneath Yucca Mountain is small, heads upgradient and downgradient from the repository have been used to infer a generally south-easterly groundwater flow direction beneath Yucca Mountain and a generally southerly flow direction in the vicinity of Fortymile Wash. Although a range of flow directions was developed to accommodate uncertainty in the horizontal anisotropy of the tuff aquifers, these flow directions all tend to parallel the orientation of Fortymile Wash.

Groundwater flow directions near Yucca Mountain are consistent with the general flow directions of the regional groundwater flow system (Section 2.2). This regional understanding includes the most important hydrogeologic units that affect flow directions, as well as bounding the overall flow rates (by comparing groundwater recharge and discharge to the water budget in the Death Valley region). This regional understanding has been used to determine the natural recharge and discharge areas and the amounts of groundwater in the basin.

Groundwater flow directions near Yucca Mountain also are consistent with flow directions inferred from geochemical and isotopic signatures (Section 2.2.4). The use of these signatures can be valuable for evaluating alternative hypotheses of flow directions because such geochemical samples generally integrate over a larger spatial and temporal scale than do discrete head or hydraulic conductivity measurements. While geochemical (as represented by chloride and sulfate observations) and isotopic (as represented by δD, ^{14}C, and $^{234}U/^{238}U$ activity ratios) trends support the southerly direction of groundwater flow near Yucca Mountain, local geologic and hydrogeologic heterogeneity affects the detailed interpretation of different mixing zones at any particular borehole.

An important consideration in understanding the saturated zone flow system is the relationship between flow in the fractured tuff aquifers immediately beneath and downgradient from Yucca Mountain, and the alluvial aquifer from which groundwater discharges in the Amargosa Valley.

The location of the tuff-alluvium contact has been a focus of the Nye County Early Warning Drilling Program. Although uncertainty exists in the exact location of the contact, the results of these investigations better constrain the location, and the remaining uncertainty has been incorporated in the saturated zone transport model.

Information on geology, hydrogeology, recharge-discharge relationships, and hydrochemistry have been used to develop integrated models of the saturated zone flow system near Yucca Mountain. These models exist at the regional and site scales. Uncertainty in hydrogeologic properties and boundary conditions have been addressed in these models. The site-scale saturated zone flow model (Section 2.3.7) has been used to project a range of possible flow paths and flow rates from the repository to the accessible environment for use in assessing the performance of the saturated zone barrier in postclosure performance assessment. The results of this model (e.g., flow rates and the fraction of the flow path length in the alluvium) have been used as input to the assessment of radionuclide transport in the saturated zone.

4.2 SUMMARY OF SATURATED ZONE TRANSPORT PROCESSES AND RELEVANCE TO REPOSITORY PERFORMANCE

After the groundwater flow fields have been defined, assessment of the radionuclide transport processes within the flow fields can be quantified. Laboratory and in situ field tests have been performed to develop transport-related parameters that support the development of the transport model.

Saturated zone transport processes affect how fast dissolved or colloidal species are transported with the flowing groundwater. Transport is affected by the velocity of the flowing groundwater within the fractured or porous geologic media and the interactions of any dissolved or colloidal species with this media, either by matrix diffusion or various retardation mechanisms.

The velocity of the flowing groundwater is a function of the specific discharge derived from the understanding of the groundwater flow system and the effective porosity of the zones through which the water flows. Water flow through the fractured tuff aquifers is generally confined to isolated fracture intervals, while flow in the alluvial aquifer is dispersed through the porous material. Cross-hole tracer tests conducted in fractured tuff aquifers at the C-Wells complex have investigated the effective porosity of the fractured tuffs at the scale of 10s of meters. Single-hole tracer tests conducted in the alluvium at the Alluvial Tracer Complex have investigated effective porosity at the scale of a few meters. Given the paucity of direct in situ observations of effective porosity at the scale of interest to repository performance, a wide range of uncertainty has been applied to this property. This uncertainty is summarized in Section 3.2.1 and 3.2.2.

Although there is no direct observation of groundwater velocity, radioisotopes can be used to infer a range of possible advective velocities. ^{14}C ages and age differences have been used to support the groundwater velocities developed from specific discharge and effective porosity information. Both lines of evidence (Section 3.2.3) indicate that the possible range of advective velocities of unretarded species is between about 2 and 40 m/year.

Dissolved radionuclides may diffuse into the matrix of fractured media (or into stagnant pore spaces of porous alluvium), causing a delay in transport times from that determined solely from advective transport. Matrix diffusion processes have been observed in tracer testing at the C-Wells complex and appropriate parameters for combined advective-diffusive transport have been developed based on these tests. The effect of matrix diffusion in delaying radionuclide transport is a function of the spacing between the fractures that contain the flowing groundwater. The flowing interval spacing, which has been developed based on observations in the C-Wells complex and in other tuff aquifers, is at the conservative end of the distribution of possible matrix diffusion effects.

Dissolved radionuclides that are transported with the groundwater have differing sorption affinities for the mineral surfaces with which they come into contact. These differences are a function of rock type, mineral assemblages within the different rocks and alluvium, groundwater chemistry, and radionuclides. A number of laboratory tests have been conducted to evaluate the range of possible sorption coefficients. The results of these tests are summarized in Section 3.3. Some radionuclides important to repository performance are not sorbed (e.g., technetium and iodine), some are moderately sorbed (e.g., neptunium and uranium), and others are largely sorbed (e.g., americium, plutonium, and cesium) on the geologic media of the saturated zone.

A saturated-zone transport model has been developed to integrate the effects of flow and transport processes relevant to repository performance. This model incorporates uncertainty in the processes and parameters describing these processes into an assessment of the overall behavior of the saturated zone barrier. The uncertainties included in this representation include specific discharge, flow path length in the tuff and alluvium, effective porosity of the tuff and alluvial aquifers, flowing interval spacing of the alluvial aquifer, matrix diffusion, and sorption coefficients for different radionuclides.

Incorporating this uncertainty in the performance assessment yields a range of breakthrough curves for different radionuclides being transported from the point they enter the saturated zone under Yucca Mountain to the point they are extracted in the hypothetical well located at the compliance point about 18 km south of Yucca Mountain. The range of breakthrough times for nonsorbing radionuclides (e.g., carbon, technetium and iodine) are between 10s of years and 10s of thousands of years, with a median time of about 700 years. For moderately sorbing radionuclides, exemplified by neptunium, the range of breakthrough times is between several hundred years to over 100,000 years, with a median time of about 20,000 years. For highly sorbing radionuclides, (e.g., plutonium), the range of breakthrough times is between several thousand years and over 100,000 years, with a median time in excess of 100,000 years.

Saturated-zone performance is portrayed in light of its role as a barrier to radionuclide transport in that it delays the arrival of radionuclides at the point of compliance where the reasonably maximally exposed individual extracts water from a hypothetical well. The barrier delays the arrival of radionuclides and reduces the concentration of radionuclides through dilution and decay that may be withdrawn from the well. For postclosure performance, the concentration is the average concentration based on an annual water demand of 3.7 million m^3 (3,000 acre-feet). The details associated with determining the concentration of radionuclides in the aquifer is not required because the annual water demand exceeds the average volumetric flow rate in the

portion of the aquifer containing radionuclides. Therefore, the barrier performance may be represented as a mass breakthrough or activity breakthrough rather than a concentration.

4.3 CONCLUDING REMARKS

Hydrogeologic investigations undertaken near Yucca Mountain over the last several decades have resulted in a broad understanding of the geology, hydrogeology, and geochemistry of the saturated zone beneath and around Yucca Mountain. The data and interpretations from these investigations have been published in documents prepared by scientific staff at Los Alamos National Laboratory and Sandia National Laboratories, Open File Reports and related monographs by the staff of the USGS, and other peer reviewed publications. The data, analyses, and models developed by DOE contractors to support this technical basis document have been collected and reviewed in accordance with Quality Assurance requirements applicable at the time they were generated. The most important references describing the performance of the saturated zone barrier have been cited here. Other documents present details of specific aspects of the saturated zone, and these generally are cited in the references that support this document.

This document is a summary and synthesis of the data, analyses, and models used to evaluate the performance of the saturated zone barrier at Yucca Mountain. This barrier is important because it affects the arrival time of radionuclides at the receptor location (about 18 km south of Yucca Mountain) that potentially may be released from the Yucca Mountain repository. Uncertainty in the performance of the saturated zone barrier is included in the results, which will be used as input to the total system performance assessment. The importance of this uncertainty, from the perspective of total risk (i.e., dose) to the reasonably maximally exposed individual, will be evaluated as part of the sensitivity analyses performed after the postclosure total system performance model is complete and validated.

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5.2 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

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MO0105HCONEPOR.000. Hydraulic Conductivity and Effective Porosity for the Basin and Range Province, Southwestern United States. Submittal date: 05/02/2001.

MO0203GSC02034.000. As-Built Survey of Nye County Early Warning Drilling Program (EWDP) Phase III Boreholes NC-EWDP-10S, NC-EWDP-18P, AND NC-EWDP-22S - Partial Phase III List. Submittal date: 03/21/2002.

MO0206GSC02074.000. As-Built Survey of Nye County Early Warning Drilling Program (EWDP) Phase III Boreholes, Second Set. Submittal date: 06/03/2002

APPENDIX A

THE HYDROGEOLOGIC FRAMEWORK MODEL/ GEOLOGIC FRAMEWORK MODEL INTERFACE (RESPONSE TO USFIC 5.10)

Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design bases at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application (LA) as the approved analyses of record at the time of LA submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the LA.

APPENDIX A

THE HYDROGEOLOGIC FRAMEWORK MODEL/ GEOLOGIC FRAMEWORK MODEL INTERFACE (RESPONSE TO USFIC 5.10)

This appendix provides a response for Key Technical Issue (KTI) Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) agreement USFIC 5.10. This KTI agreement relates to providing more information about the apparent discontinuity between the geologic framework model (GFM) and the site-scale hydrogeologic framework model (HFM).

A.1 KEY TECHNICAL ISSUE AGREEMENT

A.1.1 USFIC 5.10

KTI agreement USFIC 5.10 was reached during the U.S. Nuclear Regulatory Commission (NRC)/U.S. Department of Energy (DOE) technical exchange and management meeting on unsaturated and saturated flow under isothermal conditions held during October 31 through November 2, 2000 in Albuquerque, New Mexico (Reamer and Williams 2000). The saturated zone portion of KTI subissues 5 and 6 was discussed at the meeting. During the meeting, the DOE presentation included a discussion of the site-scale HFM, which provides the fundamental geometric framework for developing a site-scale three-dimensional groundwater flow and transport model. The DOE stated the framework provides a basis for the mathematical model, which incorporates site-specific subsurface information and will continue to be updated. The regional HFM is also being revised by the U.S. Geological Survey.

The NRC expressed concerns about the site-scale HFM report (USGS 2000) regarding the boundary between the GFM and areas to the south that present problems in correlating geologic units in faults and maintaining unit thickness. The DOE stated that the HFM is being updated to include new data.

Wording of the agreement is:

USFIC 5.10

> Provide, in updated documentation of the HFM that the noted discontinuity at the interface between the GFM and the HFM does not impact the evaluation of repository performance. DOE will evaluate the impact of the discontinuity between the Geologic Framework Model and the Hydrogeologic Framework Model on the assessment of repository performance and will provide the results in an update to the Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model Analysis and Model Report during FY 2002.

A.1.2 Related Key Technical Issue Agreements

Agreements USFIC 5.05 and Radionuclide Transport (RT) 2.09 (both delivered in FY02) presented the revised geologic cross-sections, including new Nye County borehole data, and

presented a discussion of the correlation between the geostratigraphy and hydrostratigraphy. The response to the additional information needed for USFIC 5.05 and RT 2.09 is presented in Appendix B.

