APPENDIX D

REGIONAL MODEL AND CONFIDENCE BUILDING (RESPONSE TO USFIC 5.02, USFIC 5.12, AND USFIC 5.11 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 D

REGIONAL MODEL AND CONFIDENCE BUILDING (RESPONSE TO USFIC 5.02, USFIC 5.12, AND USFIC 5.11 AIN-1)

This appendix provides a response for Key Technical Issue (KTI) agreements Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) 5.02, USFIC 5.12, and an additional information needed (AIN) request on USFIC 5.11. These KTI agreements relate to providing more information about the use of the regional-scale model in the site-scale saturated zone flow model (SSFM) and the Solitario Canyon alternative conceptual model.

D.1 KEY TECHNICAL ISSUE AGREEMENTS

D.1.1 USFIC 5.02, USFIC 5.12, and USFIC 5.11 AIN-1

KTI agreements USFIC 5.02, USFIC 5.12, and USFIC 5.11 were 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 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).

At the NRC/DOE technical exchange, the DOE explained that it had used mathematical groundwater models that: (1) incorporated site-specific climatic and subsurface information, (2) were reasonably calibrated and reasonably represented the physical system, (3) used fitted aquifer parameters that compared reasonably well with observed site data, (4) implicitly or explicitly incorporated simulated fracturing and faulting that were consistent with the geologic framework model and hydrogeologic framework model (HFM), (5) produced abstractions that were based on initial and boundary conditions consistent with site-scale modeling and the regional model of the Death Valley groundwater flow system, and (6) produced abstractions for use in performance assessment simulations using appropriate spatial and temporal averaging techniques.

The NRC asked several questions regarding the analysis of alternative conceptual models and the propagation of such models through performance assessment. The NRC also asked if permeabilities along the Solitario Canyon fault could be revised to permit additional flow from Crater Flat into the regional deep aquifer beneath Yucca Mountain. The NRC indicated, that in this way, the model could be used to evaluate alternate conceptual flow models. The DOE indicated this alternative model could be evaluated.

Wording of these agreements is:

USFIC 5.02

> Provide the update to the saturated zone PMR, considering the updated regional flow model. A revision of the Saturated Zone Flow and Transport PMR is expected to be available and will reflect the updated United States Geological

Survey (USGS) Regional Groundwater Flow Model in FY 2002, subject to receipt of the model report from the USGS (reference item 9).

"Reference item 9" refers to agreement USFIC 5.09.

USFIC 5.12

Provide additional supporting arguments for the Site-Scale Saturated Zone Flow model validation or use a calibrated model that has gone through confidence-building measures. The model has been calibrated and partially validated in accordance with AP 3.10Q, which is consistent with NUREG-1636. Additional confidence-building activities will be reported in a subsequent update to the Calibration of the Site-Scale Saturated Zone Flow Model AMR, expected to be available during FY 2002.

USFIC 5.11

In order to test an alternative conceptual flow model for Yucca Mountain, run the saturated zone flow and transport code assuming a north-south barrier along the Solitario Canyon fault whose effect diminishes with depth or provide justification not to. DOE will run the saturated zone flow and transport model assuming the specified barrier and will provide the results in an update to the Calibration of the Site-Scale Saturated Zone Flow Model AMR expected to be available during FY 2002.

A letter report responding to KTI agreement USFIC 5.11 (Ziegler 2002) was submitted. The NRC requested specific additional information after the staff review of this letter report, resulting in USFIC 5.11 AIN-1 (Schlueter 2003).

Wording of the additional information need request is:

USFIC 5.11 AIN-1

1. To examine flow and potential radionuclide transport in the deeper aquifer system, a vertical cross- sectional figure showing the flowpaths is needed. As an example, the left diagram of Figure 8 in the Calibration of the Site-Scale Saturated Zone Flow Model AMR (CRWMS M&O 2000) shows such a cross-sectional view. Two such particle tracking figures showing distance vs. depth are needed: one for the calibrated model and another for the shallow Solitario Canyon Fault alternative model.

2. To test the hypothesis that potential contaminant releases on the west side of a shallow Solitario Canyon Fault might enter the lower carbonate aquifer, DOE should provide an analysis of flow paths from the west side of a shallow Solitario Canyon Fault. Alternatively, DOE could provide an explanation of repository design and site characteristics that would preclude contaminant releases to the west side of the Solitario Canyon Fault.

The DOE responded to the NRC on April 9, 2003 (Ziegler 2003) and agreed to provide information that would satisfy USFIC 5.11 AIN-1.

D.1.2 Related Key Technical Issue Agreements

None.

D.2 RELEVANCE TO REPOSITORY PERFORMANCE

The subject of these agreements is related to the confidence building activities for the SSFM (BSC 2001), the evaluation of new data and new analyses, including the regional groundwater flow model in relation to the updated SSFM, and the evaluation of alternative conceptual models. These subjects directly affect saturated zone flow models and, therefore, the flow paths from the repository to the compliance boundary.

The site-scale area lies within the Alkali Flat-Furnace Creek groundwater basin, which is part of the larger Death Valley regional groundwater flow system. The Death Valley regional flow system model (i.e., the DVRFS model; D'Agnese et al. 1997; D'Agnese et al. 2002) provides a representation of the groundwater flow patterns within the Alkali Flat-Furnace Creek groundwater basin that can be used to define boundary conditions and calibration targets for the SSFM. Accordingly, constant-potential boundary conditions and distributed boundary fluxes for the SSFM were derived from the DVRFS model. Recharge from the site-scale unsaturated zone model area and from Fortymile Wash also is included in the SSFM. These boundary fluxes were used as calibration targets for SSFM.

Additional discussion on this topic is presented in Section 2.2, which describes the regional and site-scale models used to assess the flow of groundwater and transport of potential radionuclides in the saturated zone beneath and downgradient from Yucca Mountain. Regional and site-scale geochemical interpretations (Section 2.3) were used to develop confidence in the site-scale flow and transport representation.

D.3 RESPONSE

Response to USFIC 5.02–Analyses of fluxes extracted from the DVRFS2002 model (update of U.S. Geological Survey regional groundwater flow model), is documented in *Site-Scale Saturated Zone Flow Model* (BSC 2003a). The *Saturated Zone Process Model Report* (CRWMS M&O 2000a) will not be revised. The relevant content of the Process Model Report has effectively been included in the technical basis document. The technical basis document reflects the updated U.S. Geological Survey regional groundwater flow model.

The regional-scale DVRFS1997 model (D'Agnese et al. 1997) was used in the development and calibration of the SSFM (BSC 2001). The DVRFS2002 model (D'Agnese et al. 2002) was used as part of the validation and confidence building of the SSFM documented in *Site-Scale Saturated Zone Flow Model* (BSC 2003a).

Response to USFIC 5.12–*Site-Scale Saturated Zone Flow Model* (BSC 2003a, Section 7) documents confidence building through model validation using water level, hydrogeologic, and temperature data that were not used in developing and calibrating the SSFM.

