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BECHTEL SAIC COMPANY LLC

Hydrogeologic Framework Model for the Saturated Zone Site Scale Flow and Transport Model

Prepared for:
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OCRWM	**MODEL SIGNATURE PAGE/CHANGE HISTORY**	Page iii 1. Total Pages: 152

2. Type of Mathematical Model

☒ Process Model ☐ Abstraction Model ☐ System Model

Describe Intended Use of Model

This is a conceptual model providing a three-dimensional interpretation of the hydrostratigraphic unit locations and structure within the site-scale saturated-zone flow and transport model domain for use in the saturated-zone flow and transport numerical models.

3. Title

Hydrogeologic Framework Model for the Saturated Zone Site Scale Flow and Transport Model

4. DI (including Rev. No., if applicable):

MDL-NBS-HS-000024 REV 00

5. Total Appendices	6. No. of Pages in Each Appendix
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13. Remarks

Block #7: C.C. Faunt contributed to this report.

Block #9: C. Lum provided checking to previous versions of this report.

Section 7 of this report contains the resolution for CR3529.

Change History

14. Revision No.	15. Description of Change
REV 00	Initial Issue This report is a revision of the Scientific Analyses by the same title—Document Identifier ANL-NBS-HS-000033 (USGS 2003 [DIRS 165176]). In this new Model Report, changes were made in response to recommendations from the Regulatory Integration Team/ Natural Systems Team. The entire model documentation was revised. Changes were too extensive to use Step 5.8(1) per AP-SIII.10Q.

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ACRONYMS

2-D	two-dimensional
3-D	three-dimensional
DEM	digital elevation model
DOE	U.S. Department of Energy
DTN	data tracking number
ERP	Environmental Restoration Program
EWDP	Early Warning Drilling Program
FEHM	Finite Element Heat and Mass (Model)
FEP	feature, event, and process
GFM	geologic framework model
GPS	Global Positioning System
HFM	hydrogeologic framework model
LA	License Application
NRC	U.S. Nuclear Regulatory Commission
SZ	saturated zone
TSPA	total system performance assessment
TWP	technical work plan
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
YMP	Yucca Mountain Project
YMRP	*Yucca Mountain Review Plan, Final Report*

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1. PURPOSE

The purpose of this report is to document the 19-unit, hydrogeologic framework model (19-layer version, output of this report) (HFM-19) with regard to input data, modeling methods, assumptions, uncertainties, limitations, and validation of the model results in accordance with AP-SIII.10Q, *Models*.

The HFM-19 is developed as a conceptual model of the geometric extent of the hydrogeologic units at Yucca Mountain and is intended specifically for use in the development of the *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]). Primary inputs to this model report include the GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]), borehole lithologic logs, geologic maps, geologic cross sections, water level data, topographic information, and geophysical data as discussed in Section 4.1. Figure 1-1 shows the information flow among all of the saturated zone (SZ) reports and the relationship of this conceptual model in that flow. The HFM-19 is a three-dimensional (3-D) representation of the hydrogeologic units surrounding the location of the Yucca Mountain geologic repository for spent nuclear fuel and high-level radioactive waste.

The HFM-19 represents the hydrogeologic setting for the Yucca Mountain area that covers about 1,350 km^2 and includes a saturated thickness of about 2.75 km. The boundaries of the conceptual model (shown in Figure 1-2) were primarily chosen to be coincident with grid cells in the Death Valley regional groundwater flow model (DTN: GS960808312144.003 [DIRS 105121]) such that the base of the site-scale SZ flow model is consistent with the base of the regional model (2,750 meters below a smoothed version of the potentiometric surface), encompasses the exploratory boreholes, and provides a framework over the area of interest for groundwater flow and radionuclide transport modeling. In depth, the model domain extends from land surface to the base of the regional groundwater flow model (D'Agnese et al. 1997 [DIRS 100131], p 2). For the site-scale SZ flow model, the HFM-19 is clipped, reducing the vertical extent to the interpreted top of the water table.

The HFM-19 grid consists of a rectangular array of nodes with a spacing of 125 meters discussed in Sections 4.1, 5, and 6.3, and this selection simplifies the available data near the repository and extrapolates from very widely spaced data in other areas of the model domain. The HFM-19 is assembled by using geometric gridding techniques and software (described in Sections 3 and 6.3) to fill the domain area with 3-D elements corresponding to the 19 hydrogeologic units of interest. The HFM-19 is limited by simplifications that accommodate computer mapping, framework modeling, and modeling limitations and contains an inherent level of uncertainty that is a function of data distribution and geologic complexity. Uncertainty and limitations are discussed in Section 6.4 and model validation is discussed in Section 7.

The HFM-19 provides the hydrogeologically defined internal geometry for SZ flow and transport process models, which was used to assign unit numbers to nodes in a mesh for use in site-scale SZ flow and transport models. The *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]) directly uses the output of this report to provide the spatial boundaries for each of the hydrogeologic units.

This model report is consistent with the definition of a conceptual model found in Section 3.9 of AP-SIII.10Q:

> ***Model, Conceptual***–A set of hypotheses consisting of assumptions, simplifications, and conceptualizations that describes the essential aspects of a system, process, or phenomenon [Quality Assurance Requirements and Description] (QARD). Such a model may consist of concepts related to geometrical elements of the object (size or shape); dimensionality (1-, 2-, or 3-D); time dependence (steady-state or transient); applicable conservation principles (mass, momentum, energy); applicable constitutive relations, significant processes, natural laws, and boundary conditions; and initial conditions. Conceptual models may be implemented into mathematical models.

Parameters used in the other technical products include permeability, porosity, flowing interval spacing, distribution coefficients, and many others. The HFM-19 does not generate any of these parameter values. Rather, it provides a static 3-D; simplified conceptual model with geometric elements that represent the location of 19 differentiated hydrogeologic units in the SZ site-scale model domain. The hydrogeologic framework model (HFM) is a conceptual model because parameter values in the other technical products can be adjusted on a node-by-node or zonal basis as required in the specific technical product. For example, permeability zones can be created within a single hydrogeologic unit as necessary to represent the permeability data to reproduce observed water levels during model simulations. In this example, the HFM conceptual model provides the initial spatial bounds for the permeability parameter assigned and later modified or adjusted in the flow model analysis.

This version of the report supercedes the analysis report, *Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model* (USGS 2003 [DIRS 165176]), and documents the activities in accordance with the *Technical Work Plan for: Natural System - Saturated Zone Analysis and Model Report Integration* (BSC 2004 [DIRS 171421], Section 2.1.1.1). Activities include regulatory, technical integration and data compliance issues in order to address Regulatory Integration Team evaluation comments. Specifically, this report:

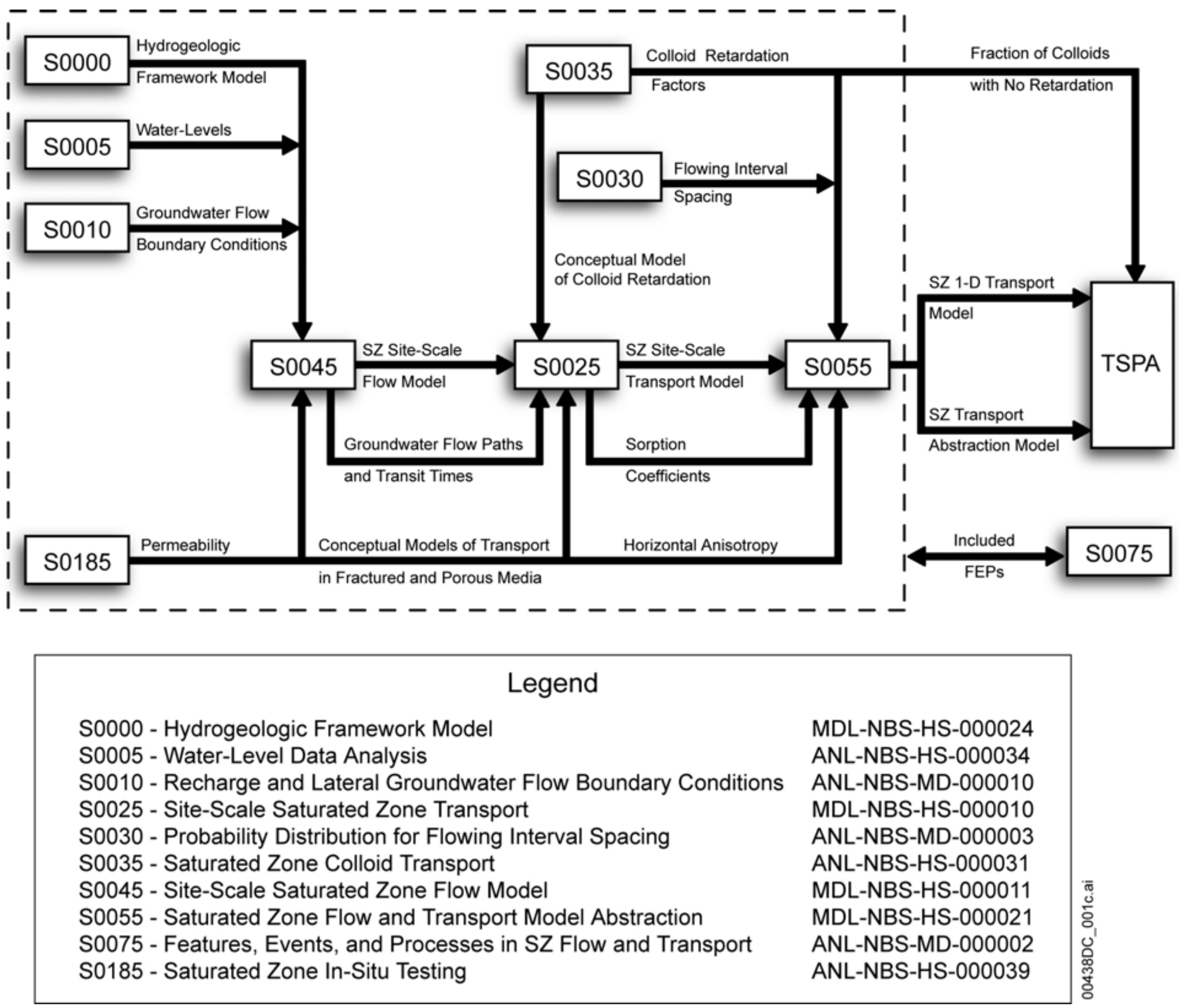
- Documents the development of the HFM-19 as a conceptual model (Section 6), and clarifies that the numerical implementation of the HFM-19 is part of the validation of the site-scale SZ groundwater flow model (BSC 2004 [DIRS 170037])

- Expands on the discussions in its predecessor report related to the: (1) adequacy, methodology, and data used during model development, and (2) justification of results (Sections 4.1 and 6)

- Includes discussion on its role in supporting arguments for related features, events, and processes (FEPs) (Section 6.2) that are identified in Table 2-1 of the technical work plan (TWP) (BSC 2004 [DIRS 171421])

- Expands the discussions of uncertainty and model limitations by documenting the inter-relationships among the HFM-19 and input models and any impacts of updates to these input models (i.e., geologic framework model (updated model discussed in this report) (GFM2000)), and evaluates the impact of new Nye County and Yucca Mountain borehole data that has been collected since initial issue of the predecessor analysis report in USGS (2003 [DIRS 165176]).

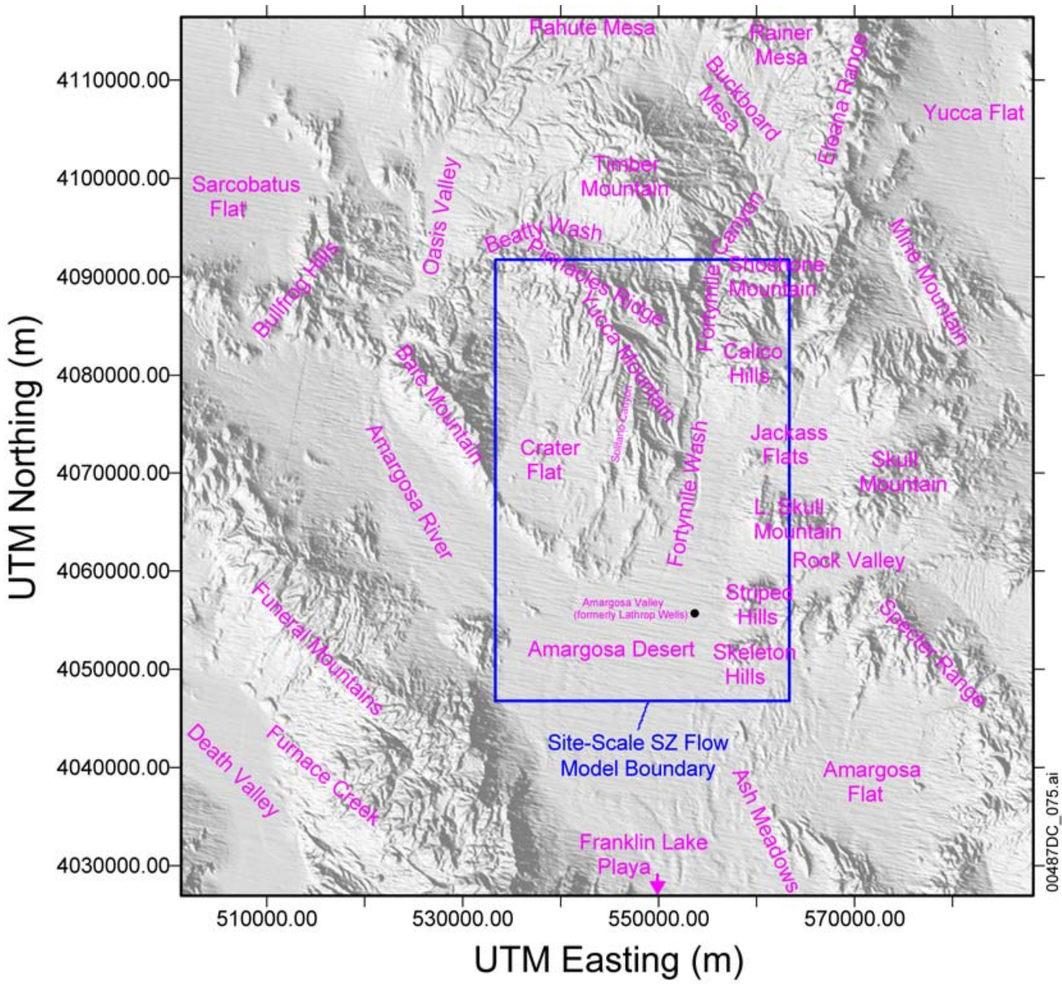
The TWP (BSC 2004 [DIRS 171421], Section 3.5) lists requirement number PRD-002/T-014 "Performance Objectives for the Geologic Repository after Permanent Closure" that is not addressed in the report. The performance objectives defined in 10 CFR 63.113 (10 CFR Part 63 [DIRS 156605]) are related to the engineered barrier system and the human intrusion scenario. The engineered barrier system and human intrusion may include aspects of the geologic framework model, but are not directly related to the HFM-19 defined in this report. Thus, requirement number PRD-002/T-014, identified generically in the TWP (BSC 2004 [DIRS 171421], Section 3.5), is not addressed in this report.