A.2 RELEVANCE TO REPOSITORY PERFORMANCE

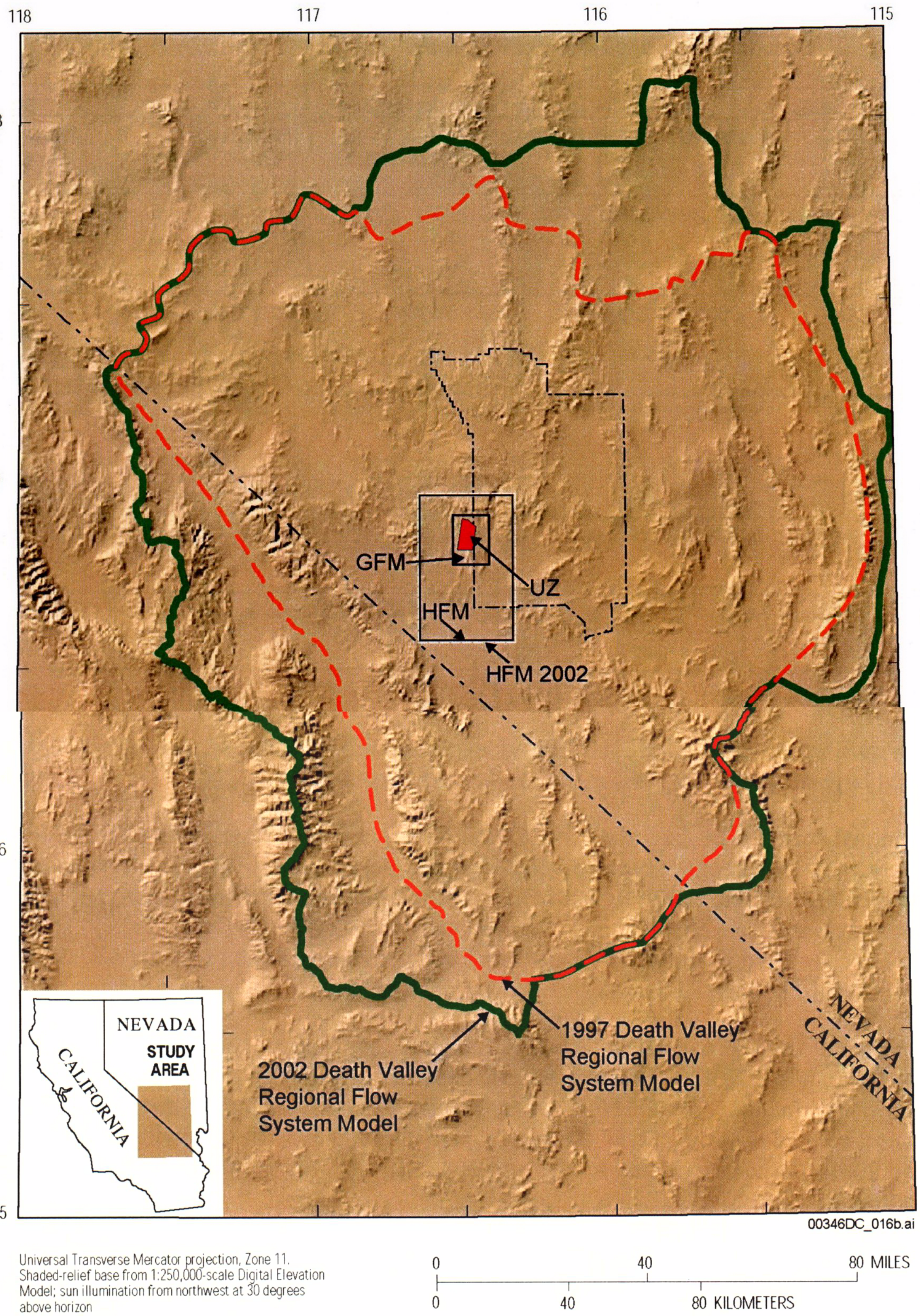
Conceptual representations of hydrogeology at the regional and site scales may differ due to the scale-dependency of the major hydrogeologic features. Although different conceptual representations can characterize subsurface systems at different scales, the boundaries between these conceptual representations should not affect the results at the scale of interest. For the boundary between the GFM (used to develop a detailed geologic profile at the scale of the repository; i.e., several kilometers in the areal plane and several hundred meters in the vertical plane) and the HFM used to develop a hydrostratigraphic profile at the scale of the site (i.e., several tens of kilometers in the areal plane and several kilometers in the vertical plane), the boundary conditions should not affect the predicted flux of groundwater across this boundary. It is conceivable that model discontinuities at the boundary could affect the predicted volume of water flow, and therefore affect predictions of radionuclide transport across the boundary.

Documentation available at the time of the site recommendation indicated the presence of a framework model discontinuity between the detailed GFM model, which was used for unsaturated zone flow and transport, and the coarser site-scale HFM, which was used to evaluate saturated zone flow.

The current hydrogeologic understanding used to assess the flow of groundwater and the transport of radionuclides in the saturated zone beneath and downgradient from Yucca Mountain is described in Section 2.3.4.

A.3 RESPONSE

Since this KTI agreement was made, the site-scale HFM and GFM (Figure A-1) used in the site recommendation have been revised to newer versions, mostly in response to needs of the models they support. The apparent discontinuities have been investigated, and adjustments have been made to the models or to the model documentation in incremental revisions (Table A-1). The HFM will be further updated as new data from Nye County and other sources are collected.



Source: Adapted from D'Agnese et al. (2002), Figure 1.

Figure A-1. Boundaries of Models in Relation to the Nevada Test Site

Table A-1. Geologic Framework Model and Hydrogeologic Framework Model, Model Documentation, and History of Revisions

Model	Scale	Model DTN	Documentation	Revision	Notes
GFM 3.1	Site	MO9901MWDGFM31.000	CRWMS M&O (1999) CRWMS M&O (2000) BSC (2001c)	REV 00 REV 00 ICN 01 REV 00 ICN 02	Used for HFM
GFM 2000	Site	MO0012MWDGFM02.002	BSC (2002)	REV 01	Used for unsaturated zone flow and transport model
HFM	Site	GS000508312332.002	USGS (2000) USGS (2001a) USGS (2001b) USGS (2003)	REV 00 REV 00 ICN 01 REV 00 ICN 02 REV 00 ICN 02, Errata	Used for saturated zone flow and transport model
HFM 2002	Site	GS021008312332.002	None	None	Slightly larger domain and higher-resolution grid than HFM
1997 DVRFS Model	Regional	GS960808312144.003	D'Agnese et al. (1997)	None	Basis for HFM
2002 DVRFS Model	Regional	None	D'Agnese et al. (2002)	None	Basis for HFM 2002

NOTE: DVRFS = Death Valley regional flow system

No new data are expected within the GFM domain, and the DOE has no plans to update or revise the GFM beyond the current version, referred to as GFM 2000 (BSC 2002).

The regional-scale HFM (i.e., the 1997 Death Valley regional flow system (DVRFS) model; D'Agnese et al. 1997) continues to be updated as new data become available. New borehole data have been obtained from the Nye County Early Warning Drilling Program, and other information has been obtained from Inyo County, the National Park Service in Death Valley, and affected Indian Tribes in Inyo County. The new data have been incorporated into the revised regional-scale HFM (the 2002 DVRFS model; D'Agnese et al. 2002).

The original site-scale HFM (USGS 2000) has been updated to HFM 2002 (DTN: GS021008312332.002) using the new data and information described above. However, of the new information, only the Nye County borehole data are within the domain of HFM 2002, and those boreholes were not in the area where the apparent discontinuities were observed (Wilson 2001). Recent updates to the site-scale HFM (USGS 2001b) address the apparent discontinuities.

Because the models that support the License Application are completed and have been accepted by the downstream user (i.e., the total system performance assessment organization) as adequate for the intended use, the DOE does not intend to further update site-scale HFM 2002 until the Nye County drilling program is complete, which is not planned to occur until after the License Application is submitted.

The following excerpt from *Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model* (USGS 2001a) describes the apparent discontinuities in thicknesses of the four units within the site-scale HFM that use the GFM as the principal source of data:

> Within the immediate site area, the site GFM was used as the principal source of subsurface data for the Upper Volcanic Confining Unit and the Prow Pass, Bullfrog, and Tram Tuffs within the Lower Volcanic Aquifer in the HFM. For these units, the GFM is essentially embedded within the HFM. However, because of differences between how data external to the GFM were used to construct the HFM and were used to establish the thicknesses of units along the lateral boundaries of the GFM, the process of embedding the GFM within the HFM introduced some apparently anomalous discontinuities in some unit thicknesses across the GFM model boundaries. These apparent discontinuities are artifacts of differences between the HFM and GFM model grids and the data interpolation and extrapolation methods used in constructing the GFM, and they do not affect the applicability of the HFM in providing a hydrogeologic framework for the site-scale saturated zone flow model.

These apparent discontinuities at the interface of the GFM and HFM do not affect the evaluation of repository performance because:

- Only one of the four units in the HFM (USGS 2001a) identified as having the GFM as the principal source of subsurface data demonstrated the discontinuity, and that discontinuity has been resolved in the current version of the site-scale HFM (DTN: GS021008312332.002).

- The GFM and HFM models are used by different subsystems within performance assessment, and both models have been validated for their intended uses.

- The HFM is used to assign units to each computational grid in the numerical model. Each unit has a range of permeabilities that are used to constrain the model calibration. An examination of the mismatched GFM and HFM units indicated that model-assigned permeabilities were within the range of the permeability of the correct GFM unit.

The information in this report is responsive to agreement USFIC 5.10 made between the DOE and NRC. The report contains the information that DOE considers necessary for the NRC to review for closure of this agreement.

A.4 BASIS FOR THE RESPONSE

A.4.1 Summary of the Issue

In the following sections, the GFM, the site-scale HFM, the process of incorporating GFM data into the site-scale HFM, the apparent discrepancies that resulted from this process, and the effect of the discrepancies on assessments of repository performance are described. A description of the site-scale HFM and its use in the context of the conceptual understanding of the flow of

groundwater and transport of radionuclides in the saturated zone beneath and downgradient from Yucca Mountain is found in Section 2.3.4.

A.4.1.1 Geologic Framework Model

The current version of the GFM is GFM 2000 (BSC 2002). The GFM is a three-dimensional interpretation of the stratigraphy and structural features (i.e., rock layers, rock properties, and mineralogy) in the repository area. The GFM encompasses an area of 168 km^2 and a volume of 771 km^3. The boundaries of the GFM were chosen to encompass exploratory boreholes and to provide a geologic framework over the area of interest for modeling hydrologic flow and radionuclide transport through the unsaturated zone near the repository. The depth of the GFM is the inferred depth of the Tertiary-Paleozoic unconformity. The GFM was constructed from geologic maps and borehole data. Additional information from measured stratigraphic sections, gravity profiles, and seismic profiles was considered. The GFM generally uses a horizontal grid spacing of 61 m; however, the topography is spaced at 30 m. This spacing was determined to be the largest that would adequately represent the input data without unreasonable computation expense.

The GFM provides a baseline representation of the locations and distributions of 50 rock layers and 44 faults in the subsurface of the Yucca Mountain area for use in geologic modeling and repository design. Data from geologic mapping and boreholes provide controls at the ground surface, and data from boreholes provide controls at borehole locations to the depth of the boreholes. The GFM is an interpretative and predictive tool that provides a small-scale representation of the subsurface geology. The GFM portrays the distribution of rock layers that are most important to models related to the total system performance assessment and other analyses that are in close proximity to the repository horizon, the largest of which are in the unsaturated zone model. The site-scale HFM directly uses some units from the GFM model as input.

A.4.1.2 Regional-Scale Hydrogeologic Framework Model

D'Agnese et al. (1997) developed the 1997 DVRFS model, which is a three-layer, three-dimensional, steady-state flow model of the saturated zone for the Death Valley region. This model incorporated large amounts of data collected in the region over the past 30 years, and 10 hydrogeologic units were described. The numerical model grid consisted of 163 rows, 153 columns, and 3 layers. The row and column grid dimension was 1,500 m, and the depth to the bottom of each of the three layers was 500 m, 1,250 m, and 2,750 m, respectively, from the water table surface. The 1997 DVRFS model (D'Agnese et al. 1997) was updated to the 2002 DVRFS model (D'Agnese et al. 2002).

A.4.1.3 Site-Scale Hydrogeologic Framework Model

The site-scale HFM is a simplified three-dimensional interpretation of the hydrostratigraphy and structure in the Yucca Mountain area and is coincident with the domain of the site-scale saturated zone flow and transport model. The HFM was built from geologic maps and sections, borehole data, geophysical data, and existing geologic framework models, and it was constructed specifically for groundwater flow through the saturated zone. The HFM provides a simplified

and generalized geometric foundation for the groundwater flow model and provides a representation of the location and distribution of hydrogeologic units in the saturated zone for use in groundwater flow modeling.

The lower boundary of the site-scale HFM is coincident with the lower boundary of the regional-scale HFM (D'Agnese et al. 1997). This boundary generally is consistent with no vertical flow in or out of the base of the site-scale model domain. A geologic map and cross sections developed for the model domain was the main input to the HFM (DTN: GS991208314221.001). Data from all available boreholes were incorporated during the construction of the HFM; however, lithologic data from Nye County boreholes and boreholes USW SD-6 and USW WT#24 were not available when the model was constructed. The top of the HFM was set to an updated potentiometric surface map (DTN: GS000508312332.001). The HFM uses a horizontal grid spacing of 125 m, which was chosen based on flow modeling requirements. Because of the large grid spacing, the HFM simplifies the available data near the repository by combining and averaging detailed GFM data. The HFM also extrapolates from widely spaced data in poorly constrained areas of the model domain. However, the HFM resolution is at a greater detail than that used for the saturated zone model computational grid, which uses a 500-m vertical resolution.

The HFM is intended for, and restricted to, development of the site-scale saturated zone flow model (SSFM), including the use of hydrogeologic unit definitions in performance assessment parameter development. Preliminary validation of techniques used to construct the model indicate that the HFM agrees with the input data within expected tolerances and is suitable for the intended use (BSC 2001b, Section 6.7.2). The HFM was examined and corrected for geologic inconsistencies; however, the model is not intended for precise geologic unit locations or identification. The HFM provides a simplified and generalized geometric foundation for the groundwater flow model.

A.4.1.4 Incorporation of Geologic Framework Model Data into the Hydrogeologic Framework Model

For the HFM within the immediate repository area, the GFM was the principal source of data for the Upper Volcanic confining unit and the Prow Pass, Bullfrog, and Tram Tuffs within the Lower Volcanic Aquifer. For these units, the GFM essentially is embedded within the HFM.

The HFM, because of its larger size, requires simplification of geostratigraphically identified units into units of hydrologic importance to the saturated zone models (site-scale and regional). The wider spacing of control points results in different model interpretations for some units common to the HFM and GFM.