A comparison of predicted and observed water levels from newly drilled Nye County Early Warning Drilling Program (EWDP) boreholes demonstrated that the SSFM can reliably predict water levels and gradients along the flow path downgradient from the repository. Differences between observed and predicted hydraulic gradients along the flow path showed minimal affects on specific discharge. A comparison of alluvium permeability values calculated from Alluvial Testing Complex (ATC) tests with the calibrated permeability value indicated close agreement. Differences between observed and calibrated permeability on specific discharge along the flow path also showed minimal affects. The combined effects of difference between observed and predicted hydraulic gradients and permeability values on specific discharge in the area of the ATC similarly indicated minimal effects. The comparison of flow paths predicted by the SSFM and those indicated by hydrochemical analyses demonstrated close agreement between flow paths, and flow paths derived from hydrochemical analyses generally enveloped those predicted by the SSFM. In addition, thermal modeling indicated that thermal models, developed from the SSFM, were capable of modeling thermal transport in the saturated zone.

Response to USFIC 5.11 AIN-1 (Comment #1 and Comment #2)–To investigate the importance of the depth of the Solitario Canyon fault, an alternative conceptualization was simulated in which the fault only extended from the water table to the top of the carbonate aquifer (BSC 2003a; see also Section D.4.3). This alternative, referred to as the shallow fault alternative model, was identical to the SSFM in all respects except for properties of the Solitario Canyon fault. The shallow fault alternative model only changed the computation grid where necessary to implement the alternate formulation of the fault. The shallow fault alternative model was calibrated in a manner identical to the SSFM. Areal and vertical slice flow paths for the different model scenarios are illustrated in Figures D-15 through D-18. For each of these figures, the left side shows the flow paths in vertical cross-section, and the right side shows the corresponding flow paths in map view.

Simulations using the two conceptualizations of the Solitario Canyon fault (original and alternate) produced essentially the same results, and the simulated water levels, hydraulic gradients, and transport pathways were little affected by the alternative conceptualization. Both conceptualizations yielded the same flow paths from the water table under the repository to the accessible environment, and transport times were not affected by the depth of the fault. The influence of reducing the depth of the Solitario Canyon fault on total system performance is expected to be minor. This alternative conceptualization resulted in no major changes to the flow system and has no consequences for radionuclide transport.

Based on current designs, the repository will be located east of the Solitario Canyon fault. A study of potential radionuclide flow paths in the unsaturated zone indicated that a negligible number of particles would reach the water table west of Solitario Canyon fault within the 10,000-year regulatory period. Therefore, the alternative conceptualizations of the Solitario Canyon fault have little effect on transport in the saturated zone.

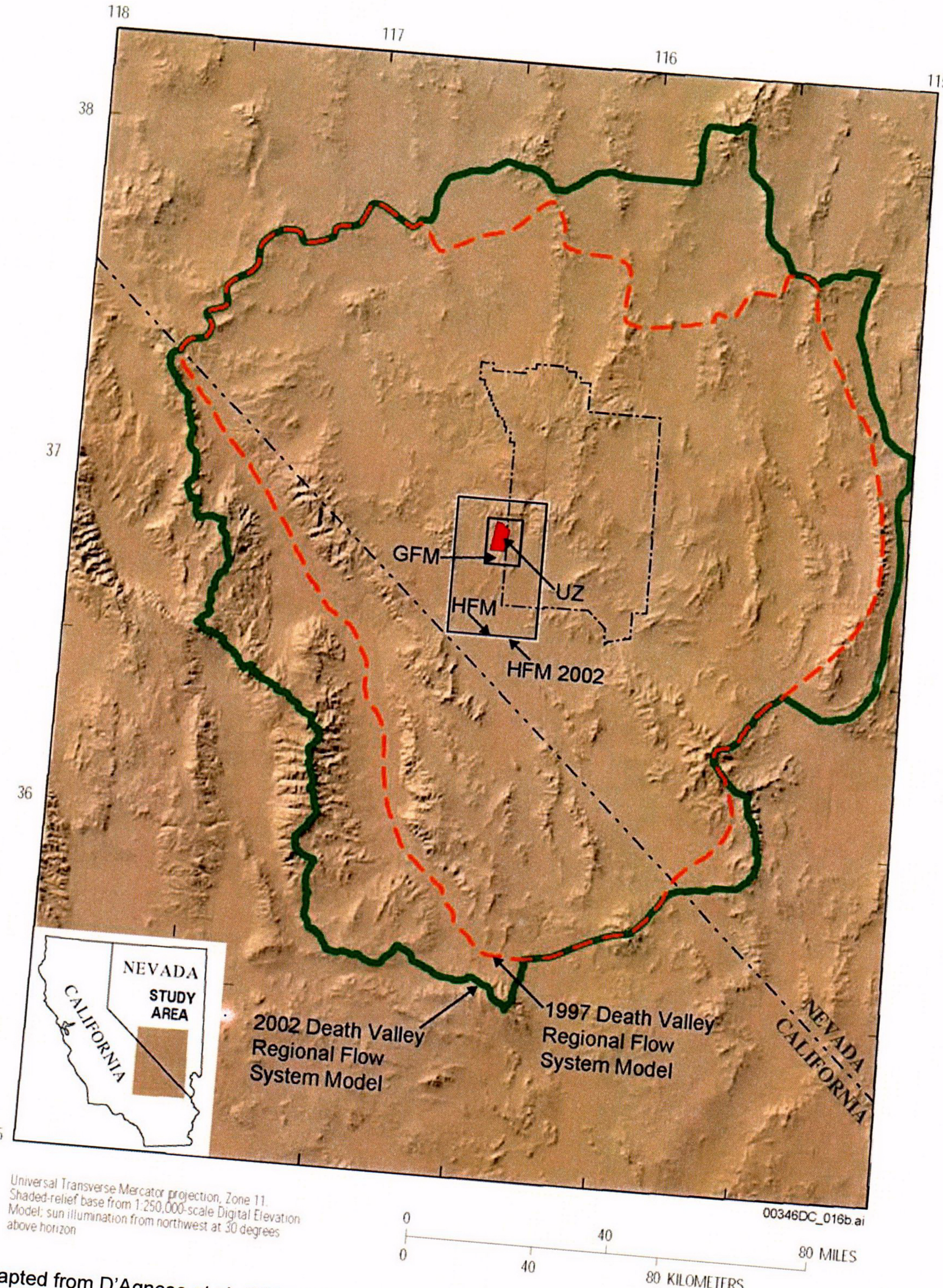
The information in this report is responsive to agreements USFIC 5.02, USFIC 5.12, and USFIC 5.11 AIN-1 made between the DOE and NRC. The report contains the information that DOE considers necessary for the NRC to review for closure of these agreements.

D.4 BASIS FOR THE RESPONSE

D.4.1 Use of the Regional Model (USFIC 5.02)

The domain of the (regional model) DVRFS2002 model is large (Figure D-1), covering about 70,000 km^2, and includes natural groundwater divides and discharge areas (D'Agnese et al. 2002). The domain of the SSFM, which lies within the domain of the DVRFS models, includes only 2 percent of the area of the larger model. Section 2.2.3 describes the DVRFS2002 model and its use in conceptual understanding relevant to modeling and in assessing the potential flow and transport of radionuclides in the saturated zone beneath and downgradient from Yucca Mountain.