NOTE This figure is a simplified representation of the flow of information among SZ reports. See the Document Input Reference System of each report for a complete listing of data and parameter inputs. This figure does not show inputs external to this suite of SZ reports.

1-D=one-dimensional; SZ=saturated zone

Figure 1-1. Relationships and Flow of Key Information among Reports Pertaining to Flow and Transport in the Saturated Zone



DTN: GS010908314221.001 [DIRS 162874].

NOTE: The blue rectangle boundary labeled Site-Model Boundary is the site-scale SZ flow and transport models domain boundary.

UTM=Universal Transverse Mercator.

Figure 1-2. Location Map of the Saturated Zone Site-scale Study Area and Associated Geographic Features

2. QUALITY ASSURANCE

Development of this model report and the supporting modeling activities is subject to the Yucca Mountain Project (YMP) quality assurance program, as indicated in the *Technical Work Plan for: Natural System - Saturated Zone Analysis and Model Report Integration* (BSC 2004 [DIRS 171421], Section 8), Work Package ARTM01. Approved quality assurance procedures identified in the TWP (BSC 2004 [DIRS 171421], Section 4) have been used to conduct and document the activities described in this model report. The TWP also identifies the methods used to control the electronic management of data (BSC 2004 [DIRS 171421], Section 8).

This model report provides a conceptual framework for hydrologic units as part of the lower natural barrier that is important to the demonstration of compliance with the postclosure performance objectives prescribed in 10 CFR 63.113 (10 CFR Part 63 [DIRS 156605]). Therefore, it is classified on the *Q-List* (BSC 2004 [DIRS 168361]) as “SC” (Safety Category), reflecting its importance to waste isolation, as defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q-List*. This report contributes to the analysis and modeling data used to support postclosure performance assessment; the conclusions do not directly impact preclosure engineered features important to safety, as defined in AP-2.22Q.

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3. USE OF SOFTWARE

The development of the HFM from input data to a 3-D volume-filled map representing these data use software designed specifically for use in visualizing data for subsurface geology. Software codes obtained from Software Configuration Management and used to support model development are shown in Table 3-1. These software codes were considered appropriate for the application, and were used only within their range of validation.

3.1 SOFTWARE TRACKED BY CONFIGURATION MANAGEMENT

Petrosys V7.60d, STN: 10168-7.60d-00 (USGS 2001 [DIRS 148306]) has the ability to create regularly spaced grids from data representing irregularly spaced data points and can incorporate offsets in regularly spaced grids across faults. Petrosys was used to create structure contour maps to represent the tops of hydrogeologic units and the potentiometric surface. ERMA Site Geologist V6.0.1, STN: 10210-6.01-00 (USGS 2001 [DIRS 148986]) was used to evaluate data and tie cross section tops to the database of grid files. Stratamodel V4.1.1, STN: 10121-SAP-4.1.1-00 (USGS 2000 [DIRS 148985]) was used to consolidate the 19 model units, associated surfaces, and data files. These software codes were used for the Death Valley regional groundwater model studies, and the Stratamodel output files were converted for use by the flow model codes, which helped to provide consistency among the SZ hydrologic framework and flow models. Usage and limitations of the software are described during the explanation of HFM-19 development and methods in Section 6.3.

Discrepancies between the installation of these software and their baseline dates occur because these software were used for model development prior to qualification completion. An impact analysis was conducted as part of the Site Recommendation inclusion process for Pre-Process Validation and Reengineering software and the appropriate documents are listed with discussion of each of the software used.

Table 3-1. Software Used to Support Model Development

Software Name and Version	Software Tracking Number	Computer Platform, Operating System, Compiler	Description
Petrosys V7.60d[a]	STN: 10168-7.60d-00 [DIRS 148306]	Windows NT Workstation V.4 CPU ID#: 15409290306 Location: San Diego Projects Office, USGS/WRD, San Diego, CA	This software was used for gridding, contouring, plotting, and visualization of the data and for evaluation of results.
ERMA Site Geologist V6.0.1[b]	STN: 10210-6.0.1-00 [DIRS 148986]	Windows NT Workstation V. 4 CPU ID#: 15409290306 Location: San Diego Projects Office, USGS/WRD, San Diego, CA	This software was used for subsurface geological studies including data analysis, interpretation, gridding, and presentation functions. Tasks include creating, and manipulating 2-D and 3-D cross sections; posting data with attribute symbology; generating boring logs; and posting cross section horizons to maps.

Table 3-1. Software Used to Support Model Development (Continued)

Software Name and Version	Software Tracking Number	Computer Platform, Operating System, Compiler	Description
Stratamodel V4.1.1 [c]	STN: 10121-4.1.1-00 [DIRS 148985]	SGI Indigo 2 IRIX 6.5 Workstation CPU ID#: 15409290306 Location: San Diego Projects Office, USGS/WRD, San Diego, CA	This software was used for consolidating the 19 model units, associated surfaces, and data files. The final output file represents the 3-D HFM-19 and used for visualization for this document.

[a] Petrosys V7.60d was qualified and baselined 09/27/01. After qualification in September 2001, Rev 00 ICN 02 (USGS 2003 [DIRS 165176]) of the report was developed and approved and the comparison confirmation methodologies (CCM) was performed and evaluated with “no impact.” The final qualification activity closed this issue for Site Recommendation. This software is considered adequate for License Application. See USGS (2003 [DIRS 171365]).

[b] ERMA Site Geologist V6.0.1 was qualified and baselined 09/24/01. After qualification in September 2001, Rev 00 ICN 02 (USGS 2003 [DIRS 165176]) of the report was developed and approved and the CCM was performed and evaluated with “no impact”. The final qualification activity closed this issue for Site Recommendation. This software is considered adequate for License Application. See USGS (2003 [DIRS 171366]).

[c] Stratamodel V4.1.1 was in use before becoming fully qualified and baselined on 07/12/00. A comparison of unqualified and qualified software output was performed. No differences were found. All previous output generated from use of Stratamodel V4.1.1 prior to qualification was found acceptable. This software is considered adequate for license application. See USGS (2000 [DIRS 171368]).

2-D=two-dimensional; 3-D=three-dimensional; CA=California; CCM=comparison confirmation methodologies; CPU=central processing unit; HFM=hydrogeologic framework model (19-layer version); ID=identification; STN=software tracking number; USGS=U.S. Geological Survey; WRD=Water Resources Division.

3.2 EXEMPT SOFTWARE

Commercial, off-the-shelf software used in support of this conceptual model is exempt from the requirements of LP-SI.11Q-BSC, *Software Management*, but meets the acceptance criteria of being able to correctly maintain and produce grids and analysis results suitable for incorporation into this report.

ARC/INFO V7.2.1 (CRWMS M&O 2000 [DIRS 157019]) is commercially available and exempt software manufactured by Environmental Systems Research Institute, Inc. ARC/INFO was used on a PC with *Windows NT 4* operating system. It was used with standard functions for data maintenance and analysis, coordinate translation, plotting, and visualization of results for use in this document. As ARC/INFO is a commercial-off-the-shelf product and cannot be altered, the executable used on an interim unqualified basis is identical to the executable, which was qualified. No further confirmation or comparison is necessary (see Software Activity Plan for ARC/INFO V7.2.1 (BSC 2002 [DIRS 171369])).