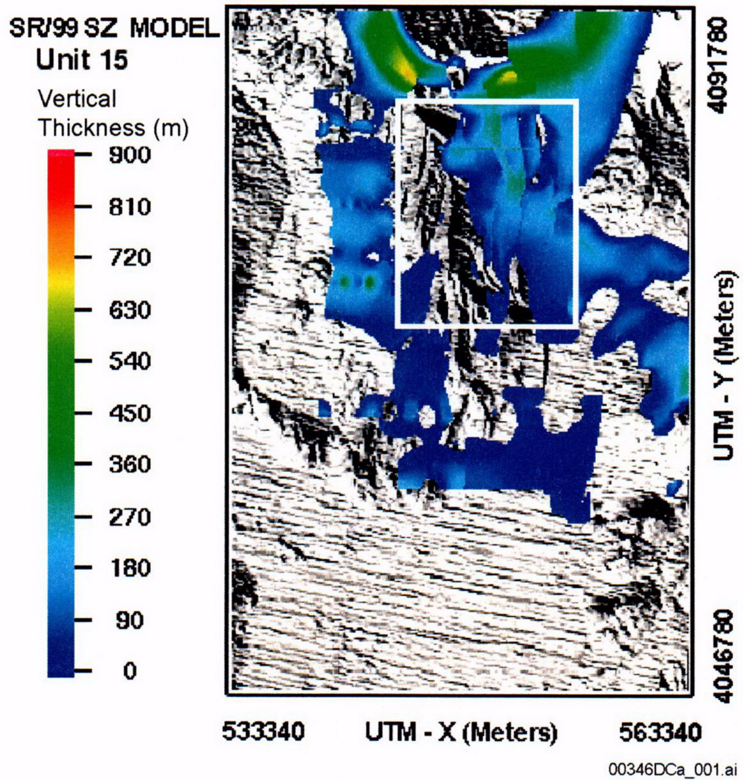
The models show differences in stratigraphic units because they serve different purposes and focus on different stratigraphic units. In addition, because they cover different areas, some assumptions and details that apply to the GFM cannot be incorporated with uniformity into the HFM (where large areas with minimal field data exist). Two examples are the portrayal of faults and the distinction between units that are mineralogically and stratigraphically distinguishable in boreholes, but regionally act as similar hydrogeologic units. The HFM is a representation of the hydrogeologic units and major structural features within the saturated zone flow system

encompassed by the domain of the SSFM. These units are subjected to different stresses and lithofacies changes, and therefore have different hydraulic properties.

In the HFM and GFM borehole databases, differences in the depths of contacts between geologic and hydrogeologic units were identified during data qualification (Wilson 2001, Section 3.4.2.1). Differences exceeding 30 feet, which approximates the minimum vertical nodal spacing in the SSFM, were found for 17 of the hundreds of data points used in constructing the hydrogeologic unit surfaces, and many of these were attributed to changes in stratigraphic unit definitions that occurred after the HFM database was compiled (Wilson 2001, Section 3.4.2.1). The software used to generate the HFM unit surfaces (USGS 2001a, Section 6.3) integrates information from many data points and provides a smoothing that minimizes the effects of discrepancies at individual locations. Wilson (2001) summarized the differences: "Most of the observed differences were minor and would not affect generalized uses of the data. Most of the larger differences were related to either variation in the application of the HFM unit top definitions or were the result of changes in stratigraphic contact definitions."

A.4.2 Discussion of Apparent Discontinuities

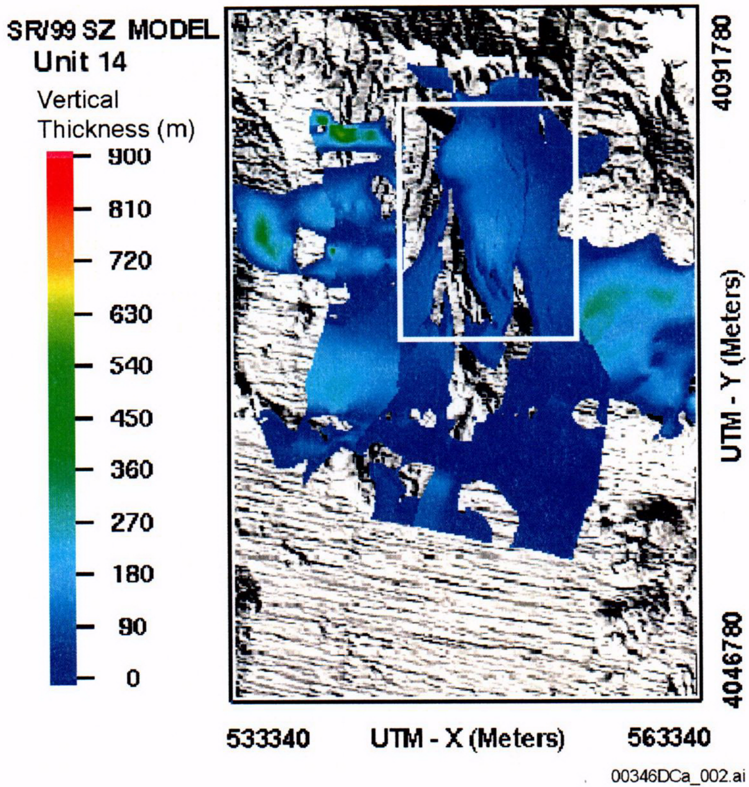
The excerpt from *Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model* (USGS 2001a), presented in Section A.3, describes the apparent discontinuities in thicknesses of the four units within the site-scale HFM that use the GFM as the principal source of data. In the following sections, maps showing vertical thicknesses are used to identify apparent discontinuities in unit thickness that may occur as a result of differences between the GFM and HFM. Discontinuities that result from thickness differences occur near the northwestern boundary of the GFM and are nearly parallel to the boundary of the GFM. In Figures A-2 through A-4, discontinuities are not apparent in the Upper Volcanic confining unit, Prow Pass Unit, or the Bullfrog Unit. However, the Tram Tuff shows a large discontinuity as a result of a thickness difference (Figure A-5).



Source: DTN: LA0304TM831231.001.

NOTE: The white rectangular box shows the GFM area, while the remainder of the figure shows the domain of the site-scale HFM. The shaded relief map used for the background, shows where the hydrogeologic unit is pinched out to zero thickness by other units or is truncated by the water table surface (white area in northeast corner). "SR/99 SZ Model" refers to the site-scale HFM (USGS 2001a).

Figure A-2. Vertical Thickness of the Upper Volcanic Unit in the HFM

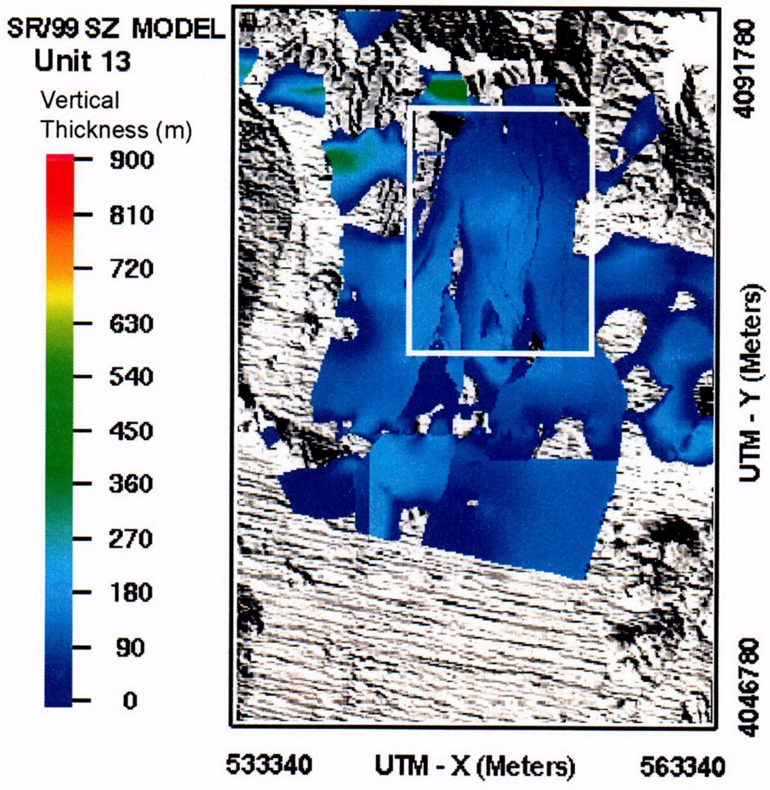


Source: DTN: LA0304TM831231.001.

NOTE: The white rectangular box shows the GFM area, while the remainder of the figure shows the domain of the site-scale HFM. The shaded relief map used for the background, shows where the hydrogeologic unit is pinched out to zero thickness by other units or is truncated by the water table surface (white area in northeast corner). "SR/99 SZ Model" refers to the site-scale HFM (USGS 2001a).

Figure A-3. Vertical Thickness of the Prow Pass Unit in the HFM

C03

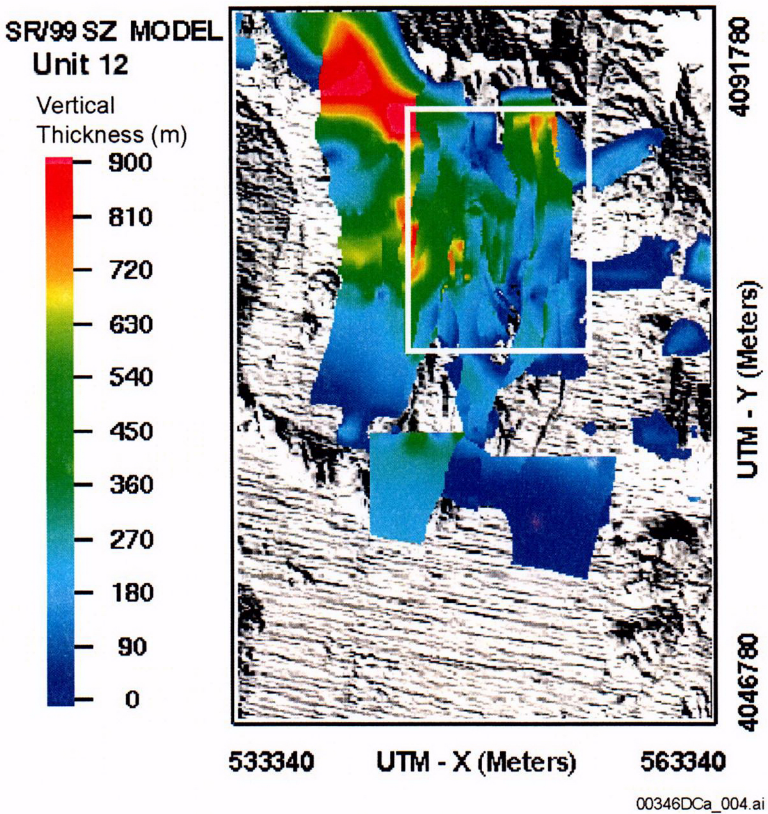


Source: DTN: LA0304TM831231.001.

NOTE The white rectangular box shows the GFM area, while the remainder of the figure shows the domain of the site-scale HFM. The shaded relief map used for the background, shows where the hydrogeologic unit is pinched out to zero thickness by other units or is truncated by the water table surface (white area in northeast corner). "SR/99 SZ Model" refers to the site-scale HFM (USGS 2001a).

Figure A-4. Vertical Thickness of the Bullfrog Unit in the HFM

C04



Source: DTN: LA0304TM831231.001.

NOTE: The white rectangular box shows the GFM area, while the remainder of the figure shows the domain of the site-scale HFM. The shaded relief map used for the background, shows where the hydrogeologic unit is pinched out to zero thickness by other units or is truncated by the water table surface (white area in northeast corner). "SR/99 SZ Model" refers to the site-scale HFM (USGS 2001a).

Figure A-5. Vertical Thickness of the Tram Unit in the HFM

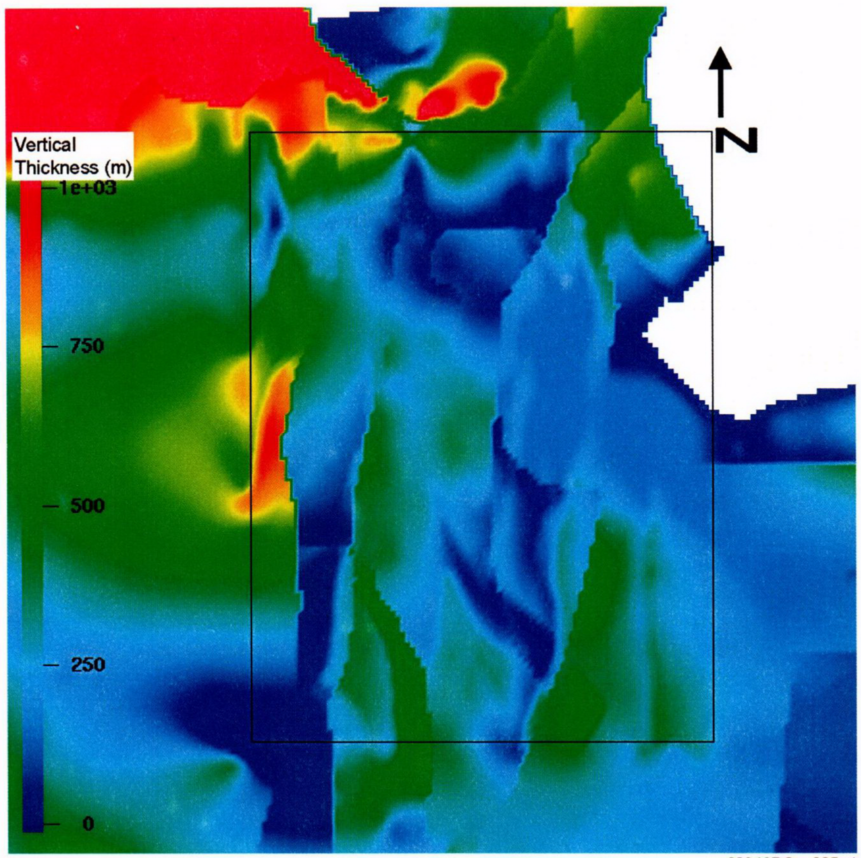
In the Tram Tuff, a large discontinuity was identified in the northwest corner of the GFM area. In this area, the Tram Tuff pinches out to zero thickness in the GFM, but it becomes thicker in the HFM. This can be seen in Figure A-5 as an abrupt change in color (straight, north-south line in northwest corner and intersecting the upper horizontal portion of the white box signifying the GFM area) where the HFM shows a thickness of about 1,000 m and the GFM shows a thickness of about 350 m.