Because the DVRFS1997 model covers the entire DVRFS and incorporates the discharge zones and groundwater divides, regional fluxes can be predicted using the DVRFS1997 model. These regional flux predictions are useful for constraining the SSFM because the SSFM does not include discharge areas and it uses fixed-head boundary conditions. Consequently, the DVRFS1997 model (D'Agnese et al. 1997) was used to identify fluxes along the boundaries of the SSFM used as calibration targets. The boundary of the SSFM domain was divided into zones (Figure D-2), and fluxes were derived from the DVRFS1997 model for each zone (Table D-1). The flux targets and SSFM results are shown in Table D-1. Table D-1 also identifies which boundary segments were used as calibration targets.



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

NOTE: HFM boundaries are coincident with the boundaries of the SSFM.

Figure D-1. Boundaries of Regional and Site-Scale Models in Relation to the Nevada Test Site

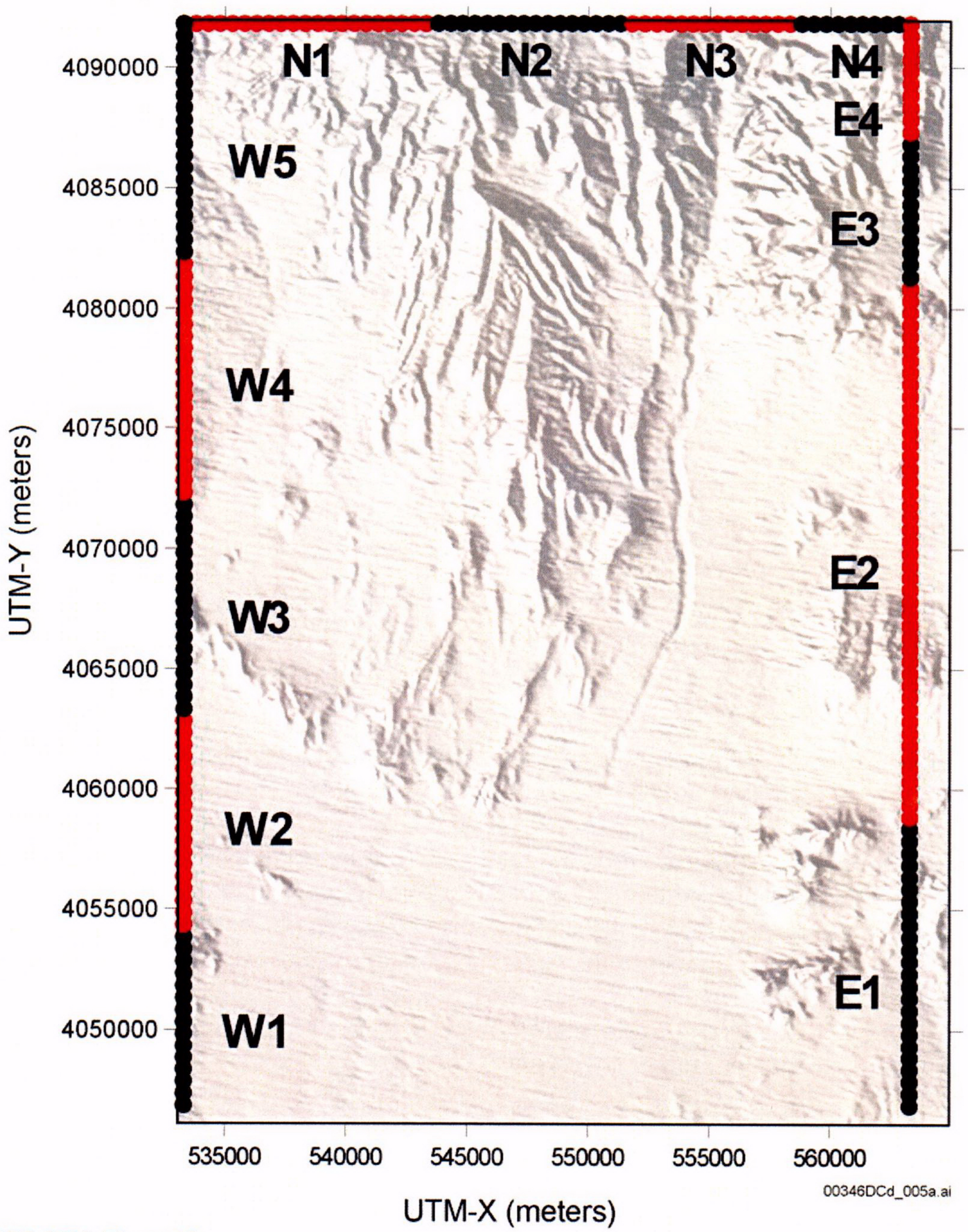
Table D-1. Regional and Site-Scale Fluxes

Boundary Zone	Regional Flux (kg/s)	Site-Scale Flux (kg/s)	Calibration Target
N1	–101	–60.0	Yes
N2	–16.5	–33.4	Yes
N3	–53.0	–30.6	Yes
N4	–18.4	–44.8	Yes
W1	3.45	4.17	No
W2	–71	–0.00719	No
W3	–6.9	–0.0000078	No
W4	2.73	–0.0000223	No
W5	–47.0	–6.85	No
E1	–555	–554	Yes
E2	–5.46	3.53	Yes
E3	2.65	16.5	Yes
E4	–3.07	16.8	Yes
S	918	724	No

Source: BSC 2001, Table 14.

NOTES: Negative values indicate flow into the model.
Information in the last column indicates whether the regional model flux for a zone was used as a calibration target for the SSFM. Regional fluxes are derived from DVRFS1997 (D'Agnese et al. 1997) and are precalibration targets. Site-scale fluxes are postcalibration results.
Some numbers in this table were rounded to three significant digits compared to those reported in the source document.

A comparison of the fluxes on the northern and eastern boundaries indicates a reasonable match between the two models (Table D-1) within the uncertainty range of the regional model water budget (see Section 2.2.1). On the northern boundary, for example, the total flux for the DVRFS1997 model was 189 kg/s, while the total flux for the SSFM was 169 kg/s. However, the distribution was somewhat different. The match was good on the eastern boundary within the lower thrust area (Figure D-2, zone E1). The other zones along the eastern boundary showed small flows in both models. Because the western boundary fluxes were not used as a calibration target, the match between the two models was not as good on the western boundary. The southern boundary flux (the sum of the other boundary fluxes plus the recharge) also was a good match, considering the water budget uncertainty.



Source: BSC 2001, Figure 16.

Figure D-2. Zones Used for Comparing Regional and Site-Scale Fluxes

C02

The DVRFS1997 model (D'Agnese et al. 1997) was updated to the DVRFS2002 model (D'Agnese et al. 2002). Improvements included increasing the vertical resolution from 3 layers to 15, replacing permeability classes with nodal permeability values, and using an improved HFM. These and other enhancements to the DVRFS2002 model made it easier to compare estimates of fluxes along the boundary of the site-scale model domain. Fluxes along the boundaries of the SSFM predicted by the DVRFS1997 and DVRFS2002 models, respectively, are presented in Table D-2.