4. INPUTS

4.1 DIRECT INPUT

Data feeds to the HFM-19 include borehole lithologic logs, geologic maps, geologic cross sections, topographic information, geophysical data, and the geologic framework model GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]). In addition, geologic cross sections developed for the U.S. Department of Energy (DOE) Environmental Restoration Program (ERP) for the Nevada Test Site (DTN: MO0106STRATHFM.024 [DIRS 155585]) are used as input data. The lower boundary of the HFM-19 was selected to be consistent with the lower boundary of the Death Valley regional groundwater flow model (D'Agnese et al. 1997 [DIRS 100131], pp. 2 and 75). The potentiometric surface (DTN: GS000508312332.001 [DIRS 149947]) as documented in *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (BSC 2004 [DIRS 170009]), was used as a clipping surface to form the top of the HFM-19. These data constitute a necessary and sufficient data set with which to represent the 3-D conceptual model at the designated scale of resolution required for the flow and transport models. On this basis, these data were determined to be adequately justified for their intended use in the site-scale SZ flow and transport models. The selection of these data and groupings of the hydrogeologic units are addressed in Section 6.1. The accuracy and adequacy of these data are discussed in the following sections.

The primary input data for the HFM-19 are stratigraphic contact data from boreholes, geologic cross sections, GFM 3.1, and the geologic map of the Yucca Mountain region, as listed in Table 4-1. The general locations of these input data for the site-scale SZ flow and transport model domain and encompassing regional area are shown in map view in Figure 4-1. The faults and hydrogeologic units that outcrop (at ground surface) in the site-scale model area are shown in Figure 4-2. Direct input data sets and associated data tracking numbers (DTNs) are listed in Table 4-1; the qualification status of the input sources are indicated in the Automated Technical Data Tracking database. The *Data Qualification Report: Stratigraphic Data Supporting the Hydrogeologic Framework Model for Use on the Yucca Mountain Project* (Wilson 2001 [DIRS 155614]) qualifies and provides analysis for hundreds of stratigraphic data points used as inputs for the HFM-19.

For each data set listed in Table 4-1, there is a description, associated DTN, and records package, if applicable. The direct input data are listed as DTNs in the second column along with their associated records package. The description for correlating data lithology to the appropriate HFM-19 hydrogeologic unit is listed in the table with two primary sources, the Final Scientific Notebook, SN-USGS-SCI-072-V2, V3 (Faunt 2002 [DIRS 171453]), and the data qualification report by Wilson (2001 [DIRS 155614]). The general correlation of source lithology to HFM-19 hydrogeology is given in Table 6-1 and the specific GFM 3.1 geologic unit correlation is given in Table 4-2. At times, the Wilson report and scientific notebooks refer to data by its author name; these are included in Table 4-1 along with the data descriptions. The affected unit for each data set is included in the last column of Table 4-1. The unit names correspond with the unit names as used in Table 2 of the Wilson report (note that the Wilson report names the lower volcanic confining unit as MVCU, and the older volcanic confining unit as LCVU). Appendix A has corresponding information and contains the direct input data listed in Table 4-1 organized by the HFM-19 unit they were used for.

The lithologic correlation to HFM-19 units is given in general in Table 6-2 and specific to the GFM 3.1 in Table 4-2.

Table 4-1. Input Data, Sources, and HFM-19 Unit Tops Directly Supported by Data

Item	Data Description and Source References*	Direct Input DTN and Records Package	Correlation of Data to HFM-19 Units*	Affected Units (Wilson unit ID)
1	Geologic Framework Model GFM 3.1 (BSC 2001 [DIRS 154622])	MO9901MWDGFM31.000 [DIRS 103769] (see Appendix B1 for the justification of the use of data)	Wilson 2001 [DIRS 155614], p. 16, and 56-66, Appendix C	UVA, UVCU, LVA (Tcp, Tcb, Tct), MVCU
2	Digital Elevation Model, (Turner et al, 1996 [DIRS 171658])	GS000400002332.001 [DIRS 148924] MOY-000242-15-02 ACC MOL.20041013.0268 (Death Valley East)	N/A, used as top surface and to tie data to surface	Alluvium, Playas, Amarls, Basalts, UVA, UVCU, LVA (Tcp, Tcb, Tct), MVCU, LVA, LVCU, Leaky, UCA, UCCU, LCA, LCA-T2, LCCU, Granites
3	Water-level data analysis for the saturated zone site-scale flow and transport model (USGS 2001 [DIRS 154625])	GS000508312332.001 [DIRS 149947]	N/A, Used as truncating top surface for clipped version of HFM-19	N/A Used to clip the model top for clipped version of HFM-19
4	Geologic Map and Cross sections of the Yucca Mountain Region By Potter et al. (2002 [DIRS 160060], Map I-2755)	GS010908314221.001 [DIRS 162874]	Faunt 2002 [DIRS 171453], p. 242 Wilson 2001 [DIRS 155614], pp. 20, 30, and 56 to 66, Appendix D-1	Alluvium, Playas, Basalts, UVCU, UVA, LVA (Tcp, Tcb, Tct), LVCU, MVCU, Leaky, UCCU, LCA, LCA-T2, LCCU, Granites
5	Yucca Mountain Project (YMP) Borehole Locations	MO9906GPS98410.000 [DIRS 109059]	N/A, These x, y coordinates update various well locations	N/A, No lithology in this data set.

Table 4-1. Input Data, Sources, and HFM-19 Unit Tops Directly Supported by Data (Continued)

Item	Data Description and Source References*	Direct Input DTN and Records Package	Correlation of Data to HFM-19 Units*	Affected Units (Wilson unit ID)
6	Locations for the Felderhoff 5-1 and 25-1 boreholes	MO0007BLFHF525.000 [DIRS 152892]	N/A, Only x, y locations data used	N/A, No lithology in this data set
7	Lithologic data for Felderhoff 5-1 borehole By Carr et al. 1995 [DIRS 104671]	MO0007LLGLOG51.000 [DIRS 152894] MOY-001110-12-03 ACC: MOL.20001114.0019	Wilson 2001 [DIRS 155614], p 31, 34-35, Appendix Table B-1	Basalts, Leaky, LCA
8	Lithologic data for Felderhoff 25-1 borehole By Carr et al. 1995 [DIRS 104671]	MO0007LGLOG251.000 [DIRS 152893] MOY-001110-12-04 ACC: MOL.20001114.0021	Wilson 2001 [DIRS 155614], p 31, 34-35, Appendix Table B-1	Basalts, Leaky, LCA
9	Lithologic data for borehole USW UZ-N62 By Geslin et al. 1995 [DIRS 103330]	GS940208314211.002 [DIRS 145577] MOY-000329-10-01 ACC: NNA.19940323.0352	Wilson 2001 [DIRS 155614], Appendix Table C-1	UVA
10	Lithologic data for borehole USW UZ-N27 By Geslin et al. 1995 [DIRS 103330]	GS940208314211.004 [DIRS 145579] MOY-000518-01-03 ACC: NNA.19940414.0082	Wilson 2001 [DIRS 155614], Appendix Table C-1	UVA
11	Lithologic data for borehole USW UZ-N34 By Geslin et al. 1995 [DIRS 103330]	GS950108314211.009 [DIRS 152556] MOY-000518-01-03 ACC: MOL.19960219.0177	Wilson 2001 [DIRS 155614], Appendix Table C-1	UVA
12	Lithologic data for borehole USW UZ-N35 By Geslin et al. 1995 [DIRS 103330]	GS940208314211.007 [DIRS 155533] MOY-000303-04-15 ACC: NNA.19940414.0078	Wilson 2001 [DIRS 155614], Appendix Table C-1	UVA
13	Lithologic data for boreholes USW UZ-N57, -N58, -N59, and –N61 By Geslin et al. 1995 [DIRS 103330]	GS940208314211.008 [DIRS 145581] MOY-000807-02-17 ACC: NNA.19940323.0344	Wilson 2001 [DIRS 155614], Appendix Table C-1	UVA
14	Lithologic data for borehole UE-25 UZN#63 By YMP 1993 [DIRS 171575]	GS940308314211.017 [DIRS 155534] MOY-000518-01-01 ACC: MOL.19941101.0064	Wilson 2001 [DIRS 155614], Appendix Table C-1	UVA
15	Lithologic data for borehole USW UZ-N36 By YMP 1992 [DIRS 171575]	GS940308314211.018 [DIRS 145589] MO-000322-17-05 ACC: MOL.19941101.0062	Wilson 2001 [DIRS 155614], Appendix Table C-1	UVA