This apparent discontinuity was identified (Wilson 2001), and Yucca Mountain Project personnel worked to ensure that units common to both models were handled in a uniform manner. The discontinuity was resolved within the HFM by adding contours with increasing elevation to the GFM and by continuing this incline in the HFM definition, resulting in a smooth transition from the lower Tram tuff thickness in the northeast corner to the greater thicknesses seen towards Claim Canyon Caldera and beyond the GFM boundaries. The current version of the HFM, HFM 2002 (DTN: GS021008312332.002), is consistent with data from boreholes and is consistent with the current version of the GFM (GFM 2000; BSC 2002). The smooth transition enhances

C05

the applicability of the HFM in providing a hydrogeologic framework for the site-scale flow model.

Figures A-5 and A-6 show the thickness of the Tram Tuff unit. HFM 2002 (Figure A-6) shows a smooth transition from the GFM-defined thickness to the area outside of the GFM. In general, HFM 2002 shows fewer anomalies (e.g., trenches and peaks). These features normally do not show up in 500-m computational grids, but they are addressed and resolved in HFM 2002 to create a smoother surface.



Source: DTN: GS021008312332.002.

NOTES: The black rectangular box shows the GFM area, while the remainder of the figure shows the domain of the site-scale HFM. This figure was scaled such that the rectangular box approximately matches the size of the rectangular box in the previous figures. White gaps appear where the hydrogeologic unit is pinched out to zero thickness by other units or is truncated by the water table surface.

Figure A-6. Vertical Thickness of the Tram Unit in HFM 2002

A.4.3 Permeability Values for HFM Computational Grid Nodes

In HFM 2002, there are no major discontinuities near the boundary of the GFM that result from the incorporation of GFM 2000 data into HFM 2002. However, there are some differences in the assignment of geologic and geohydrologic units in the two models. Differences between the GFM 2000 and HFM 2002 models have been quantified along two cross-sections, and the effects of differing permeabilities due to these differences are evaluated in the following sections.

C06

A.4.3.1 Cross-Sections

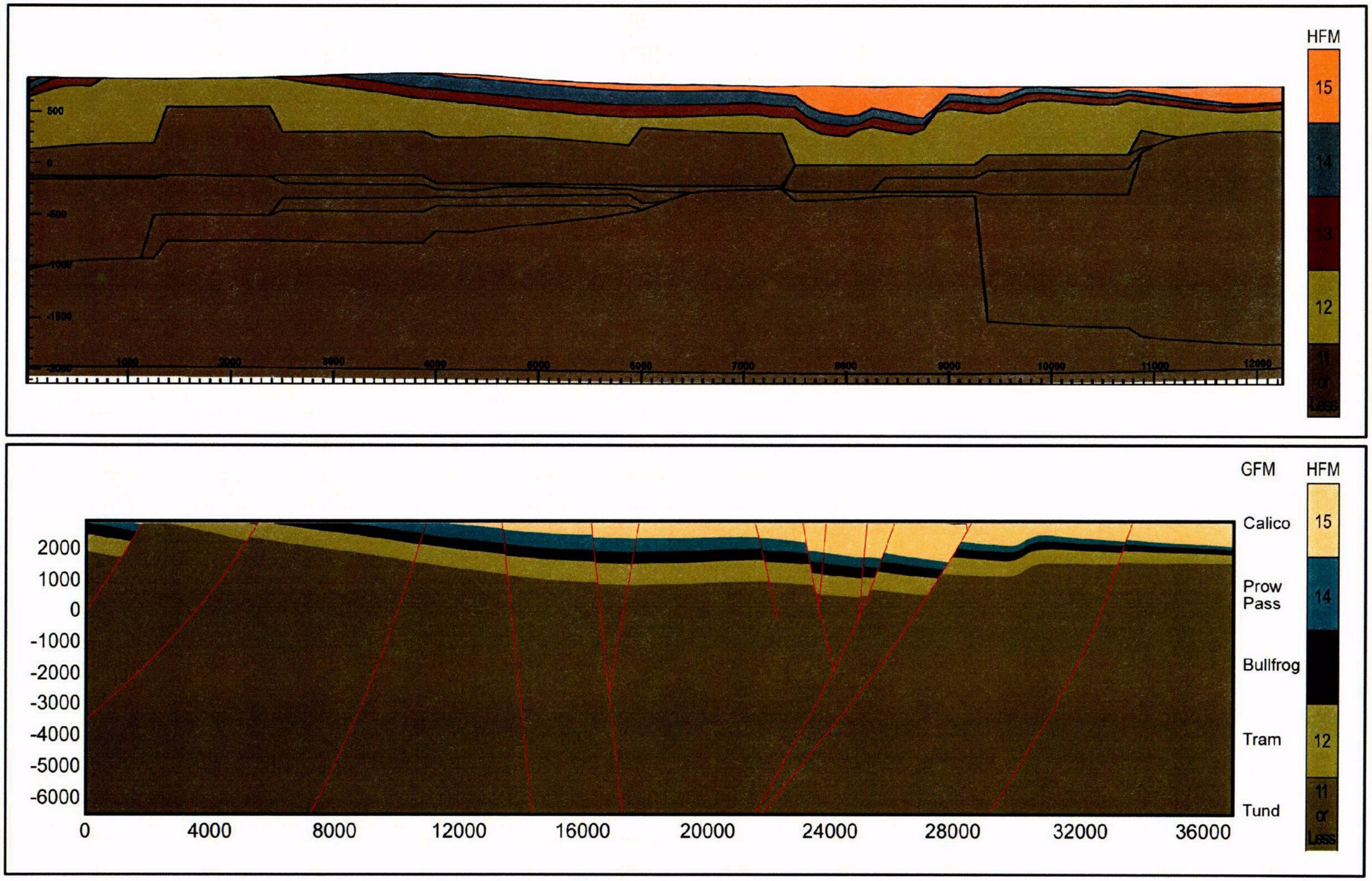
Cross-sections were constructed through the GFM 2000 and HFM 2002 model areas to examine the general form of the geologic units. A west-to-east cross-section was located about one quarter of the way south from the north edge of the GFM. For the HFM, the cross-section follows the same line, but extends beyond the boundaries of the GFM by 500 m. Another cross-section extends diagonally across the GFM from near the southwest corner to near the northeast corner. For the HFM, this cross-section extends more than 1 km beyond the boundaries of the GFM on each end of the diagonal. Both cross-sections were constructed along lines of grid nodes from the HFM computational grid, which was used for the calibration and calculation of flow properties.

The cross-sections are presented in Figures A-7 and A-8. The general form of the cross sections is similar. In both figures, faults are apparent in the GFM, and the geologic and geohydrologic units follow the same form but without faulting in the HFM model. The GFM cross-sections extend higher above sea level than the HFM cross-sections, resulting in a slightly different appearance at the top of the cross-sections.

The correspondence between GFM geologic units and HFM hydrogeologic units is not exact. Three units correspond well: the GFM Prow Pass, Bullfrog, and Tram units correspond well with HFM units 14, 13, and 12, respectively. For constructing the cross-sections, the units above these three units were lumped into an "Above Unit 15" category, and the units below were lumped into a "Unit 11 or less" category. In general, the GFM contains a finer division of geologic units in the upper part of the geologic section, and the HFM defines more units in the lower part of the geologic section.

The cross-sections were compared more rigorously by identifying the geologic and hydrogeologic units that occur at each node in the HFM computational grid. A total of 1,095 unique computational grid nodes were compared in the two cross-sections. Equivalent geologic-geohydrologic units were found at 738 (67 percent) nodes; the remaining 357 nodes did not match. The effect of the 357 mismatches on predicted flow was evaluated by examining the permeabilities assigned to each of these nodes in the site-scale flow model (Table A-2). The HFM was used to assign units to each computational node in the numerical model.

For each unit, permeability is represented by a range of values in stochastic modeling. For the 357 nodes where the GFM and HFM units did not match, the permeability value assigned to the flow model node was within the range of values assigned to the equivalent GFM geologic unit (Table A-2), and therefore, the discrepancies had no affect on predicted flow.

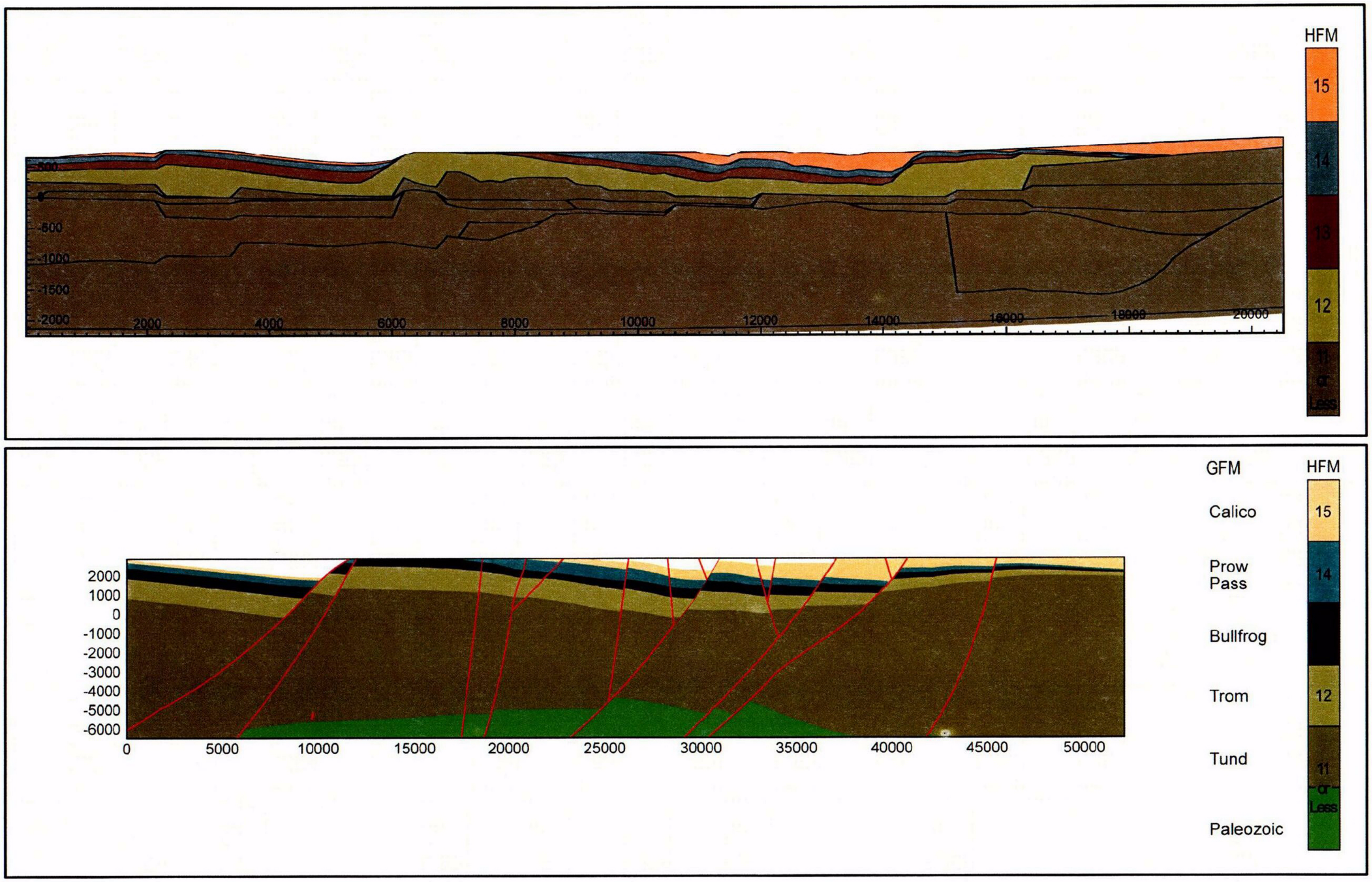


00346DC_093.ai

NOTE: The upper cross-section is from the HFM (distances in meters), and the lower cross-section is from the GFM (distances in feet). The vertical scale is elevation relative to sea level, and the horizontal scale is from the beginning point of the cross-section. There is no vertical exaggeration.