Table D-2. Site-Scale Boundary Fluxes Predicted by the DVRFS1997 and DVRFS2002 Models

DVRFS1997 Model [a]			DVRFS2002 Model [b]		
West Boundary					
From (m)	To (m)	Flux (kg/s)	From (m)	To (m)	Flux (kg/s)
4,046,780	4,054,280	3.45	4,046,500	4,052,500	210.45
4,054,280	4,063,280	−71.00	4,052,500	4,057,000	−0.08
4,063,280	4,072,280	−6.90	4,057,000	4,067,500	−56.12
4,072,280	4,082,780	2.73	4,067,500	4,085,500	−1.31
4,082,780	4,091,780	−46.99	4,085,500	4,091,500	−28.43
	Sum	−118.71		Sum	124.51
East Boundary					
From (m)	To (m)	Flux (kg/s)	From (m)	To (m)	Flux (kg/s)
4,046,780	4,058,780	−555.45	4,046,500	4,054,000	−69.71
4,058,780	4,081,280	−5.46	4,054,000	4,058,500	0.01
4,081,280	4,087,280	2.65	4,058,500	4,078,000	−138.06
4,087,280	4,091,780	−3.07	4,078,000	4,084,000	0.09
			4,084,000	4,091,500	−1.53
	Sum	−561.33		Sum	−209.21
North Boundary					
From (m)	To (m)	Flux (kg/s)	From (m)	To (m)	Flux (kg/s)
533,340	543,840	−101.24	533,000	545,000	−219.47
543,840	551,840	−16.48	545,000	552,500	−57.07
551,840	558,840	−63.39	552,500	558,500	6.90
558,840	563,340	−18.41	558,500	563,000	−1.39
	Sum	−199.52		Sum	−271.03
South Boundary					
From (m)	To (m)	Flux (kg/s)	From (m)	To (m)	Flux (kg/s)
533,340	563,340	918.00	533,000	563,000	430.02
Total Fluxes (kg/s)					
	Sum	38.44		Sum	74.30

Source: BSC 2003a, Table 7.5-5.

NOTE: [a] Extracted from the DVRFS1997 model (D'Agnese et al. 1997)
[b] Extracted from the DVRFS2002 model (D'Agnese et al. 2002)

The boundary flux targets changed from the DVRFS1997 to the DVRFS2002 models (Table D-2). The biggest differences occur on the east and west sides of the model domain. In particular, the thrust zone in the southeastern corner of the model area was removed from the

DVRFS2002 model. As a result, the flux target decreased from -555.45 kg/s to -69.71 kg/s in the southern-most zone on the eastern boundary. The boundary fluxes along the western boundary are significantly different (-118.71 kg/s to 124.51 kg/s), but this difference is attributed to outflow from the southwestern portion of the site-scale model domain becoming more westerly (i.e., exiting from zone W1 of Figure D-2). If the outflow from this zone (210.45 kg/s) is added to the total flux out of the southern boundary (430.02 kg/s), the net outflow (640.47 kg/s) is similar to that of the DVRFS1997 model, especially considering the significantly reduced influx across the thrust zone. Again, these differences are within the range of uncertainty in the regional water budget presented in Section 2.2.1.

In summary, the updated DVRFS2002 model has been considered in the evaluation of regional and site-scale flow patterns in the vicinity of Yucca Mountain.

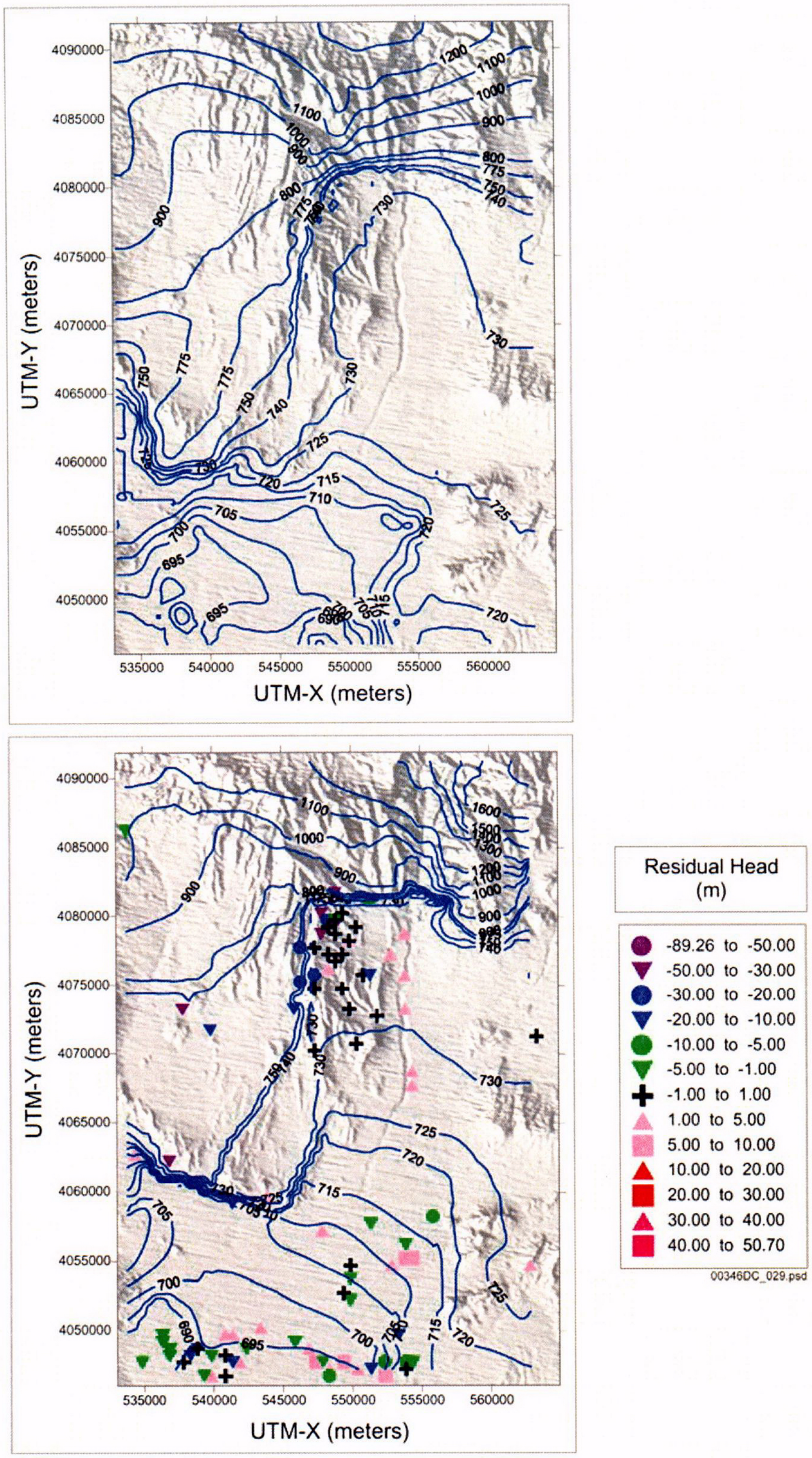
D.4.2 Additional Confidence-Building Activities for the SSFM (USFIC 5.12)

The SSFM, developed for the total system performance assessment for the site recommendation (CRWMS M&O 2000b), has undergone additional validation and confidence building activities. The results of these activities are documented in *Site-Scale Saturated Zone Flow Model* (BSC 2003a). The SSFM also was used to evaluate alternative conceptual models and to conduct sensitivity analyses. The SSFM produces output (flow fields and fluxes) that are used as input to the saturated zone transport model that generate radionuclide breakthrough curves for use in the total system performance assessment for the license application.