Table 4-1. Input Data, Sources, and HFM-19 Unit Tops Directly Supported by Data (Continued)

Item	Data Description and Source References*	Direct Input DTN and Records Package	Correlation of Data to HFM-19 Units*	Affected Units (Wilson unit ID)
16	Lithologic data for boreholes USW UZ-N15, -N16, and -N17 By YMP 1993 [DIRS 171575]	GS940308314211.019 [DIRS 145591] MOY-000228-09-05 ACC: MOL.19941101.0061	Wilson 2001 [DIRS 155614], Appendix Table C-1	UVA
17	Lithologic data for USGS NWIS database boreholes See Appendix A for specific names	MO0109STRATHFM.001 [DIRS 156252]	Faunt 2002 [DIRS 171453], p. 51 Wilson 2001 [DIRS 155614], Appendix Table B-1	UVA, UCCU
18	Lithologic data for RF boreholes See Appendix A for specific names. By Gibson et al. 1992 [DIRS 102323]	MO0106STRATHFM.002 [DIRS 155537] MOY-010731-30-01	Wilson 2001 [DIRS 155614], pp. 82 and 83, Appendix Table C-1	UVA
19	Lithologic data for Water resource wells See Appendix A for specific names.	MO0106STRATHFM.003 [DIRS 155538] MOY-010717-04-01 ACC: MOL.20010725.0225 and JOL.20010725.0225	Faunt 2002 [DIRS 171453], pp. 90 and 92 Wilson 2001 [DIRS 155614], pp. 19, 84 to 89, Appendix B, Table B-1	Amarls, Leaky, LCA
20	Lithologic data for boreholes USW G-3 and USW GU-3 By Scott and Castellanos 1984 [DIRS 101291]	MO0106STRATHFM.004 [DIRS 155539] MOY-010717-04-01 ACC: MOL.20010725.0225 and JOL.20010725.0225	Wilson 2001 [DIRS 155614], Appendix Table C-1, C-2, and C-3 C-5 and C-6 (for G-3)	UVA, UVCU, LVA (Tcp), MVCU, LVA
21	Lithologic data for borehole USW UZ-13 By Kume and Hammermeister 1991 [DIRS 171582]	MO0106STRATHFM.005 [DIRS 155540] MOY-000303-04-15 ACC: NNA.19940414.0078	Wilson 2001 [DIRS 155614], p. 82, Appendix Table C-1	UVA
22	Lithologic data for borehole USW UZ-7 By Kume and Hammermeister 1991 [DIRS 171582]	MO0106STRATHFM.006 [DIRS 155541] MOY-010731-30-01 ACC: MOL.20010731.0029	Wilson 2001 [DIRS 155614], p. 82, Appendix Table C-1	UVA
23	Lithologic data for borehole UE-25 JF#3 By Plume and La Camera 1996 [DIRS 141659]	MO0106STRATHFM.007 [DIRS 155542] MOY-010731-30-01 ACC: MOL.20010731.0030	Wilson 2001 [DIRS 155614], pp. 21 to 25, 89 to 90, Appendix Table B-1	UVA, UVCU
24	Lithologic data for borehole USW VH-1 By Carr 1982 [DIRS 101519]	MO0106STRATHFM.008 [DIRS 155543] MOY-010731-30-01 ACC: NNA.19870518.0057	Wilson 2001 [DIRS 155614], pp. 21 to 27, 90 to 91, Appendix Table B-1	UVA, UVCU, LVA (Tcp, Tcb)
25	Lithologic data for borehole USW VH-2 By Carr and Parrish 1985 [DIRS 101093]	MO0106STRATHFM.009 [DIRS 155544] MOY-010731-30-01 ACC: HQS.19880517.1918	Wilson 2001 [DIRS 155614], p. 21-27, 90-91, Appendix Table B-1	UVA, UVCU, LVA (Tcp, Tcb)

Table 4-1. Input Data, Sources, and HFM-19 Unit Tops Directly Supported by Data (Continued)

Item	Data Description and Source References*	Direct Input DTN and Records Package	Correlation of Data to HFM-19 Units*	Affected Units (Wilson unit ID)
26	Lithologic data for borehole USW H-1 By Rush et al. 1983 [DIRS 107944]	MO0106STRATHFM.028 [DIRS 155589] MOY-010731-30-01 ACC: NNA.19870519.0103	Wilson 2001 [DIRS 155614], Appendix Tables C-1, C-2, C-3, C-5, and C-6	UVA, UVCU, LVA (Tcp), MVCU, LVA
27	Lithologic data for borehole UE-25 p#1 By Carr et al. 1986 [DIRS 102046]	MO0106STRATHFM.029 [DIRS 155590] MOY-010731-30-01 ACC: HQS.19880517.2633	Wilson 2001 [DIRS 155614], Appendix Tables C-1, C-2, C-3, C-5, and C-6	UVA, UVCU, LVA (Tcp), MVCU, LVA, OVCU, LCA
28	Lithologic data for borehole USW G-1 By Spengler et al. 1981 [DIRS 101297]	MO0106STRATHFM.030 [DIRS 155591] MOY-010731-30-01 ACC: NNA.19870406.0222	Wilson 2001 [DIRS 155614], Appendix Tables C-1, C-2, C-3, C-5, and C-6	UVA, UVCU, LVA (Tcp), MVCU, LVA
29	Lithologic data for borehole USW G-2 By Maldonado and Koether 1983 [DIRS 101805]	MO0106STRATHFM.031 [DIRS 155592] MOY-010731-30-01 ACC: NNA.19870506.0143	Wilson 2001 [DIRS 155614], Appendix Tables C-1, C-2, C-3, C-5, and C-6	UVA, UVCU, LVA (Tcp), MVCU, LVA
30	Cross sections from Swadley and Carr, 1987 [DIRS 101300]	MO0106STRATHFM.010 [DIRS 155545] TIC: 203089	Faunt 2002 [DIRS 171453], p. 5 Wilson 2001 [DIRS 155614], p. 20-22, Appendix Table-D-1	Basalts, UVA, LVA (Tcp, Tcb)
31	Cross sections from Maldonado, 1985 [DIRS 104160]	MO0106STRATHFM.011 [DIRS 155546] TIC: 203087	Faunt 2002 [DIRS 171453], p. 4 Wilson 2001 [DIRS 155614], pp. 20-22, Appendix Table D-1	Basalts, UVA, UVCU, LVA (Tcp), MVCU, LVCU, UCCU
32	Cross sections from McKay and Sargent 1970 [DIRS 155611]	MO0106STRATHFM.012 [DIRS 155572] TIC: 212447	Faunt 2002 [DIRS 171453], p. 12 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA, LVA (Tcp)
33	Cross sections from Sargent et al. 1970 [DIRS 155615]	MO0106STRATHFM.013 [DIRS 155573] TIC: 212446	Faunt 2002 [DIRS 171453], p. 12 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA, UVCU, LVA (Tcp, Tcb, Tct), Leaky, LCA
34	Cross sections from Orkild and O'Conner 1970 [DIRS 106459]	MO0106STRATHFM.014 [DIRS 155755] TIC: 212359	Faunt 2002 [DIRS 171453], p. 11 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA, UVCU