Figure A-7. East-West Cross-Sections through the HFM and GFM

C07



00346DC_092a.ai

NOTE: The upper cross-section is from the HFM (distances in meters), and the lower cross-section is from the GFM (distances in feet). The vertical scale is elevation relative to sea level, and the horizontal scale is from the beginning point of the cross-section. There is no vertical exaggeration.

Figure A-8. Diagonal Cross-Sections through the HFM and GFM

C098

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Unit 12	1.00000E-18	5.00000E-15	Unit 11 or less	2.00000E-15
Unit 12	1.00000E-18	5.00000E-15	Unit 11 or less	2.00000E-15
Unit 12	1.00000E-18	5.00000E-15	Unit 11 or less	2.00000E-15
Unit 12	1.00000E-18	5.00000E-15	Unit 11 or less	1.00000E-17
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	1.68201E-14
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	1.00000E-17
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 13	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes (Continued)

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-12
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-12
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-12
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-12
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes (Continued)

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-12
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-12
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	5.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	5.00000E-15

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes (Continued)

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	5.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-17
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	5.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.04806E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.00000E-17
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.04806E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.04806E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.00000E-15
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	2.36480E-13
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.04806E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.04806E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.04806E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.04806E-18
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.68201E-14
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.68201E-14
Unit 11 or less	1.00000E-18	2.36480E-12	Unit 12	1.68201E-14
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes (Continued)

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 14	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 12	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 12	1.00000E-18	1.54100E-11	Unit 13	1.00000E-17
Unit 12	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 12	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 12	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 12	1.00000E-18	1.54100E-11	Unit 13	1.04806E-18
Unit 12	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 12	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 12	1.00000E-18	1.54100E-11	Unit 13	1.00000E-17
Unit 12	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 12	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 12	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 12	1.00000E-18	1.54100E-11	Unit 13	1.04806E-18
Unit 12	1.00000E-18	1.54100E-11	Unit 13	1.54100E-11
Unit 11 or less	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 11 or less	1.00000E-18	1.54100E-11	Unit 13	2.36480E-13
Unit 13	1.04806E-18	2.00000E-11	Unit 14	2.36480E-13
Unit 13	1.04806E-18	2.00000E-11	Unit 14	1.54100E-11
Unit 13	1.04806E-18	2.00000E-11	Unit 14	2.36480E-12
Unit 13	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 13	1.04806E-18	2.00000E-11	Unit 14	1.54100E-11
Unit 13	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 13	1.04806E-18	2.00000E-11	Unit 14	1.04806E-18
Unit 13	1.04806E-18	2.00000E-11	Unit 14	1.04806E-18
Unit 13	1.04806E-18	2.00000E-11	Unit 14	1.54100E-11
Unit 13	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 13	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 13	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 13	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 13	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 13	1.04806E-18	2.00000E-11	Unit 14	1.54100E-11
Unit 13	1.04806E-18	2.00000E-11	Unit 14	5.69014E-13
Unit 13	1.04806E-18	2.00000E-11	Unit 14	5.69014E-13
Unit 13	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes (Continued)

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	2.00000E-11
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Above Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Above Unit 15	1.04806E-18	2.00000E-11	Unit 14	8.00000E-12
Unit 12	1.04806E-18	2.00000E-11	Unit 14	2.36480E-13
Unit 12	1.04806E-18	2.00000E-11	Unit 14	1.00000E-17
Unit 12	1.04806E-18	2.00000E-11	Unit 14	2.36480E-13
Unit 12	1.04806E-18	2.00000E-11	Unit 14	2.36480E-13
Unit 12	1.04806E-18	2.00000E-11	Unit 14	1.00000E-17
Unit 12	1.04806E-18	2.00000E-11	Unit 14	2.36480E-13
Unit 11 or less	1.04806E-18	2.00000E-11	Unit 14	2.36480E-13
Unit 13	1.04806E-18	1.54100E-10	Unit 15	2.36480E-13
Unit 13	1.04806E-18	1.54100E-10	Unit 15	1.54100E-11
Unit 13	1.04806E-18	1.54100E-10	Unit 15	1.04806E-18
Unit 13	1.04806E-18	1.54100E-10	Unit 15	1.54100E-10
Unit 13	1.04806E-18	1.54100E-10	Unit 15	1.54100E-11
Unit 13	1.04806E-18	1.54100E-10	Unit 15	1.04806E-18

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes (Continued)

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Unit 13	1.04806E-18	1.54100E-10	Unit 15	1.04806E-18
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-11
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Unit 14	1.04806E-18	1.54100E-10	Unit 15	3.55634E-15
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	1.54100E-10
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	1.54100E-11
Unit 14	1.04806E-18	1.54100E-10	Unit 15	1.04806E-18
Unit 14	1.04806E-18	1.54100E-10	Unit 15	1.04806E-18
Unit 14	1.04806E-18	1.54100E-10	Unit 15	3.55634E-15
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Unit 14	1.04806E-18	1.54100E-10	Unit 15	1.54100E-11
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Unit 14	1.04806E-18	1.54100E-10	Unit 15	3.55634E-15
Unit 14	1.04806E-18	1.54100E-10	Unit 15	3.55634E-15
Unit 14	1.04806E-18	1.54100E-10	Unit 15	1.04806E-18
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-11
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	1.54100E-11
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Unit 14	1.04806E-18	1.54100E-10	Unit 15	1.00000E-13
Unit 14	1.04806E-18	1.54100E-10	Unit 15	8.00000E-11
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 14	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Above Unit 15	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Above Unit 15	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Above Unit 15	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Above Unit 15	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Above Unit 15	1.04806E-18	1.54100E-10	Unit 15	8.00000E-12
Above Unit 15	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes (Continued)

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Above Unit 15	1.04806E-18	1.54100E-10	Unit 15	5.00000E-14
Unit 12	1.04806E-18	1.54100E-10	Unit 15	2.36480E-13
Unit 12	1.04806E-18	1.54100E-10	Unit 15	2.36480E-13
Unit 12	1.04806E-18	1.54100E-10	Unit 15	2.36480E-13
Unit 12	1.04806E-18	1.54100E-10	Unit 15	1.00000E-17
Unit 12	1.04806E-18	1.54100E-10	Unit 15	2.36480E-13
Unit 13	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Unit 13	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-13
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-12
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-12
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-12
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17

Table A-2. Permeability in the North-South Direction for Mismatched HFM-GFM Grid Nodes (Continued)

HFM Equivalent Unit from GFM	Range of Permeability Values from HFM for the HFM Equivalent Unit from GFM		HFM Unit from HFM	Permeability at the Flow Model Node
	Minimum	Maximum		
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-12
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-13
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	1.00000E-17
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-12
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-14
Above Unit 15	1.00000E-17	1.54100E-11	Unit 16	8.00000E-12
Unit 12	1.00000E-17	1.54100E-11	Unit 16	2.36480E-13
Unit 12	1.00000E-17	1.54100E-11	Unit 16	2.36480E-13
Unit 12	1.00000E-17	1.54100E-11	Unit 16	2.36480E-13
Unit 12	1.00000E-17	1.54100E-11	Unit 16	2.36480E-13
Unit 12	1.00000E-17	1.54100E-11	Unit 16	2.36480E-13
Unit 12	1.00000E-17	1.54100E-11	Unit 16	2.36480E-13
Unit 12	1.00000E-17	1.54100E-11	Unit 16	1.54100E-11

Source: DTN: LA0304TM831231.002.

In summary, the current revisions of the GFM and HFM models (GFM 2000 and HFM 2002, respectively) resolve the major differences in this thickness of the hydrogeologic units in the northwest corner of the GFM model domain. These two models are used by different groups within the Performance Assessment organization. Both models have been validated for the intended uses: the GFM focusing on geologic units close to the repository horizon, and the HFM focusing on hydrogeologic units covering a large geographic area. The HFM and GFM are different model interpretations of the Yucca Mountain area and have different intended applications within performance assessment; therefore, the slight differences that remain are irrelevant to the assessment of repository performance.

Mismatches in the assignment of geologic and hydrogeologic units to nodes in the HFM computational grid also are irrelevant to the assessment of repository performance. An examination of the discrepancies indicated that there was no affect on the saturated zone flow model because the final calibrated permeabilities at all of the mismatched GFM-HFM nodes in the flow model were within the range of permeabilities that would have been assigned to these units in the absence of the discrepancies.

A.5 REFERENCES

A.5.1 Documents Cited

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USGS 2001a. *Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model*. ANL-NBS-HS-000033 REV 00 ICN 02. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20011112.0070.

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Wilson, C. 2001. Data Qualification Report: Stratigraphic Data Supporting the Hydrogeologic Framework Model for Use on the Yucca Mountain Project. TDR-NBS-HS-000013 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010725.0225.

A.5.2 Source Data, Listed by Data Tracking Number

GS000508312332.001. Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model. Submittal date: 06/01/2000.

GS000508312332.002. Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model. Submittal date: 06/01/2000.

GS021008312332.002. Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model, Version YMP_9_02. Submittal date: 12/09/2002.

GS960808312144.003. Hydrogeologic Evaluation and Numerical Simulation of the Death Valley Regional Ground-Water Flow System, Nevada and California, Using Geoscientific Information Systems. Submittal date: 08/29/1996.

GS991208314221.001. Geologic Map of the Yucca Mountain Region. Submittal date: 12/01/1999.

LA0304TM831231.001. SZ Flow and Transport Model, Hydrogeologic Surface Files. Submittal date: 04/07/2003.

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APPENDIX B

HYDROSTRATIGRAPHIC CROSS SECTIONS (RESPONSE TO RT 2.09 AIN-1 AND USFIC 5.05 AIN-1)

Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design bases at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application (LA) as the approved analyses of record at the time of LA submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the LA.

APPENDIX B

HYDROSTRATIGRAPHIC CROSS SECTIONS (RESPONSE TO RT 2.09 AIN-1 AND USFIC 5.05 AIN-1)

This appendix provides a response to an additional information needed (AIN) request from the U.S. Nuclear Regulatory Commission (NRC) for Key Technical Issue (KTI) agreements Radionuclide Transport (RT) 2.09 and Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) 5.05. These KTI agreements relate to providing updated hydrostratigraphic cross sections that include additional borehole data.

B.1 KEY TECHNICAL ISSUE AGREEMENT

B.1.1 RT 2.09 and USFIC 5.05

KTI agreement USFIC 5.05 was reached during the NRC/U.S. Department of Energy (DOE) technical exchange and management meeting on unsaturated and saturated flow under isothermal conditions held during October 31 through November 2, 2000, in Albuquerque, New Mexico (Reamer and Williams 2000a). The saturated zone portion of KTI subissues 5 and 6 was discussed at the meeting.

KTI agreement RT 2.09 was reached during the NRC/DOE technical exchange and management meeting on radionuclide transport held December 5 through 7, 2000, in Berkeley, California. Radionuclide transport KTI Subissues 1, 2, and 3 were discussed at that meeting (Reamer and Williams 2000b).

A letter report responding to these agreements (Ziegler 2002) was prepared. The report included hydrostratigraphic and geologic cross sections with Nye County data. Specific additional information was requested by the NRC after the staff review of this letter report was completed, resulting in RT 2.09 AIN-1 and USFIC 5.05 AIN-1 (Schlueter 2002). The comments for these two AINs are identical.

Wording of these agreements is as follows:

USFIC 5.05

> Provide the hydrostratigraphic cross sections that include the Nye County data. DOE will provide the hydrostratigraphic cross sections in an update to the Hydrogeologic Framework Model for the Saturated Zone Site-Scale Flow and Transport Model AMR expected to be available during FY 2002, subject to availability of the Nye County data.

RT 2.09

> Provide the hydrostratigraphic cross sections that include the Nye County data. DOE will provide the hydrostratigraphic cross sections in an update to the Hydrogeologic Framework Model for the Saturated Zone Site-Scale Flow and

Transport Model AMR expected to be available during FY 2002, subject to availability of the Nye County data.

USFIC 5.05 AIN-1 and RT 2.09 AIN-1

DOE should provide hydrostratigraphic cross sections containing Nye County data in the forthcoming revised Hydrogeologic Framework Model AMR or separate report. NRC staff suggests the revised report also address the two comments for corrected information and the seven comments for additional information needs previously discussed in the staff comments section of this review.

The seven comments relating to AINs to fulfill the intent of USFIC 5.05 and RT 2.09 agreements (Schlueter 2002) are as follows:

1. One of the critical underlying technical goals of the agreements was to develop information about geologic cross sections that are important to reducing uncertainties in groundwater flow and transport. For example, information derived from properly constructed and technically defendable geologic cross sections could greatly reduce uncertainties with regard to the location of the tuff-alluvium contact and the thickness and identification of tuff and alluvium within the upper several hundred meters of the basin sections. The cross sections presented in the June 28, 2002 letter report are insufficient to support these technical goals. The cross sections instead depict approximately 6,000 m (20,000 ft) of section in which the details of the near surface stratigraphy are obscured by the gross scale of cross-section construction.

2. Figures 4 through 12 present hydrogeologic cross sections extracted from a "2002 Hydrogeologic Framework Model." No reference is provided for this hydrogeologic framework model, which is apparently an updated model based on the stratigraphic interpretations in Plate 1 of the report. The hydrogeologic framework model used in DOE performance assessments to date–the one reviewed by NRC–was published in 2000 (CRWMS M&O 2000). It is not clear whether this revised hydrogeologic framework model will be used to update the site-scale saturated zone flow model and the performance assessment abstraction for saturated zone flow and transport. If the revised model is not to be used as input to performance assessment analyses, then a comparison of the revised model, which is presumed to be the best DOE interpretation, to the older model used in performance assessments should be provided.