The SSFM provides the flow component to the site-scale saturated zone flow and transport model, which is an analysis tool that facilitates the understanding of solute transport in the aquifers beneath and downgradient from the repository. This model also is a computational tool used for predicting radionuclide migration in the saturated zone. The SSFM must be validated for its intended use, that is, "confidence that a mathematical model and its underlying conceptual model adequately represents with sufficient accuracy the phenomenon, process, or system in question" (AP-SIII.10Q, *Models*, Section 3.14) must be established. Confidence-building activities include predevelopment and postdevelopment activities. Predevelopment activities consisted of using field and laboratory testing to identify pertinent processes and to derive model parameters, using established mathematical formulations to describe pertinent processes, and using calibration processes to estimate hydraulic parameters that best fit the field data. Postdevelopment confidence building activities consisted of comparing observed and predicted water levels, comparing permeability data to calibrated permeability values, comparing hydrochemical data trends to calculated particle pathways, comparing predicted groundwater velocity estimates to velocity estimates from ATC single-borehole tracer tests, and thermal modeling. The results of these confidence-building activities are summarized below.

Water Levels–The adequacy of the model can be assessed by its ability to accurately predict observed water levels and the observed potentiometric surface. The model is calibrated through an optimization process that seeks to minimize differences between observed and predicted water levels at each target location by adjusting permeability and boundary flux parameters in the model. Observed and predicted water levels at each target water-level location are presented in *Site-Scale Saturated Zone Flow Model* (BSC 2003a, Table 6.6-1).

Predicted and observed potentiometric surfaces, as well as residual water levels (i.e., differences between predicted and observed) at each water-level target location, are presented in Figure D-3. The average, unweighted residual over the entire model domain is 30 m. However, large residuals are distributed unevenly throughout the domain (Figure D-3). The largest residuals (about 100 m) are located in the northern part of the model domain in the high-gradient area. These head values largely are the result of the low weighting factor applied during calibration and the uncertainty in these measurements, possibly due to perched conditions. Higher weights are applied to observation points in areas of greatest significance, principally along the flow paths from the repository, so that good calibration is obtained there. The next highest group of head residual values borders the east-west barrier and Solitario Canyon fault. These residuals (about 50 m) likely result from the inability of the 500-m grid blocks to resolve the 50-m drop (780-m to 730-m) in head that occurs over a short distance just east of these features. Residuals east and southeast of the repository in Fortymile Wash area generally are small (Figure D-3). This is the expected flow path from the repository, and the generally good agreement between predicted and observed water levels in this area provides confidence that the calibrated SSFM reliably simulates flow from the repository.



Source: BSC 2003a, Figure 6.6-2.

Figure D-3. Observed (Upper) and Simulated (Lower) Potentiometric Surfaces with Residuals

C03

The predicted and observed potentiometric surfaces are similar (Figure D-3). It should be noted that both surfaces are contoured and that the data distribution for both surfaces is not uniform. Evident are the low-gradient region in the Fortymile Wash region, the high-gradient region north of Yucca Mountain, and the flow disruption caused by the Solitario Canyon fault. These results indicate that the model, at least qualitatively, represents the current water table in the vicinity of Yucca Mountain.

Since the SSFM was calibrated, a number of boreholes have been installed or deepened as part of the Nye County EWDP. Comparison of the water levels in the new boreholes with water levels predicted by the SSFM offers an opportunity to validate the SSFM using new data not available during calibration.

The SSFM was calibrated using 115 water-level and head measurements, eight of which were from Nye County EWDP boreholes. With the addition of the Nye County boreholes, 26 water-level observations are now available in the Nye County EWDP area (southern part of the model domain (Table D-3 Figure D-4). The SSFM was used to predict water levels at the location and depth of each of these additional boreholes (Table D-3). Water-level data from newly completed intervals in existing boreholes are now available and, for this comparison, replace water levels previously available at these locations (Table D-3). Although water levels from boreholes NC-EWDP-2D, NC-EWDP-3D, and NC-Washburn-1X were previously used as calibration targets, water levels from these boreholes also are included in Table D-3.

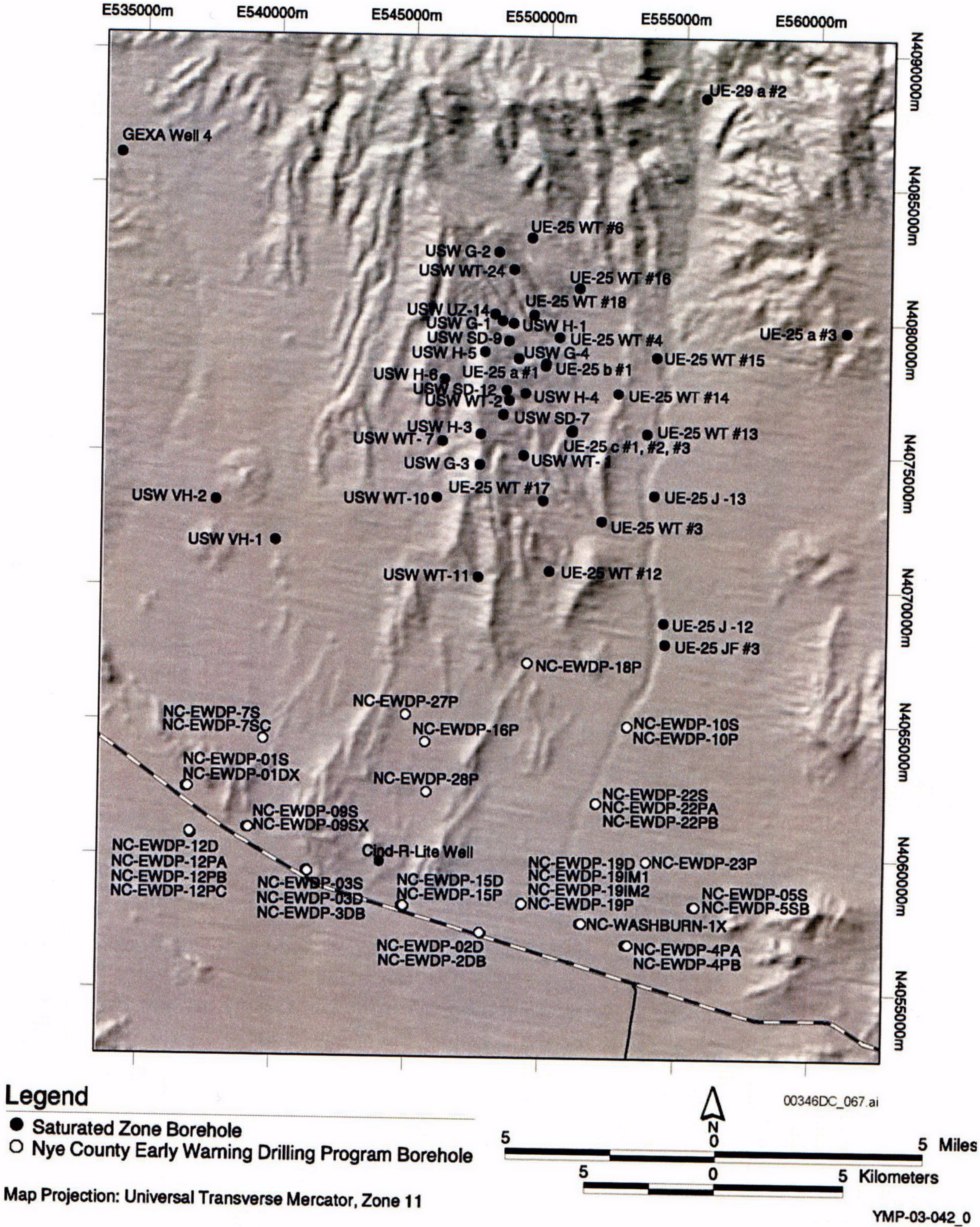
Residuals from predicted and observed water levels (Table D-3) were used to evaluate the calibrated SSFM. The magnitude of the residuals depends on the borehole location. Residuals generally were higher in the western portion of the Nye County EWDP area. The gradients are steeper in this area and the SSFM generally is less capable of predicting these rapid water level changes. A detailed discussion of the residuals from this area is presented in *Site-Scale Saturated Zone Flow Model* (BSC 2003a, Section 7.1).