Table 4-1. Input Data, Sources, and HFM-19 Unit Tops Directly Supported by Data (Continued)

Item	Data Description and Source References*	Direct Input DTN and Records Package	Correlation of Data to HFM-19 Units*	Affected Units (Wilson unit ID)
35	Cross sections from McKay and Williams 1964 [DIRS 155612]	MO0106STRATHFM.015 [DIRS 155574] TIC: 212351	Faunt 2002 [DIRS 171453], p. 8 Wilson 2001 [DIRS 155614], pp. 21, 22, and 32, Appendix Table D-1	UVA, UVCU, LCA-t2, UCCU
36	Cross sections from Lipman and McKay 1965 [DIRS 104158]	MO0106STRATHFM.016 [DIRS 155575] TIC: 212352	Faunt 2002 [DIRS 171453], p. 8 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA, UVCU
37	Cross sections from Christiansen and Lipman (1965 [DIRS 100566])	MO0106STRATHFM.017 [DIRS 155610] TIC: 212357	Faunt 2002 [DIRS 171453], p. 9 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA, UVCU
38	Cross section from Byers et al. 1976 [DIRS 103624]	MO0106STRATHFM.018 [DIRS 155579] TIC: 204573	Faunt 2002 [DIRS 171453], p. 4 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA, UVCU
39	Cross sections from Frizzell and Shulters 1990 [DIRS 105454]	MO0106STRATHFM.019 [DIRS 155580] TIC: 200459	Faunt 2002 [DIRS 171453], p. 6 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA, UVCU, LVA (Tcp), MVCU, LVCU
40	Cross section from Young 1972 [DIRS 103023]	MO0106STRATHFM.020 [DIRS 155581] MOY-010731-30-01 ACC: NNA.19870519.0070	Faunt 2002 [DIRS 171453], p. 14 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA
41	Cross sections from USGS 1984 [DIRS 101305]	MO0106STRATHFM.021 [DIRS 155582] MOY-010731-30-01 ACC: NNA.19891009.0305	Faunt 2002 [DIRS 171453], p. 94 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UVA, UVCU, LVA (Tcp), MVCU, LVCU, Leaky, LCAt2, UCCU, LCA, LCCU
42	Cross sections from Faulds et al. 1994 [DIRS 105126]	MO0106STRATHFM.022 [DIRS 155583] TIC: 211484	Faunt 2002 [DIRS 171453], p. 95 Wilson 2001 [DIRS 155614], p. 20-22, Appendix Table D-1	Basalts, UVA, UVCU, LVA (Tcp, Tcb, Tct)
43	Cross sections from Moench 1965 [DIRS 155613]	MO0106STRATHFM.023 [DIRS 155584] TIC: 250152	Faunt 2002 [DIRS 171453], p. 94 Wilson 2001 [DIRS 155614], pp. 21, 22, and 36, Appendix Table D-1	UVA, LCA, LCCU, UCCU
44	Cross sections from NTS ERP DTN: GS000400002 332.002 [DIRS 149021]	MO0106STRATHFM.024 [DIRS 155585] MOY-010731-30-01 ACC: MOL.20000619.0540	Faunt 2002 [DIRS 171453], p. 129-130 Wilson 2001 [DIRS 155614], p. 21-22, Appendix Table D-1	UCA, UCCU, LCA, LCCU

Table 4-1. Input Data, Sources, and HFM-19 Unit Tops Directly Supported by Data (Continued)

Item	Data Description and Source References*	Direct Input DTN and Records Package	Correlation of Data to HFM-19 Units*	Affected Units (Wilson unit ID)
45	Seismic refraction profiles from Oliver et al. 1995 [DIRS 106447]	MO0106STRATHFM.025 [DIRS 155586] MOY-010731-30-01 ACC: MOL.19980305.0122	Faunt 2002 [DIRS 171453], p. 131 Wilson 2001 [DIRS 155614], pp. 33 to 34	LCA
46	Resistivity soundings from Greenhaus and Zablocki 1982 [DIRS 105144])	MO0106STRATHFM.026 [DIRS 155587] MOY-010731-30-01 ACC: HQS.19880517.2687, Figure 2.	Faunt 2002 [DIRS 171453], p. 101 Wilson 2001 [DIRS 155614], p. 92	LCA
47	Cross sections from Scott and Bonk 1984 [DIRS 104181]	GS930283117461.001 [DIRS 107027] MOY-940125-02-18 ACC: HQS.19880517.1443	Faunt 2002 [DIRS 171453], p. 15 Wilson 2001 [DIRS 155614], pp. 21 to 22, Appendix Table D-1	UVA, UVCU, LVCU
48	Regional Geophysical Lines 2 and 3 from Brocher	Brocher et al. 1996 [DIRS 101495], Figures 16 and 17 (see Appendix B, Section B.2 for the justification for use of data)	Faunt 2002 [DIRS 171453], pp. 129 to 130 Wilson 2001 [DIRS 155614], pp. 21 to 22, Appendix Table D-1	LCA

NOTE: Shorthand used: Faunt 2002 [DIRS 171453] = SN-USGS-SCI-072-V2, V3 by Faunt 2002 [DIRS 171453], Wilson 2001 [DIRS 155614] = Data Qualification Report: Stratigraphic Data Supporting the HFM for Use on the YMP, by Wilson 2001 [DIRS 155614].

* These columns are for informational purposes and are considered indirect input.

DTN=data tracking number; ERP=Environmental Restoration Program; GFM=geologic framework model; HFM=hydrogeologic framework model (19 layer version); ID=identification; N/A=not applicable; NTS=Nevada Test Site; RF=repository facilities; USGS=U.S. Geological Survey; YMP=Yucca Mountain Project.

4.1.1 Accuracy and Appropriateness of Use

The HFM-19 was developed between 1990 and 2000. During this time, the identification of hydrogeologic units and data appropriate for the SZ flow and transport models evolved in definition and increased accuracy in response to analysis, evaluations, and availability of new data. The development of the HFM-19 is documented in the scientific notebook SN-USGS-SCI-072-V2, V3 (Faunt 2002 [DIRS 171453]). The accuracy and appropriateness of the HFM-19 is achieved and documented in the scientific notebook as an iterative process. This process includes the steps of data acquisition, data analysis, two-dimensional (2-D) and 3-D gridding results, and evaluation of units representing the framework model. Each iteration is documented in the scientific notebook (Faunt 2002 [DIRS 171453]) by evaluation and review. The reviewers include management (Faunt 2002 [DIRS 171453], pp. 39, 71, 89, 103, 156, 175, 187), experts in field (Faunt 2002 [DIRS 171453], pp. 107 to 109, 110, 281 to 282), the SZ flow modelers (Faunt 2002 [DIRS 171453], pp. 161 to 172, 240 to 241), and YMP Branch data submittal (Faunt 2002 [DIRS 171453], pp. 215 to 222), each followed by review responses and another iteration until completion. The accuracy and uncertainty of the resulting HFM-19 depends on the accuracy of the data points used to identify top of units (discussed in this section), the software and methods used to interpolate and fill space between data points (discussed in Sections 3 and 6.3), and the grouping of stratigraphic units into hydrogeologic units (Section 6.1). The level of acceptable accuracy and the appropriateness is determined by the requirements of the flow model including domain size, resolution, and selection of units and features relevant to flow, and grid definitions as discussed in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]), Sections 6.3 and 6.5, respectively. Accuracy checks and qualification efforts after the HFM-19 was clipped and used in the flow and transport models do not pertain to the HFM-19 elements above the water table that were removed and not used.