3. Critical information and discussion of the identification of the various tuff units encountered in the Nye County Wells are absent from the report. In parallel with the technical goals stated in [AIN-1] #1 above, identification of the tuff units in these wells could provide the DOE with the necessary information to either validate or improve the flow and transport model

depiction of groundwater in the shallow alluvial aquifer of Fortymile Wash. Staff anticipated that the report would include such information as it was informally presented at a previous technical exchange (Spengler 2000).

4. The technical basis for identification of the geologic or hydrologic units encountered in the Nye County wells is not provided in the report. The geologic units are simply named in summary tables with references to other data sources. The report lacks sufficient technical discussion of the criteria used to identify the geologic units or the resulting data and interpretations used to generate the stratigraphic units from the Nye County well cuttings. Without such information, there is insufficient technical basis to support interpretations in the cross sections.

5. There is no technical basis or discussion provided in the report about how the geophysical data were used to develop the stratigraphic information in the cross sections. The report simply identifies the data sources and associated reports and papers. Without such information, there is insufficient technical basis to support interpretations in the cross sections.

6. There is no technical basis or technical discussion provided in the report about how the regional geologic data from geologic maps or cross sections were used to develop the stratigraphic information in the cross sections. The report simply identifies the data sources and associated reports and papers. Without such information, there is insufficient technical basis to support interpretations in the cross sections.

7. Many of the lithologic identifications used in the report are unique to these cross sections (e.g., lithologic units Tgegl-Tgeg6 in Table 2 of the letter report), without apparent consideration of existing geologic information. Many of these similar aged units have been identified, described, and mapped in the surrounding outcrop exposures of bedrock[5]. It is not clear whether the previously identified lithologic units have been renamed, or whether new lithologic units are being proposed.

   [Footnote 5 from NRC document: Murray, D.A., Stamatakos, J.A., and Ridgway, K.D., "Regional Stratigraphy of Oligocene and Lower Miocene Strata in the Yucca Mountain Region." Center for Nuclear Waste Regulatory Analyses San Antonio Texas, July 2002, IM01402.220.]

B.1.2 Related Key Technical Issue Agreements

None.

B.2 RELEVANCE TO REPOSITORY PERFORMANCE

The purpose of this appendix is to provide a technical response to the NRC AIN request to the agreements described in Section B.1. The subject of the original agreements was the update of stratigraphic and hydrostratigraphic cross sections based on additional borehole data. The AIN

responses are provided in the context of the technical adequacy of the original KTI agreement transmittal to satisfy that agreement.

B.3 RESPONSE

Response to Request for Corrected Information–The DOE acknowledges that Schlueter (2002) requested corrected and additional information related to apparent errors or inconsistencies in a report delivered by the DOE to the NRC. A self-assessment was conducted (BSC 2003a) to evaluate the condition raised by Schlueter's concerns. It was found that the apparent errors and inconsistencies do not affect the hydrogeologic framework model (HFM) or the results of the model. The DOE will correct these inconsistencies if the material is used as a licensing basis.

Response to AIN-1 Comment #1–Additional characterization obtained from Nye County Early Warning Drilling Program (EWDP) borehole lithologies and aeromagnetic studies helped reduce uncertainties in the tuff-alluvium contact (Appendix G), and groundwater flow and transport in the areas covered by the Nye County cross sections. Additional information on the tuff-alluvium contact is provided in Section 2.3.4. Flow and transport parameter uncertainty is captured in the stochastic parameter distributions that are sampled for the saturated zone flow and transport model simulations. Specifically, the alternative conceptual model of "channeling in the alluvium," with the key assumption that high permeability channels exist in the alluvium that can provide preferential pathways for flow and transport, is implicitly included in the saturated zone transport model through the range of uncertainty in the effective porosity values (BSC 2003b, Table 6.4-1).

Response to AIN-1 Comment #2–Since development of the hydrogeologic framework model (HFM) 1999, which was used for the site-scale saturated zone flow model (SSFM), the hydrogeology at Yucca Mountain has been reinterpreted using data from the Nye County EWDP area and using reinterpreted data from other areas, including geophysical data from the northern area of the site. The new HFM is referred to as HFM2002 (DTN: GS021008312332.002). Changes were made in the southern part of the model to the depths and extent of the alluvial layers. The northern part of the model domain also changed, largely as a result of reinterpreting geophysical data on the depth of the carbonate aquifer. The shape and extent of the carbonate aquifer changed and is now not believed to intersect the northern boundary of the SSFM domain. The number and distribution of hydrogeologic units was modified from 19 hydrogeologic units in HFM1999 to 27 units in HFM2002.

HFM2002 is notably different from HFM1999 in the hydrogeology at the water table in the area of the Nye County boreholes and along the anticipated flow path from the repository. Important changes occurred in the hydrogeologic units at the water table in the southern part of the model domain where the volcanic and sedimentary units replace the valley-fill aquifer as the most pervasive unit in HFM2002. HFM2002 has improved discretization in lower Fortymile Wash to correct for known deficiencies in HFM1999. The northernmost new discretization, the alluvial uncertainty zone, was included to represent a transition from the volcanic aquifer system to the alluvial aquifer system (Appendix G). This change was made in HFM2002 because, based on logs from borehole NC-EWDP-19D, the alluvial aquifer extends farther north than was represented in HFM1999. The permeability of the new alluvial uncertainty zone is a calibration

parameter that can represent either aquifer system. A second zone of improved discretization is the lower Fortymile Wash zone. It represents a distinct subset of the alluvial aquifer that is characterized by a higher proportion of gravel in the lower-most portion of Fortymile Wash. The Calico Hills volcanic unit replaced the upper volcanic confining unit. In the SSFM, however, the Calico Hills material no longer separates the upper and lower portions of Fortymile Wash. Farther north, the Paintbrush volcanic aquifer replaces the upper volcanic aquifer as the dominant unit, at least near the water table. The Yucca Mountain block remains composed of the Crater Flat Group: Prow Pass, Bullfrog, and Tram units. The Crater Flat units are more continuous to the north and west of Yucca Mountain in HFM2002 than in HFM1999. Because permeability in the Crater Flat group is relatively high, the new representation provides a high permeability path at the water table, upgradient from Yucca Mountain, that was not present in the original HFM.

Development of HFM2002 was influenced primarily by data from new Nye County boreholes. The most pronounced difference in the two HFMs is the relative abundance of the Crater Flat group to the west of Yucca Mountain in HFM2002. The Crater Flat group represents relatively high permeability rock. However, the flow paths of fluid particles leaving the repository area are likely to be to the east of Yucca Mountain. Thus, this change in HFM2002 may not greatly influence the ability of the SSFM to replicate flow paths predicted with the original HFM. The Crater Flat group is more continuous on the east side of Yucca Mountain, possibly influencing the specific discharge predictions of the SSFM.

Based on the flow paths predicted by the SSFM, differences in the two HFMs along the expected flow paths from the repository to the accessible environment were identified. Flow near the repository area with the new HFM is expected to be similar to that in the SSFM with the original HFM because the changes to the HFM were small in this region.

The use of the site-scale HFM is discussed in relationship to overall saturated zone flow and transport in Section 2.3.4.

Cross sections were constructed to augment the HFM (USGS 2001) (as stated in the KTI agreement items), which extends to depths on the order of 3 km. The printed version of the cross sections included in the June 28, 2002, letter report to NRC was formatted to display at a scale of approximately 1:25,000. Updated cross sections have recently become available. The revised cross sections will be provided under separate cover. New information continues to be gathered and evaluated, and it will continue to be provided as project schedules require. For example, updated information on geologic cross sections has recently been completed (DTN: GS030408314211.002). Work continues on the HFM as new information becomes available, and if updates become available before the license application, an impact analysis will be conducted under AP-2.14Q, *Review of Technical Products and Data*, to evaluate if current products that depend on the revised product require modification to meet Yucca Mountain Project goals. The current HFM (USGS 2001) is valid for the total system performance assessment for license application. This more recent information is available to NRC onsite staff, but is not the information that was used in the site-scale saturated zone flow and transport model, so it only confirms that assumptions about the Alluvial Contact Uncertainty Zone (Appendix G) are reasonable.

Response to AIN-1 Comment #3–The technical basis for the identification of tuff units is available in many of the references included with the cross sections (DTN: GS030408314211.002) that refer to lithostratigraphic descriptions of Nye County EWDP boreholes. The lithostratigraphic data packages for Nye County EWDP boreholes contain the technical bases for the identification of tuff units along with additional information such as the "level of confidence" associated with each stratigraphic interpretation and a description of any corroborative geophysical log responses. Additional information concerning the technical basis for the identification of lithostratigraphic units encountered in Nye County EWDP boreholes can be found in Sections 4.1 and 4.3 of the June 28, 2002, letter report to the NRC (Williams and Fray 2002). Supporting documentation for this report can be made available to NRC onsite staff.

Response to AIN-1 Comment #4–The technical basis for identifying the lithostratigraphic units encountered in the Nye County EWDP boreholes is provided in the supporting documentation, as cited in the June 28, 2002, letter report to NRC. Selected references in Section 4.1 and Section 4.3 provide information on the criteria used to identify lithostratigraphic units. This supporting documentation is available to NRC onsite staff. If necessary, and unavailable elsewhere, the supporting documentation referenced is available in the project records information system and can be made available to NRC onsite staff.

Response to AIN-1 Comment #5–Descriptions of the use of borehole geophysical data are presented in references on the lithostratigraphic interpretations of Nye County EWDP Phases I, II, and III. Additional illustrative information regarding the use and spatial relation of surface-based geophysical information used in construction of the cross sections can be found in DTN: GS030408314211.002. This data package, developed to aid in satisfying some of the concerns identified in this Appendix B, is composed in part of 2 poster-size presentations (sheets). Sheet 1 contains four maps that illustrate the spatial position of all the information used in the construction of the cross sections. These data include: (1) locations of Nye County EWDP boreholes used in the construction of Nye-1, Nye-2, and Nye-3, (2) interpretive locations of faults, (3) locations of isostatic gravity anomalies, (4) locations of aeromagnetic anomalies, (5) depth-to-basement contours, (6) locations of seismic refraction profiles (near the Nye-2 section only), (7) locations of outcrops, and (8) location of potentiometric contours. Sheet 2 contains updated versions of the 3 cross sections provided in the June 28, 2002, letter report to the NRC. These cross sections are all presented on one poster-size sheet and are presented in color, which greatly enhances the readability of the cross sections even at the printed scale of 1:25,000. Many of the earlier problems regarding the difficulty in seeing detailed lithostratigraphic relations near the upper part of the sections (close to the water table) have been resolved through the use of color in the cross sections. A "water table" profile has been included on all cross sections to facilitate inspection of this part of the cross sections. Supporting documentation is available to NRC onsite staff.

The June 28, 2002, letter report to NRC, Table 1 and Section 3.3, provides a discussion of how the referenced geophysical data were used as corroborative data to develop the more detailed cross sections and, specifically, to help locate the top of the Paleozoic strata and identify possible buried structures.

Response to AIN-1 Comment #6–Revised cross sections in the two-poster sheet format DTN: GS030408314211.002) now include a display of outcrops and structures relevant to the

locations of Nye-1, Nye-2, and Nye-3. These geologic features were drawn or revised based on geologic information contained on regional geologic maps and cross sections. This supporting documentation is available to NRC onsite staff.

Response to AIN-1 Comment #7–The lithologic identifications are not unique to these cross sections and existing geologic information was considered. Existing geologic information described by Wahl et al. (1997), Buesch et al. (1996), and the data report for NC-EWDP-2DB (DTN: GS011008314211.001) was considered. Lithologic units Tgeg1-Tgeg6 represent subunits within unit Tge (unit Tge [Prevolcanic sedimentary rocks] as described by Wahl et al. 1997). The data report for NC-EWDP-2DB (DTN: GS011008314211.001) indicates that the nomenclature of lower volcanic units and Tertiary sedimentary strata in NC-EWDP-2DB, for the most part, follows that of Wahl et al. (1997) and Buesch et al. (1996). The thin Tgeg1-Tgeg6 gravel layers, described in the data report for NC-EWDP-2DB (DTN: GS011008314211.001), contain unique lithologic components that currently are found in the vicinity of borehole NC-EWDP-2DB and potentially represent important marker beds, traceable from one borehole to another. Therefore, they were informally assigned a subunit status (i.e., g1, g2, g3, g4, g5, and g6, for these gravels). Wahl et al. (1997) note that these rocks were formerly designated as the Horse Spring Formation but are older than the Miocene type Horse Spring Formation of the Lake Mead area.

The Center for Nuclear Waste Regulatory Analyses report, dated July 2002, cited in Footnote 5 of the AIN-1 #7, postdates all of these references as well as the subject letter report (Ziegler 2002). In particular reference to the Center for Nuclear Waste Regulatory Analyses report, dated July 2002, the general correlations shown and described in this report, which begin in the Frenchman Flat area, extend west to Fortymile Wash, and terminate in the Funeral Mountains, lack fundamental correlations of regional pyroclastic deposits. Without concerted attempt to correlate these key marker horizons with well-constrained time lines, erroneous interpretations and correlations of the regional Tertiary sedimentary stratigraphy are likely to occur.