Table D-3. Observed and Predicted Water Levels at Nye County EWDP Boreholes

Borehole Name	UTM Easting (m)	UTM Northing (m)	Elevation (m) [a]	Observed Head (m)	Modeled Head (m) [b]	Residual Difference (m)
NC-EWDP-1DX, deep	536768	4062502	585.7	748.8	762.7	13.9
NC-EWDP-1DX, shallow	536768	4062502	133.1	786.8	756.7	–30.1
NC-EWDP-1S, P1	536771	4062498	751.8	787.1	767.3	–19.8
NC-EWDP-1S, P2	536771	4062498	730.8	786.8	767.3	–19.5
NC-EWDP-2DB	547800	4057195	–77	713.7	717.0	4.3
NC-EWDP-2D	547744	4057164	507.1	706.1	709.2	3.3
NC-EWDP-3D	541273	4059444	377.9	718.3	703.7	–14.6
NC-EWDP-3S, P2	541269	4059445	682.8	719.8	702.5	–17.3
NC-EWDP-3S, P3	541269	4059445	642.3	719.4	702.6	–16.8
NC-EWDP-5SB	555676	4058229	707.8	723.6	718.0	–6.6
NC-EWDP-9SX, P1	539039	4061004	765.3	766.7	731.7	–35.0
NC-EWDP-9SX, P2	539039	4061004	751.3	767.3	731.7	–35.6
NC-EWDP-9SX, P4	539039	4061004	694.8	766.8	731.7	–35.1
NC-Washburn-1X	551465	4057563	687.0	714.6	714.5	–0.1
NC-EWDP-4PA	553167	4056766	687.0	717.9	715.5	–2.4
NC-EWDP-4PB	553167	4056766	582.5	723.6	715.5	–8.1
NC-EWDP-7S[c]	539638	4064323	826.6	830.1	769.6	–60.5
NC-EWDP-12PA	536951	4060814	666.7	722.9	705.3	–17.6
NC-EWDP-12PB	536951	4060814	666.7	723.0	705.3	–17.7
NC-EWDP-12PC	536951	4060814	713.7	720.7	704.3	–16.4
NC-EWDP-15P	544848	4058158	716.9	722.5	711.0	–11.5
NC-EWDP-19P	549329	4058292	694.7	707.5	713.2	5.7
NC-EWDP-19D	549317	4058270	549.7	712.8	713.2	0.4
NC-EWDP-16P	545648	4064247	723.8	730.9	711.0	–19.9
NC-EWDP-27P	544936	4065266	724.9	730.3	713.2	–17.1
NC-EWDP-28P	545723	4062372	719.2	729.7	713.2	–16.5

Source: Based on BSC 2003a, Table 7.1-2.

NOTES: [a](elevation) refers to the midpoint of the open interval of an uncased well.
[b]Modeled head predicted using the SSFM.
[c]The single observed head was made after well completion. Initial heads observed during drilling are lower.



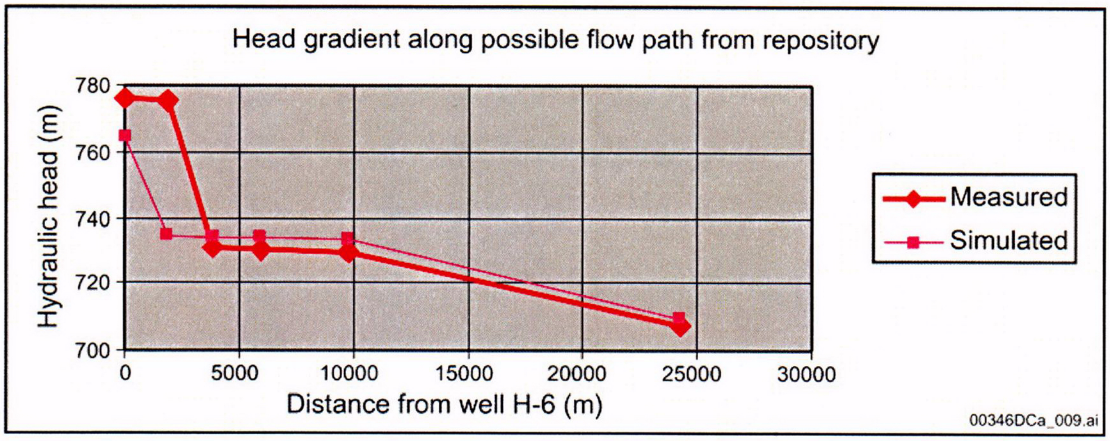
Sources: CRWMS M&O 2000a, Figure 3-7; DTNs: MO0105GSC01040.000, MO0106GSC01043.000, MO0203GSC02034.000, and MO0206GSC02074.000.

Figure D-4. Location of Boreholes Used to Characterize Groundwater Flow near Yucca Mountain

Residuals tend to be smaller in boreholes located farther to the east (ranging, for example, from -14.6 to –17.3 m in boreholes NC-EWDP-3S, -3D, and -3DB). With an observed residual of -11.5 m at NC-EWDP-15P, the residuals decrease in boreholes located farther east. At the NC-EWDP-19 boreholes (the ATC), the residuals improve, with values of +0.4 and +5.7 m, and other residuals in this area (NC-Washburn-1X, NC-EWDP-4, and NC-EWDP-5) are similarly small. These boreholes are in the predicted flow path from the repository. Thus, the additional water-level data confirm the capability of the SSFM to accurately predict water levels in this portion of the flow path.

For validation and confidence building, a comparison of hydraulic gradients along the flow path from the repository observed through field data and predicted by the SSFM was performed. These gradients directly affect predictions of specific discharge along the flow path, and they can be used to determine the effects of model error on the calculation of specific discharge.

Water-level data from six boreholes extending from near the repository to borehole NC-EWDP-19P are presented in Figure D-5.



Source: BSC 2003a, Figure 7.1-2.