4.1.1.1 HFM Cell Resolution

The HFM-19 has grid cells of 125 meters on a side and variable vertical thickness as defined by the unit surfaces. This relatively small grid spacing over such a large area is predicated by flow model constraints requiring an equal or finer resolution of input than the computational flow grid using it, in order to be represented accurately. Tests conducted to determine an adequate resolution for computational flow (Bower et al. 2000 [DIRS 149161]) have shown that the 500-meter resolution used in the base-case model (BSC 2004 [DIRS 170037]) is sufficient to represent the stratigraphy accurately. Though the 125-meter resolution is not necessarily consistent with the resolution of geologic data, especially in areas outside the immediate site area or deep in the model, the 125-meter spacing does allow the location of faults at a greater accuracy than required by the flow model with the 500-meter spacing (BSC 2004 [DIRS 170037], Section 6.5.3.2). In many areas, the geologic data are not detailed enough to support the 125-meter grid resolution. The result is a smoothly interpreted or interpolated surface at a resolution that is finer than required by the geologic data. This finer resolution does not add additional error to the gridding process. The resolution is too coarse to represent accurately some features such as faults, but provides enough detail to capture fault-induced truncation of hydrogeologic units by representing faults as planar interfaces between units (Section 5, Assumption 3). Both maps and cross sections were used to locate and incorporate chosen faults. The coverage of the input data over the site-scale and regional domains are shown in Figure 4-1. The process of building the HFM-19 from these data, and how these data were selected, is described in Section 6.

4.1.1.2 Geologic Framework Model (GFM 3.1)

As shown in Figure 4-1, the GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]) domain lies well within the HFM-19 domain and involves only the top units, from the lower volcanic aquifer, up to the upper volcanic confining unit (as shown in Table 4-2). The geologic framework model has stratigraphic layers at a resolution finer than HFM-19. The GFM was developed to support the site-scale unsaturated zone flow and transport models, providing further consistency between the SZ flow model and other flow models in larger and smaller domains. For unit tops where the GFM was used, the GFM grid points were resampled to the 125-meter grid resolution of the HFM-19, providing accurate and appropriate data input as discussed in Section 6.3.2.

Table 4-2. Hydrogeologic Units and Corresponding GFM Units

HFM-19 Unit ID and Names	GFM 3.1 Unit Names
15 - Upper Volcanic Confining Unit	Calico, Calicobt
14 - Lower Volcanic Aquifer – Prow Pass Tuff	Prowlv, Prowlc, Prowmd, Prowuc, Prowuv, Prowbt
13 - Lower Volcanic Aquifer – Bullfrog Tuff	Bullfroglv, Bullfroglc, Bullfrogmd, Bullfroguc, Bullfroguv, Bullfrogbt
12 - Lower Volcanic Aquifer - Tram Tuff	Tramlv, Tramlc, Trammd, Tramuc, Tramuv, Trambt

DTN: MO9901MWDGFM31.000 [DIRS 103769].

GFM=geologic framework model; HFM-19=hydrogeologic framework model 19 layer.

Acceptable differences were identified between the depths of hydrogeologic unit contacts in the HFM-19 and GFM 3.1 borehole databases during the data qualification process (Wilson 2001 [DIRS 155614], Section 3.4.2.1). Differences exceeding 9.1 meters were found for only 17 of the hundreds of data points used in constructing the hydrogeologic unit surfaces, and many of these can be attributed to changes in stratigraphic unit definitions that occurred since the HFM-19 database was compiled. According to Wilson (2001 [DIRS 155614], Section 3.4.6), "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-19 unit top definitions or were the result of changes in stratigraphic contact definitions." Except for the relatively few cases that exceeded 9.1 m, the range of difference is less than the smallest vertical spacing of 10 meters in the flow grid, and much less than its horizontal spacing of 500 meters.

4.1.1.3 Geologic Map of the Yucca Mountain Region

The geologic map used in this analysis is contained in the qualified DTN: GS010908314221.001 [DIRS 162874]. Potter et al (2002 [DIRS 160060], pp. 1 to 2) note that this DTN was specifically prepared to support development of the site-scale SZ flow model (BSC 2004 [DIRS 170037]). These data supercede the original maps (DTN: GS991208314221.001 [DIRS 145263]) that were used in the earlier version of this report (USGS 2003 [DIRS 165176]). The original Potter map data used in the area of the SZ flow model domain are included unchanged in the superceding version of the data, which adds supplemental information to identify areas of uncertainty. These changes have no impact at the 125-meter resolution used in the HFM-19.

4.1.1.4 Digital Elevation Model Data

The digital elevation data are from 1:250,000-scale topographic maps, USGS 3-arc-second 1- by 1-degree DEM files, with a grid spacing of approximately 90 meters (DTN: GS000400002332.001 [DIRS 148924]). All 1- by 1-degree DEMs have hypsographic information consistent with the planimetric features normally found on 1:250,000-scale topographic maps. The production criteria were to provide an absolute horizontal accuracy of a 130-meter circular error at 90 percent probability and relatively finer than the resolution of the HFM-19 grid cells and the flow model grids (Turner et al. 1996 [DIRS 171658], p. 7).

The original production objective for the 3-arc-second digital elevation models (DEMs) was to provide an absolute vertical accuracy related to mean sea level of ± 30 meters with a 90 percent probability (Turner et al. 1996 [DIRS 171658], pp. 5 to 7). This absolute vertical accuracy may be too strict as a measure of vertical accuracy; however, 3-arc-second DEMs also are defined as having a root-mean-square-error of elevation values equal to one-third the contour interval and no errors greater than two-thirds the contour interval. Because the source maps in this region have contour intervals of about 30 or 60 meters (100 or 200 feet), corresponding root-mean-square-error values no greater than 10 or 20 meters may be expected. The grid interpolation functions used to construct the 1-degree DEM gridded elevation values may favor values corresponding to contour-line elevations. Furthermore, USGS (1990 [DIRS 171634], p. 5) documentation concerning DEM data files state that the relative horizontal and vertical accuracy, although not specified, will in many cases, conform to the actual hypsographic features with higher integrity than indicated by the absolute accuracy. In other words, errors in the relative elevation of nearby features may be considerably less (on the order of 10 m) than their absolute elevation accuracy relative to mean sea level.

4.1.1.5 Borehole Data

The borehole data accuracy depends on the initial stratigraphic picks and borehole location. In general, these are much more accurate than the geologic cross section data. The location is given in degrees, minutes, and seconds of latitude and longitude. The accuracy of the location of a drill-hole depends on the method used to determine its location. For example, many wells are now located with Global Positioning System (GPS) and are fairly accurate. In the past, many boreholes were located on a topography map, by estimating the location from the surrounding features. These would probably be inherently less accurate. Borehole locations that provided unreasonable values (in comparison to nearby borehole locations) were found during the analysis process and not included in HFM-19 (see excluded data in Section 4.1.2). Note that x, y coordinate information for various wells have been updated with GPS and are contained in DTN: MO9906GPS98410.000 ([DIRS 109059]). These coordinates supercede only the location data of the previous DTNs. The borehole top altitudes were estimated at a vertical depth from the DEM for data model consistency, and provide a suitable degree of spatial resolution for the borehole locations.