The information in this report is responsive to agreements RT 2.09 AIN-1 and USFIC 5.05 AIN-1 made between the DOE and NRC. The report contains the information that DOE considers necessary for the NRC to review for closure of these agreements.

B.4 BASIS FOR THE RESPONSE

The seven parts of this AIN comprise a request for information that was provided in Section B.3.

B.5 REFERENCES

B.5.1 Documents Cited

BSC (Bechtel SAIC Company) 2003a. *Self Assessment of the Apparent Errors or Inconsistencies Identified by NRC in the Report Submitted to the NRC Addressing KTI Agreement Items USFIC 5.05 and RT 2.09.* SA-LAP-2003-002. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030814.0304.

BSC 2003b. *Site-Scale Saturated Zone Transport.* MDL-NBS-HS-000010 REV 01A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030626.0180.

Buesch, D.C.; Spengler, R.W.; Moyer, T.C.; and Geslin, J.K. 1996. *Proposed Stratigraphic Nomenclature and Macroscopic Identification of Lithostratigraphic Units of the Paintbrush Group Exposed at Yucca Mountain, Nevada.* Open-File Report 94-469. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970205.0061.

Reamer, C.W. and Williams, D.R. 2000a. Summary Highlights of NRC/DOE Technical Exchange and Management Meeting on Unsaturated and Saturated Flow Under Isothermal Conditions. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20001128.0206.

Reamer, C.W. and Williams, D.R. 2000b. Summary Highlights of NRC/DOE Technical Exchange and Management Meeting on Radionuclide Transport. Meeting held December 5-7, 2000, Berkeley, California. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20010117.0063.

Schlueter, J.R. 2002. "Additional and Corrected Information Needs Pertaining to Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) Agreement 5.05 and Radionuclide Transport (RT) Agreement 2.09." Letter from J.R. Schlueter (NRC) to J.D. Ziegler (DOE/ORD), December 19, 2002, 1223025549, with attachment. ACC: MOL.20030214.0140.

USGS (U.S. Geological Survey) 2001. *Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model.* ANL-NBS-HS-000033 REV 00 ICN 02. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20011112.0070.

Wahl, R.R.; Sawyer, D.A.; Minor, S.A.; Carr, M.D.; Cole, J.C.; Swadley, W.C.; Laczniak, R.J.; Warren, R.G.; Green, K.S.; and Engle, C.M. 1997. *Digital Geologic Map Database of the Nevada Test Site Area, Nevada.* Open-File Report 97-140. Denver, Colorado: U.S. Geological Survey. TIC: 245880.

Williams, N. and Fray, R. 2002. "Contract No. DE-AC08-01RW12101 - Key Technical Issue (KTI) Agreements: Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) 5.05 and Radionuclide Transport (RT) 2.09." Letter from N. Williams (BSC) and R. Fray (BSC) to J.D. Ziegler (DOE/YMSCO), June 28, 2002, TB:cg - 0628023173, with enclosure. ACC: MOL.20020820.0068.

Ziegler, J.D. 2002. "Transmittal of a Report Addressing Key Technical Issue (KTI) Agreement Items Unsaturated and Saturated Zone Flow Under Isothermal Conditions (USFIC) 5.05 and Radionuclide Transport (RT) 2.09." Letter from J.D. Ziegler (DOE/YMSCO) to J.R. Schlueter (NRC), July 2, 2002, OL&RC:TCG-1351, 0703023215. ACC: MOL.20020911.0119, MOL.20020820.0068.

B.5.2 Codes, Standards, Regulations, and Procedures

AP-2.14Q, Rev. 2, ICN 2. *Review of Technical Products and Data.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20030206.0001.

B.5.3 Source Data, Listed by Data Tracking Number

GS010908314221.001. Geologic Map of the Yucca Mountain Region, Nye County, Nevada. Submittal date: 01/23/2002.

GS011008314211.001. Interpretation of the Lithostratigraphy in Deep Boreholes NC-EWDP-19D1 and NC-EWDP-2DB Nye County Early Warning Drilling Program. Submittal date: 01/16/2001.

GS021008312332.002. Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model, Version YMP_9_02. Submittal date: 12/09/2002.

GS030108314211.001. Interpretation of the Lithostratigraphy in Deep Boreholes NC-EWDP-18P, NC-EWDP-22SA, NC-EWDP-10SA, NC-EWDP-23P, NC-EWDP-19IM1A, and NC-EWDP-19IM2A, Nye County Early Warning Drilling Program, Phase III. Submittal date: 02/11/2003.

GS030408314211.002. Subsurface Geologic Interpretations Along Cross Sections Nye-1, Nye-2, and Nye-3, Southern Nye County, Nevada - 2002. Submittal date: 05/09/2003.

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APPENDIX C

POTENTIOMETRIC SURFACE AND VERTICAL GRADIENTS (RESPONSE TO USFIC 5.08 AIN-1)

Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design bases at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application (LA) as the approved analyses of record at the time of LA submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the LA.

APPENDIX C

POTENTIOMETRIC SURFACE AND VERTICAL GRADIENTS (RESPONSE TO USFIC 5.08 AIN-1)

This appendix provides a response to the additional information needed (AIN) request from the U.S. Nuclear Regulatory Commission (NRC) for Key Technical Issue (KTI) agreement Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) 5.08. This KTI agreement relates to providing more information about the potentiometric surface and vertical gradients.

C.1 KEY TECHNICAL ISSUE AGREEMENT

C.1.1 USFIC 5.08 AIN-1

KTI agreement USFIC 5.08 was reached during the NRC/U.S. Department of Energy (DOE) technical exchange and management meeting on unsaturated and saturated flow under isothermal conditions held October 31 through November 2, 2000, in Albuquerque, New Mexico. The saturated zone portion of KTI subissues 5 and 6 were discussed at that meeting (Reamer and Williams 2000).

A letter report responding to this agreement and containing an updated potentiometric surface map and explanatory text (Ziegler 2002) was submitted. Specific additional information was requested by the NRC after the staff review of this letter report was completed, resulting in USFIC 5.08 AIN-1 (Reamer and Williams 2000).

The wording of these agreements is:

USFIC 5.08

> Taking into account the Nye County information, provide the updated potentiometric data and map for the regional aquifer, and an analysis of vertical hydraulic gradients within the site scale model. DOE will provide an updated potentiometric map and supporting data for the uppermost aquifer in an update to the Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model AMR expected to be available in October 2001, subject to receipt of data from the Nye County program. Analysis of vertical hydraulic gradients will be addressed in the site-scale model and will be provided in the Calibration of the Site-Scale Saturated Zone Flow Model AMR expected to be available during FY 2002.

USFIC 5.08 AIN-1

1. Incorporate data for well SD-6, which was drilled several years ago (DOE 1999) and provide key information about hydraulic heads close to the Solitario Canyon Fault, into the analysis of water levels near Yucca Mountain and provide the analysis for NRC review. The same data given in tables in the water-level AMR for other wells should be provided for SD-6.

2. Provide a hydrogeologic interpretation for the high heads observed in wells UZ-14 and H-5.

3. Provide an updated hydrogeologic interpretation for groundwater elevations in wells G-2 and WT#6 (i.e., wells that define the large hydraulic gradient) based on newly available data from well WT-24.

4. Provide the basis for assuming that the water level in Well NC-EWDP-7S represents perched water.

C.1.2 Related Key Technical Issue Agreements

None.

C.2 RELEVANCE TO REPOSITORY PERFORMANCE

The purpose of this appendix is to provide a technical response to the NRC AIN request to the agreement described in Section C.1. The subject of the original agreements was the update of the potentiometric surface map based on additional borehole data. The AIN responses are provided in the context of the technical adequacy of the original KTI agreement transmittal to satisfy that agreement.

Additional related discussion can be found in Section 2.3.4.

Potentiometric surface interpretations are important to the site-scale saturated zone flow model (SSFM) because the information generated is one of the primary datasets used for calibration. It is also important that some information be used for model validation. When the original potentiometric interpretations were made, some of the more recent data points were not yet qualified or had not stabilized from the stress of drilling. Therefore, these data were not used in the potentiometric interpretations. Rather, these more recent data points were used in the validation process to see if the interpretation without them could predict the new head measurements, which successfully indicated that the model was adequate for its intended purpose.

C.3 RESPONSE

In addition to the response to the four AIN questions, a discussion of an updated potentiometric surface and vertical hydraulic gradient analyses is provided in this response. The two analyses provide the relationship of water-level elevations in the subject boreholes to the potentiometric surface and use in the flow modeling.

Response to AIN-1 #1–The water-level information requested for borehole USW SD-6 was used for model validation in *Calibration of the Site-Scale Saturated Zone Flow Model* (BSC 2001). The predicted head at borehole USW SD-6 was 734.84 m, compared to the observed head of 731.2 m. This is a more direct use of borehole USW SD-6 water-level data than is the incorporation of this information into the potentiometric surface. *Site-Scale Saturated Zone Flow Model* (BSC 2003) contains the same results for USW SD-6. Moreover, as indicated in Section C.4, this information would not materially change the potentiometric surface depicted in

Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model (USGS 2001, Figure 6-1).

The recorded water level in borehole USW SD-6 was 731.2 m and including data from that borehole would not require a change in the shape and spacing of the potentiometric contours. USW SD-6 water level elevation could be plotted on the potentiometric map without any changes to the contours.

Information from borehole USW SD-6 was used by the NRC Center for Nuclear Waste Regulatory Analysis in *Revised Site-Scale Potentiometric Surface Map For Yucca Mountain, Nevada* (Hill et al. 2002), which states that the revised potentiometric surface map agrees favorably with the map provided in the water-level report (USGS 2001). The differences are:

- The contour intervals used
- The interpreted potentiometric surface in Hill et al. (2002) is limited to the Yucca Mountain area north of the Amargosa Farms area.
- Recent Nye County water-level data, which includes preliminary data for Phase-3 boreholes and the most recent water-level measurements for Phase-2 boreholes, were used in the interpretation for the revised potentiometric surface map.

None of these differences would be affected by the addition of data from borehole USW SD-6. There are no noted differences between the water levels measured at borehole USW SD-6 and those measured at adjacent boreholes. Differences at other sites are not important because they principally apply to areas away from the potential flow paths, and updates from preliminary to final results for Nye County Phase 2 and Phase 3 boreholes are unlikely to result in changes beyond the current uncertainty range of the water-level interpretations. Water level attributes for borehole USW SD-6 are listed in Table C-1.

SD-6 water level attributes from S0045 Table 13 are listed in Table C-1.

Table C-1. SD-6 Water Level Attributes

Site Name	Fig. 22	*x* (UTM) (m)	*y* (UTM) (m)	*z* (elevation) (m)	Head Data (m)	Model Data (m)	Model Data New Recharge Map (m)	Weight
USW SD-6	94	547578	4077550	725.9	731.2	734.84	734.81	20

Source: Excerpted from BSC 2003, Table 6.6-1.

Response to AIN-1 #2–The high potentiometric level in borehole USW H-5 has been attributed to the presence of a splay of the Solitario Canyon fault penetrated by the borehole (Ervin et al. 1994, pp. 9 to 10). This splay is believed to be an extension of the hydrologic barrier to west-to-east groundwater flow from Crater Flat (related to the Solitario Canyon fault). The high heads in USW H-5 (about 775 m) are related to heads in Crater Flat (ranging from about 780 to 775 m), and this borehole defines part of the moderate hydraulic gradient along the western edge of Yucca Mountain. Borehole USW UZ-14 is in a transition zone between the large and moderate hydraulic-gradient areas, and the high potentiometric level (about 779 m) is related to either of these areas. Rousseau et al. (1999, p. 172) hypothesized that perched water in borehole

USW UZ-14 could be caused by a nearby projected growth fault that impedes percolation of water from the surface. This fault may also impede groundwater flow in the saturated zone. The high heads in borehole USW UZ-14 also could be caused by the low-permeability rocks in the upper part of the saturated zone at that borehole.

Response to AIN-1 #3–There are not enough data to unequivocally prove the presence of perched water at boreholes USW G-2 and UE-25 WT#6. The evidence for the possibility of perched water is presented by Czarnecki et al. (1997), which was cited in the water-level report (USGS 2001). However, the U.S. Geological Survey (USGS) (USGS 2001, p. 7) presents an alternative concept for the large hydraulic gradient. Both conceptual models of the large hydraulic gradient were tested with the flow model, and both yielded nearly identical flow fields and flow paths. The potentiometric surface map presented in the water-level report (USGS 2001) was not intended as a replacement for the previous maps (except in the south where there are new data from Nye County boreholes). The purpose of the report (USGS 2001) was to provide an alternative concept that could be tested with the SSFM and to update data with water levels from borehole USW WT-24 and the latest available Nye County data. The concept of semi-perched conditions (Flint et al. 2001) differs only in that the underlying rocks are fully saturated, rather than unsaturated as in the perched-water concept. An expert elicitation panel (CRWMS M&O 1998) concluded that the existence of the large hydraulic gradient or perched conditions does not impact the performance of Yucca Mountain. The panel suggested that to understand the cause, a borehole could be drilled and tested, which led to the drilling of borehole USW WT-24. Drilling, testing, and monitoring of borehole USW WT-24 indicated the existence of perched conditions and a regional water-table elevation of 840 m. After the water-bearing fracture was penetrated, the water level remained constant after the borehole was deepened by more than 100 m, indicating the probability that the water level represents the regional potentiometric surface rather than another perched zone. However, because borehole USW WT-24 is completed within the relatively low permeability Calico Hills Formation, as are boreholes USW G-2 and UE-25 WT#6, it cannot be ruled out that the 840-m water level in borehole USW WT-24 could represent a second perched zone. Because the water encountered was from a fracture below a long interval of dry rock, it may be more reasonable to conclude that the water level represents a regional potentiometric surface (connected by a network of water-bearing fractures within tight, dry rocks) rather than a second perched zone of saturated rocks. The alternative conceptual models were implemented and evaluated in the saturated zone flow model base case.