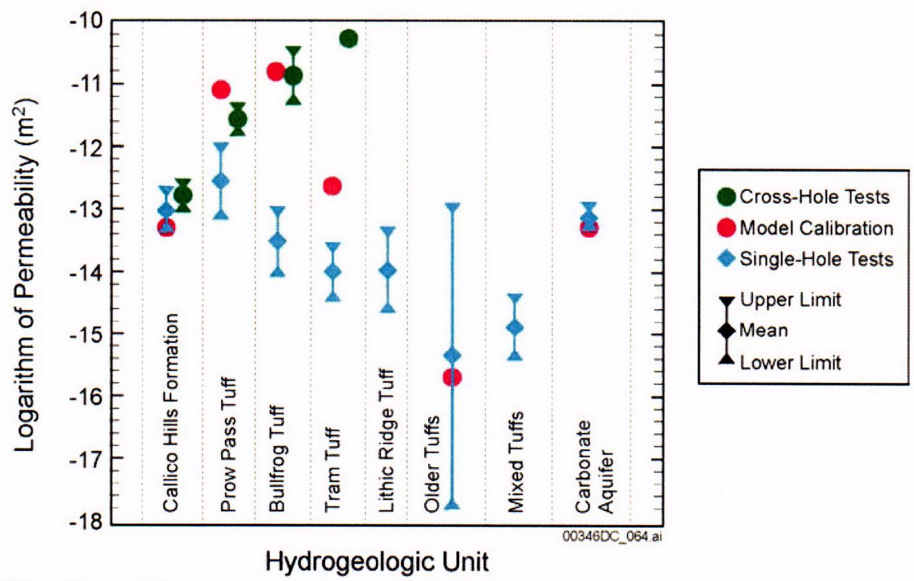
Figure D-5. Measured and Simulated Water Levels

The observed and predicted gradients along the flow path are in good agreement, except in the northernmost part of the flow path (Figure D-5). Discrepancies between boreholes USW H-6 and USW WT-2 (located about 3,500 m downgradient from USW H-6) are the result of the manner in which the model accounts for the effect of the splay of the Solitario Canyon fault, which lies near these boreholes. However, while the model does not accurately predict the precise location of the drop in head across the fault, the overall drop in head predicted between USW H-6 and USW WT-2 agrees reasonably well with the observed water levels.

Comparison of Permeability Data to Calibrated Permeability Values–The SSFM was calibrated by adjusting permeability values for individual hydrogeologic units until the sum of the weighted-residuals squared (the objective function) was minimized. The residuals include the differences between the measured and simulated hydraulic heads and the differences between the groundwater fluxes simulated using the regional and site-scale models. Permeabilities estimated from hydraulic tests were neither formally included in the calibration as prior information nor considered in the calculation of the objective function. Instead, field-derived permeabilities were used to guide the selection of bounds on the possible range of permeabilities considered during calibration and to check on the reasonableness of the final permeability estimates produced by the calibrated model. Consequently, a comparison of permeability data to calibrated permeability values can be used to provide confidence in the ability of SSFM to adequately represent saturated zone flow near Yucca Mountain. In addition, new permeability data are available from the ATC that were not used in calibrating the SSFM. Comparisons of the new measurements with calibrated permeability values provide a further opportunity to validate the model using new data.

Data are available for determining the permeability of individual hydrogeologic units at Yucca Mountain and the Nevada Test Site (BSC 2003a, Section 7.2). In addition, inferences about permeability can be drawn from regional observations.

Calibrated and measured permeabilities from Yucca Mountain (Figure D-6) and the Nevada Test Site (Figure D-7) were compared to determine if the estimated values were representative of measured values. Permeabilities from cross-hole tests conducted at the C-Wells complex also are shown (Figure D-6).



Source: BSC 2003a, Figure 7.2-1.

Figure D-6. Observed and Estimated Permeabilities from Yucca Mountain

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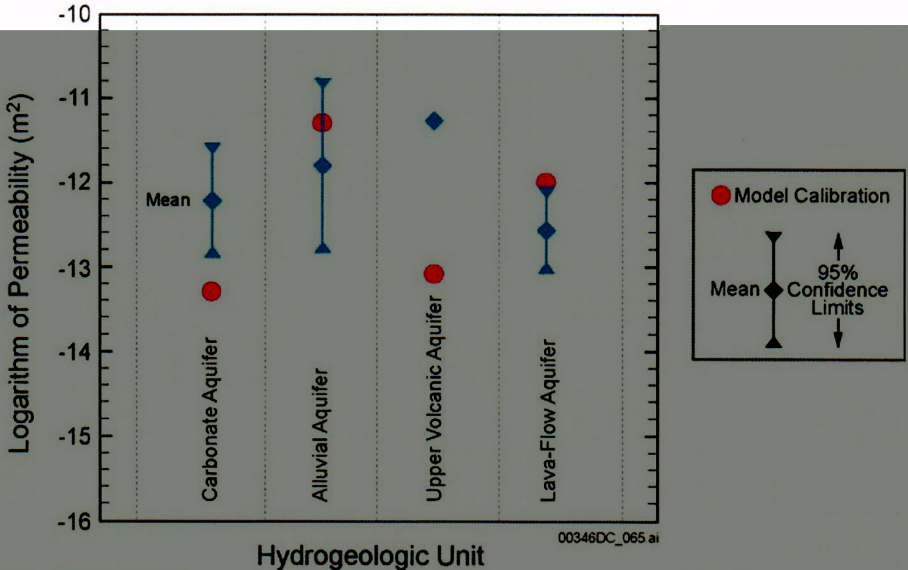

Source: BSC 2003a, Figure 7.2-2.

Figure D-7. Observed and Estimated Permeabilities from the Nevada Test Site

Calibrated permeabilities for the Calico Hills Formation, the Pre-Lithic Ridge Tuffs, and the carbonate aquifer are within the 95 percent confidence limits of the mean permeabilities estimated from single-hole pump test analyses at Yucca Mountain (Figure D-6). The calibrated permeability for the Bullfrog Tuff is within the 95 percent confidence limits of the mean-measured permeability determined from the cross-hole tests. The calibrated permeability of the Prow Pass Tuff is higher than the mean permeability estimated from the cross-hole tests, whereas the calibrated permeability of the Tram Tuff is between the mean permeabilities estimated for the unit from the single-hole and cross-hole tests (Figure D-6).

Except for the upper volcanic aquifer, the calibrated permeabilities are consistent with most of the permeability data from Yucca Mountain and the Nevada Test Site. The calibrated permeability of the Tram Tuff is lower than the mean permeability derived from the cross-hole tests, but higher than the permeability estimated from the single-hole tests. The relatively high permeability estimated for the Tram Tuff from the cross-hole tests may be partially attributable to local conditions at the C-Wells complex. A breccia zone is present in the Tram Tuff at boreholes UE-25 c#2 and UE-25 c#3 (Geldon et al. 1997, Figure 3), which may have caused a local enhancement in the permeability of the Tram Tuff.

Permeability data recently obtained from single-hole and cross-hole testing at the ATC were not included in Figure D-6. Single-borehole hydraulic testing of the saturated alluvium in borehole NC-EWDP-19D1 was conducted between July 2000 and November 2000. During this testing, a single-borehole test of the alluvial aquifer to a depth of 247.5 m below land surface was initiated to determine the transmissivity and hydraulic conductivity of the entire alluvium system at the NC-EWDP-19D1 location. Analyses of these data resulted in a permeability measurement of 2.7×10^{-13} m^2 for the alluvial aquifer (BSC 2003a, Section 7.2.1.2). A cross-hole hydraulic test was conducted in January 2002. During this test, borehole NC-EWDP-19D1 was pumped in the open-alluvium section, while water level measurements were made in two adjacent boreholes. The intrinsic permeability measured in this test for the tested interval was 2.7×10^{-12} m^2. The

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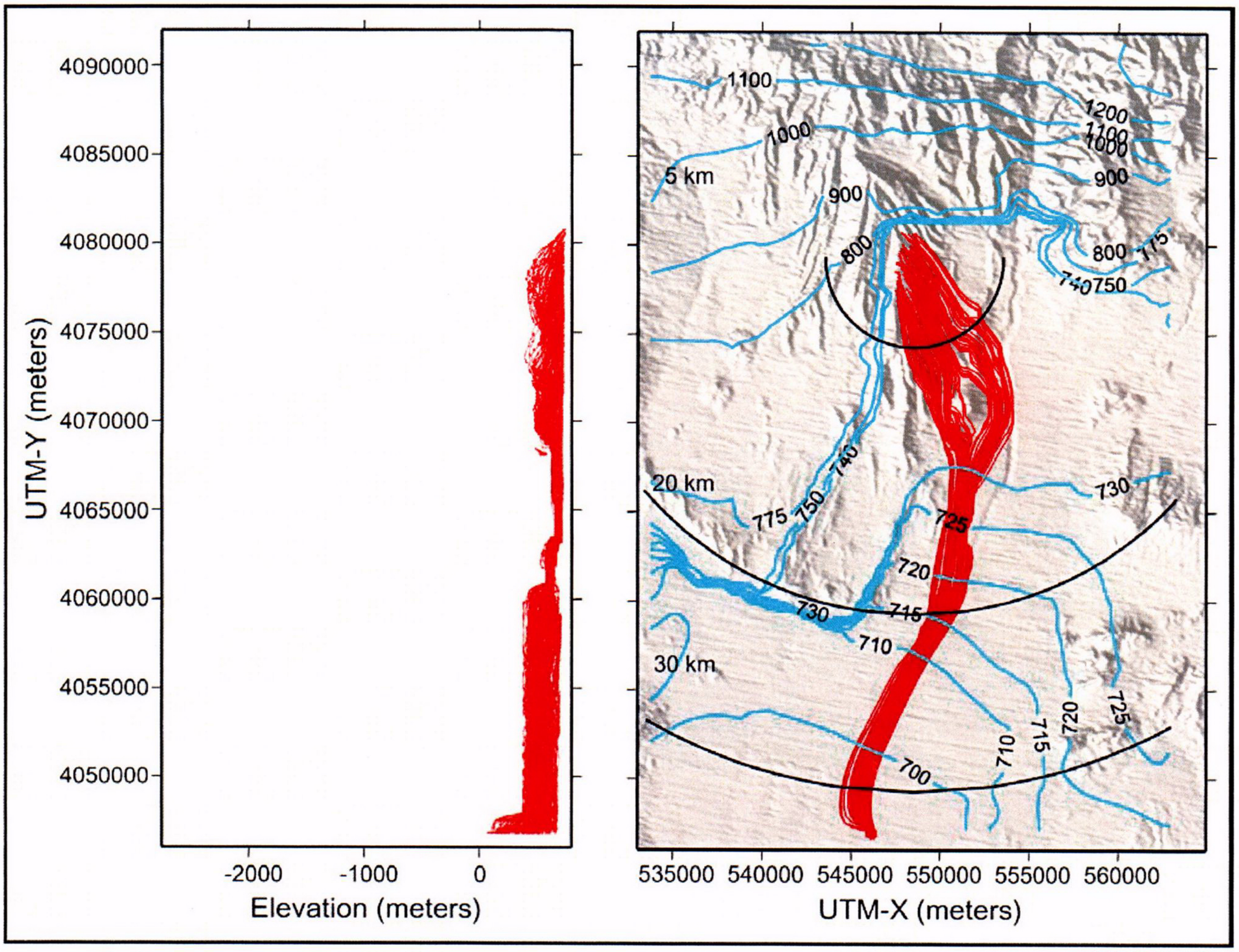
calibrated permeability of the alluvial uncertainty zone was 3.20×10^{-12} m^2. Thus, the calibrated permeability for the alluvial uncertainty zone was only 19 percent greater than the permeability value measured in the cross-hole test. While permeability values reported from the single-hole tests were about an order of magnitude less than the calibrated value, the cross-hole tests yielded a permeability measurement similar to the calibrated permeability values for the alluvial aquifer (BSC 2003b, Section 6.4).

While the calibrated permeabilities of the many geologic units and features represented in the SSFM influence the predicted specific discharge, the calibrated permeabilities of the geologic units along the flow path from the repository to the compliance boundary most directly determine the specific discharge value predicted by the SSFM. Particle tracking with the SSFM (BSC 2003a, Section 7.3) indicated that fluid particles leaving the repository generally travel downward until they reach the Crater Flat Bullfrog unit. Because of the high permeability of the Bullfrog unit, the particles travel in that unit until it ends. At that point, fluid particles generally enter the alluvial portion of the flow system after briefly flowing through the upper volcanic confining unit. The flow path through the alluvial deposits is represented in the SSFM by the alluvial uncertainty and lower Fortymile Wash zones. Thus, the calibrated permeabilities that most directly control the prediction of specific discharge are those for the Bullfrog unit, the alluvial uncertainty zone, and lower Fortymile Wash Zone.

For the Bullfrog unit, the calibrated value was 1.54×10^{-11} m^2 (BSC 2003a, Table 6.6-2), and the mean permeability of the cross-hole measurements was 1.37×10^{-11} m^2 (BSC 2003a, Table 6.8.1). Thus, the calibrated permeability was 12 percent greater than the mean of the measured value. As previously discussed, the calibrated permeability for the alluvial uncertainty zone was 19 percent greater than the permeability value measured in the cross-hole test at the ATC.

Because new water level data and permeability measurements are available from the ATC, predicted and observed values of hydraulic gradient and permeability at this location can be used to calculate specific discharge. The calculated specific discharge values can then be compared to evaluate the combined effect on specific discharge for post-model development validation. As previously discussed (Figure D-5, Table D-4), the predicted hydraulic gradient between UE-25 WT#3 and NC-EWDP-19P/NC-EWDP-2D is only 7 percent greater than the observed gradient between these two locations. The calibrated permeability for the alluvial uncertainty zone was 19 percent greater than the measured value at the ATC. Because the combined effect of the differences between predicted and observed values of these parameters on specific discharge is the product of their individual effects, the calculated specific discharge based on predicted values of hydraulic gradient and the calibrated value of permeability is only 27 percent greater than the value calculated using the observed values. This independent validation of the SSFM further enhances confidence in the ability of the model to predict specific discharge along the flow path from the repository to the accessible environment.

Comparison of Hydrochemical Data Trends with Calculated Particle Pathways–A comparison of flow paths identified using hydrochemical data with those predicted by the (calibrated) SSFM provides opportunity for building confidence in and validating the SSFM. The (calibrated) SSFM was used to predict flow paths from the repository (Figure D-8). Groundwater flow paths (Figure D-9) also were identified from the analyses of geochemical and isotopic parameters, scatterplots, and inverse mixing and reaction models (BSC 2003a, Section 7.3).



Source: BSC 2003a, Figure 6.6-3.

NOTE: Blue lines are head contours; red lines are particle tracks. Circles are 5, 18, and 30-km from the repository. The left panel is the north-south vertical plane; the right panel is the areal view.

Figure D-8. Flow Paths from the Repository with Simulated Hydraulic Head Contours