Response to AIN-1 #4–As the water-level report (USGS 2001) was being prepared, there were only two water levels for borehole NC-EWDP-7S, and no subsurface information was available. Contouring the 830-m potentiometric level would have produced an anomalously high bull's-eye pattern that was unjustified based on available data. With no additional evidence, it was assumed that the water level represented a perched condition. Since the water-level report (USGS 2001) was written, data from a new Nye County borehole, borehole NC-EWDP-7SC, provides evidence for alternative interpretations other than perched-water conditions. Large downward gradients are observed between the deep and shallow monitored intervals at borehole NC-EWDP-1DX (head difference of 38 m) and NC-EWDP-7SC (head differences ranging from about 9 m to as much as 78 m). The depth-to-water at both of these locations is anomalously shallow and probably represents locally perched conditions or the presence of a low permeability

confining unit close to the surface that effectively impedes the downward migration of water to the more contiguous tuff and alluvium aquifers at greater depths.

Borehole NC-EWDP-7SC is completed at 4 depth intervals. The head in the uppermost interval is high, about 818 m, but heads decrease with depth to a level of about 740 m. However, the rocks appear to be at least partially saturated below the uppermost water-bearing zone. The high water levels in the uppermost zone may be partially perched by clay layers present below the uppermost zone. This is similar to conditions in Ash Meadows, although water levels there are above the land surface. Water-quality data from borehole NC-EWDP-7S indicate that the water may be more related to carbonate-aquifer water than volcanic-aquifer water. Another possible explanation raised by Nye County consultants (Questa Engineering Corporation 2002) suggests that results for spinner surveys and a 48-hour pump test indicate that the borehole (NC-EWDP-7S and NC-EWDP-7SC) was insufficiently developed and that lower screens monitored zones of lower permeability. The testing also suggested that there was a zone of severely damaged formation in the immediate vicinity of the borehole consistent with the history of large amounts of polymer and bentonite gel mud being lost to the hole during completion. Thus, data from this borehole are questionable. Because it is distant from the predicted flow paths from Yucca Mountain and outside of the compliance boundaries, the effect of the uncertainty in this data is minor relative to potential radionuclide transport to the accessible environment.

The information in this report is responsive to agreement USFIC 5.08 AIN-1 made between the DOE and NRC. The report contains the information that DOE considers necessary for the NRC to review for closure of this agreement.

C.4 BASIS FOR THE RESPONSE

The basis for the response to the request for an updated potentiometric surface, an analysis of vertical gradients, and additional information regarding specific issues about the potentiometric surface are provided below. Additional related discussion can be found in Sections 2.2.2 and 2.3.3.

C.4.1 Updated Potentiometric Surface

The analysis of water level data was updated (USGS 2001) and provided as part of the original response. That analysis included water level data collected through December 2000, including water-level data obtained from the expanded Nye County Early Warning Drilling Program and data from borehole USW WT-24. Using standard practices, in a manner similar to USGS (2000), a potentiometric surface map representative of the upper part of the saturated zone in the early 1990s was generated. Besides new water level data, the primary difference in the approach taken to generate the new potentiometric surface was the assumption that water levels in the northern portion of the model domain, acquired from boreholes USW G-2 and UE-25 WT#6, represent perched conditions rather than a continuous regional potentiometric surface. As a result, the revised potentiometric surface map represents an alternative concept from that presented by the USGS (2000) for the large hydraulic gradient area north of Yucca Mountain. Another difference in the preparation of the two maps is the use of hand contouring for the USGS (2001) map rather than using an automated (computerized) contouring approach.

The older (USGS 2000, Figure 1-2) and newer (USGS 2001, Figure 6-1) potentiometric surface maps are similar (potentiometric contours are similar). The most important difference is the portrayal of the large hydraulic gradient area north of Yucca Mountain. The concept that water levels in boreholes USW G-2 and UE-25 WT#6 represent perched conditions is used to create the newer potentiometric surface map (USGS 2001, Figure 6-1). Neglecting the data from those two boreholes, the large hydraulic gradient is reduced from about 0.11 m/m (Tucci and Burkhardt 1995, p. 9) to between 0.06 m/m to 0.07 m/m, and the potentiometric contours are more widely spaced. Another important difference is that potentiometric contours are no longer offset where they cross faults. Such offsets (USGS 2000) are not expected where the contours are perpendicular or nearly perpendicular to fault traces. Direct evidence of offset, which would be provided by boreholes that straddle the fault, does not exist at Yucca Mountain. Faults were used, however, to help in the placement of contours that are oriented parallel or approximately parallel to faults. The contour interval used in the newer map (USGS 2001, Figure 6-1) is somewhat different from that used in the older map (USGS 2000, Figure 1-2), which used a uniform contour interval of 25 m. The contour interval used in the newer (USGS 2001) map has an interval of 50 m for contours greater than 800 m, and 25 m is used for contours less than 800 m. Two additional contours, 730 m and 720 m, are included in the newer map (USGS 2001). The inclusion of these contours helps to visualize the effect of the fault along Highway 95 (south of Yucca Mountain) on the groundwater flow system. USGS (2000) maps were used as input for the base case model. Data from the *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* report (USGS 2001) was used as, and evaluated as, an alternative conceptual model.

The current potentiometric surface analysis (USGS 2001) and analyses in previously published reports imply that a hydraulically well-connected flow system exists within the uppermost saturated zone (Tucci and Burkhardt 1995).

Water-level data from Nye County Phase 3 and Phase 4 boreholes, drilled since completion of the current report (USGS 2001) provide an update to the potentiometric surface south of Yucca Mountain. Nye County Phase 3 boreholes include boreholes NC-EWDP-10S, NC-EWDP-18P, NC-EWDP-22S, and NC-EWDP-23S at the south end of Jackass Flats. Water levels from these boreholes range from about 724 m to about 728 m. The 720-m and 725-m potentiometric contours based on these data would be placed south of those shown on the current potentiometric surface map (USGS 2001). The revised placement of these contours results in a hydraulic gradient in Jackass Flats of less than 0.0001 m/m, which is less than that in the previous report (USGS 2001; i.e., 0.0001 m/m to 0.0004 m/m). Nye County Phase 4 boreholes NC-EWDP-16P, NC-EWDP-27P, and NC-EWDP-28P were drilled directly south of Yucca Mountain, north of the Lathrop Wells Cone, and west of the Stagecoach Road fault. Water levels from these boreholes ranged from 729 to 730 m and were from 2 m to more than 10 m less than levels that can be interpolated from the contours shown for that area in the newer report (USGS 2001). Revised potentiometric contours in this area would have the 730-m contour placed about 1.5 to 2 km to the west of the position shown in the water-level report (USGS 2001) and would result in flow vectors in a more southerly direction for groundwater flow south of Yucca Mountain. This is being assessed in the total system performance assessment for the license application.

C.4.2 Analysis of Vertical Gradients

Within the SSFM area (USGS 2001, Figure 1-1), 18 boreholes are currently used to monitor water levels in more than one vertical interval (Table C-2). These intervals were selected to monitor water levels between different geologic units or between different permeable intervals within the same geologic unit. Water-level data from these boreholes allow for the calculation of the difference in potentiometric heads at each monitored interval. Upward (head increases with depth) and downward (head decreases with depth) vertical gradients have been observed. Fewer downward gradients (6 cases) are observed than upward gradients (12 cases). Upward vertical head differences range from 0.1 m to almost 55 m, and downward vertical head differences range from 0.5 m to 78 m.

Table C-2. Vertical Head Differences

Borehole	Open Interval (m below land surface)	Potentiometric Level (m above sea level)	Head Difference deepest to shallowest intervals (m)
USW H-1 tube 4	573-673	730.94	54.7
USW H-1 tube 3	716-765	730.75	
USW H-1 tube 2	1097-1123	736.06	
USW H-1 tube 1	1783-1814	785.58	
USW H-3 upper	762-1114	731.19	28.9
USW H-3 lower	1114-1219	760.07	
USW H-4 upper	525-1188	730.49	0.1
USW H-4 lower	1188-1219	730.56	
USW H-5 upper	708-1091	775.43	0.2
USW H-5 lower	1091-1219	775.65	
USW H-6 upper	533-752	775.99	2.2
USW H-6 lower	752-1220	775.91	
USW H-6	1193-1220	778.18	
UE-25 b#1 upper	488-1199	730.71	-1.0
UE-25 b#1 lower	1199-1220	729.69	
UE-25 p#1 (volcanic)	384-500	729.90	21.4
UE-25 p#1 (carbonate)	1297-1805	751.26	
UE-25 c#3	692-753	730.22	0.4
UE-25 c#3	753-914	730.64	
USW G-4	615-747	730.3	-0.5
USW G-4	747-915	729.8	
UE-25 J -13 upper	282-451	728.8	-0.8
UE-25 J -13	471-502	728.9	
UE-25 J -13	585-646	728.9	
UE-25 J -13	820-1063	728.0	
NC-EWDP-1DX (shallow)	WT-419	786.8	-38.0
NC-EWDP-1DX (deep)	658-683	748.8	
NC-EWDP-2D (volcanic)	WT-493	706.1	7.6
NC-EWDP-2DB (carbonate)	820-937	713.7	

Table C-2. Vertical Head Differences (Continued)

Borehole	Open Interval (m below land surface)	Potentiometric Level (m above sea level)	Head Difference deepest to shallowest intervals (m)
NC-EWDP-3S probe 2	103-129	719.8	-1.5
NC-EWDP-3S probe 3	145-168	719.4	
NC-EWDP-3D	WT-762	718.3	
NC-EWDP-4PA	124-148	717.9	5.7
NC-EWDP-4PB	225-256	723.6	
NC-EWDP-7SC probe 1	24-27	818.1	
NC-EWDP-7SC probe 2	55-64	786.4	
NC-EWDP-7SC probe 3	82-113	756.6	-77.9
NC-EWDP-7SC probe 4	131-137	740.2	
NC-EWDP-9SX probe 1	27-37	766.7	0.1
NC-EWDP-9SX probe 2	43-49	767.3	
NC-EWDP-9SX probe 4	101-104	766.8	
NC-EWDP-12PA	99-117	722.9	2.2
NC-EWDP-12PB	99-117	723.0	
NC-EWDP-12PC	52-70	720.7	
NC-EWDP-19P	109-140	707.5	5.3
NC-EWDP-19D	106-433	712.8	

Source: Based on USGS 2001, Table 6-1.

NOTE: Negative values indicate downward gradient.

Only two sites, UE-25 p#1 and NC-EWDP-2D/2DB (Table C-2), provide information on vertical gradients between volcanic rocks and the underlying Paleozoic carbonate rocks. At borehole UE-25 p#1, water levels currently are monitored only in the carbonate aquifer; however, water-level data were obtained from within the volcanic rocks as the borehole was drilled and tested. At this site, water levels in the Paleozoic carbonate rocks are about 20 m higher than those in the overlying volcanic rocks. Borehole NC-EWDP-2DB penetrated Paleozoic carbonate rocks toward the bottom of the borehole (Spengler 2001). Water levels measured in the deep part of the borehole are about 6 m higher than levels measured in volcanic rocks penetrated by borehole NC-EWDP-2D (for NC-EWDP-2DB, DTN: MO0306NYE05111.151; for NC-EWDP-2D, DTN: MO0306NYE05354.152).

Water levels monitored in the lower part of the volcanic-rock sequence are higher than levels monitored in the upper part of the volcanics. Boreholes USW H-1 (tube 1) and USW H-3 (lower interval) monitor water levels in the lower part of the volcanic-rock sequence, and upward gradients are observed at these boreholes (head differences of 54.7 m, and 28.9 m, respectively). The gradient at USW H-3 is not completely known because the water levels in the lower interval had been rising continuously before the packer that separates the upper and lower intervals failed in 1996.

An upward gradient is observed between the alluvial deposits monitored in borehole NC-EWDP-19P and the underlying volcanic rocks monitored in borehole NC-EWDP-19D. The vertical head difference at this site is 5.3 m; however, levels reported for NC-EWDP-19D represent a composite water level for alluvium and volcanics, so the true head difference between those units is not known.

Downward gradients also are observed within the SSFM area. The largest downward gradient is between the deepest and shallowest monitored intervals at borehole NC-EWDP-7SC (i.e., head difference of nearly 80 m). The depth to water at this site is shallow (20 m) and within Tertiary spring deposits. Other downward gradients are smaller. In all, vertical gradient information is consistent with its implementation in the SSFM. Additional discussion is provided in Appendix D, Section D.4.2.

In summary, a discussion of the updated potentiometric surface and vertical hydraulic gradient analyses has been provided. The two analyses demonstrate the relationship of water level elevations in the subject boreholes to the potentiometric surface and use in the flow modeling. This response should provide the additional information requested as well as the technical basis for the response.

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C.5.2 Source Data, Listed by Data Tracking Number

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