4.1.1.6 Geologic Cross Sections

The geologic cross sections used (Table 4-1) were all at a scale of 1:100,000 or larger. The data are only accurate to the scale of the hard copy of the source data being digitized. Due to the digitization process, an additional small loss in accuracy may occur but is insignificant at the resolution used for the site-scale SZ flow model. The scanning process uses a resolution of 0.0013 in. This small error is equivalent to 3 in. on a cross section with a scale of 1:100,000. The cross sections are leveled and digitally referenced to the map traces. The geologic cross section files are referenced to their true location in Universal Transverse Mercator (UTM) coordinates. The cross sections are labeled with the appropriate hydrogeologic unit designation and are tied to the HFM-19 database as described in Section 6.3. Most of the cross sections are from qualified data sources in the form of formally reviewed and published USGS reports and maps.

4.1.1.7 Water-Level Data

All of the water-level data used in the development of HFM-19 are from DTN: GS000508312332.001 ([DIRS 149947]) which are used to develop the potentiometric surface shown in Section 6.3.4 (Figure 6-3) and are discussed in *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (USGS 2001 [DIRS 154625]). These water level data were used as calibration targets for the development of the site-scale SZ flow model (BSC 2004 [DIRS 170037], Section 6.4.4). These data were used to form a clipping surface for the top of the HFM-19 to reduce the total size of the model for computational purposes. The clipping surface impacts the flow and transport models because the locations above this surface have been removed and cannot be used for water-level interpretations that rise above the clipped elements of HFM-19. The clipped version is considered the final version and is used in the flow and transport models. The unclipped version can be used instead, or the clipped version can be reconstructed without the clipping surface, using Stratamodel software. HFM-19 is submitted as both a clipped and unclipped version for use in flow models, see the *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037], Sections 6.4.4 and 6.4.5) for discussion of water table rise and alternate potentiometric surfaces.

4.1.2 Excluded Data

The building process for HFM-19 began with hundreds of wells, which were gridded and built into surfaces, incorporated into 3-D volume elements, and evaluated. This process was iterative and as results were evaluated, some data were removed from use in the final HFM-19. Early in the development process, some data were excluded because they provided duplicate information (or lumping of units into the hydrogeologic units) (Faunt 2002 [DIRS 171453], pp. 63 and 69).

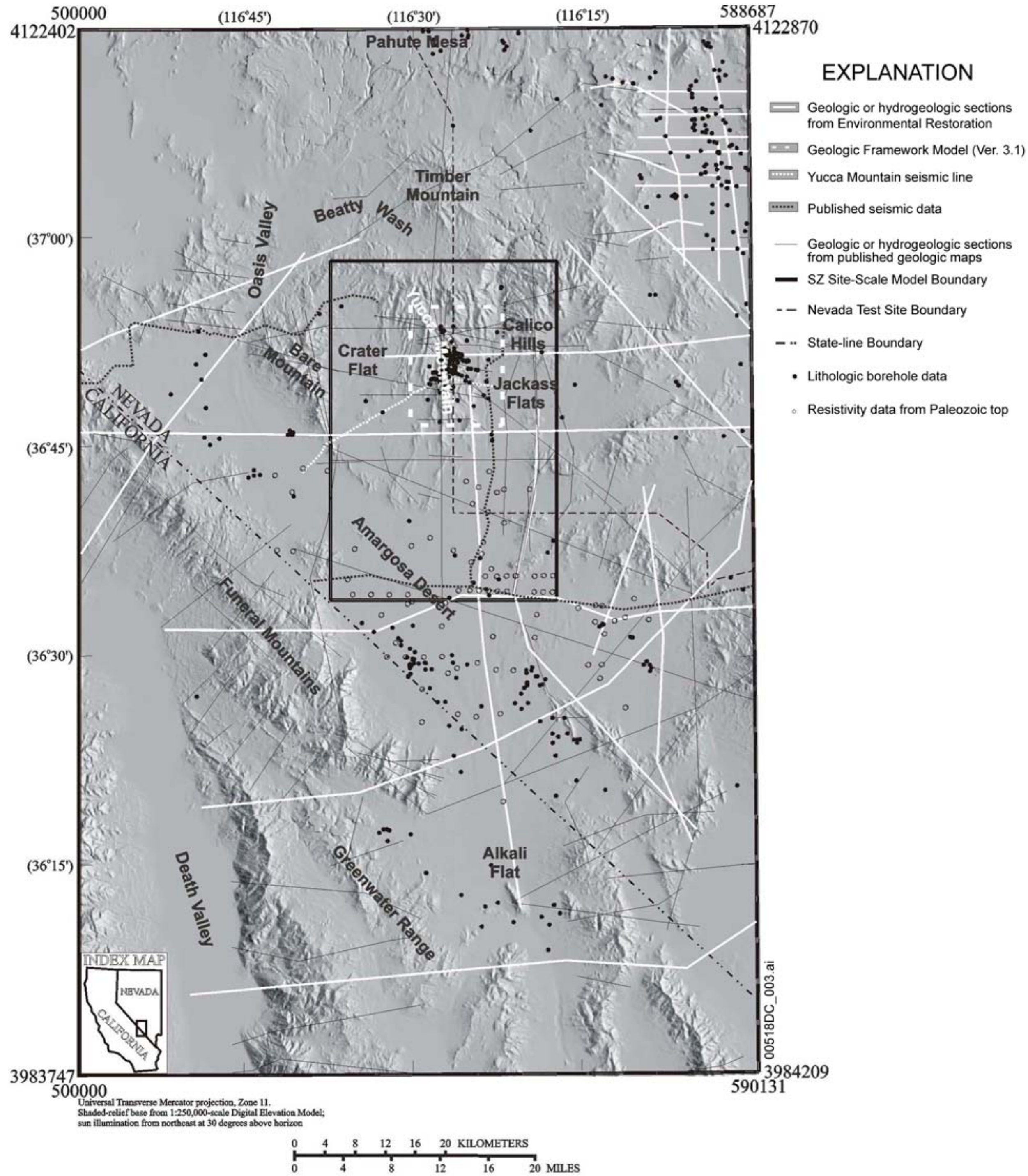
Cross section units that were very small or very thin, relative to the domain scale, were omitted. In a few cases, boundaries of units were simplified or extended to meet units from other data sources. In places where two or more cross sections intersect, they were checked for consistency. In a few cases, the geologic interpretations shown on the cross sections did not agree because one cross section was greatly generalized relative to the other(s). In these cases, a decision was made to omit the more generalized cross section from the HFM-19 (Faunt 2002 [DIRS 171453], p. 96).

The data qualification report by Wilson (2001 [DIRS 155614], p. 114), recommended the removal of one data point from the borehole data associated with the original submission of DTN: GS950508312333.002 ([DIRS 105131]). Named as borehole AM-101 by Wilson, this single data point out of the hundreds used for this model was not traceable except by its latitude and longitude location of 116° 26' 45" and 36° 37' 14" (within 200 meters of Felderhoff 5-1 borehole). The point is described as part of a group of five boreholes that were private water wells within lithologic logs prepared by the drillers (Wilson 2001 [DIRS 155614], p 108). This point has no effect on the model because the data point is consistent with the trend established by other boreholes in the area. This borehole does not control the configuration of this surface and is not used as direct input for HFM-19.

4.1.3 New Data

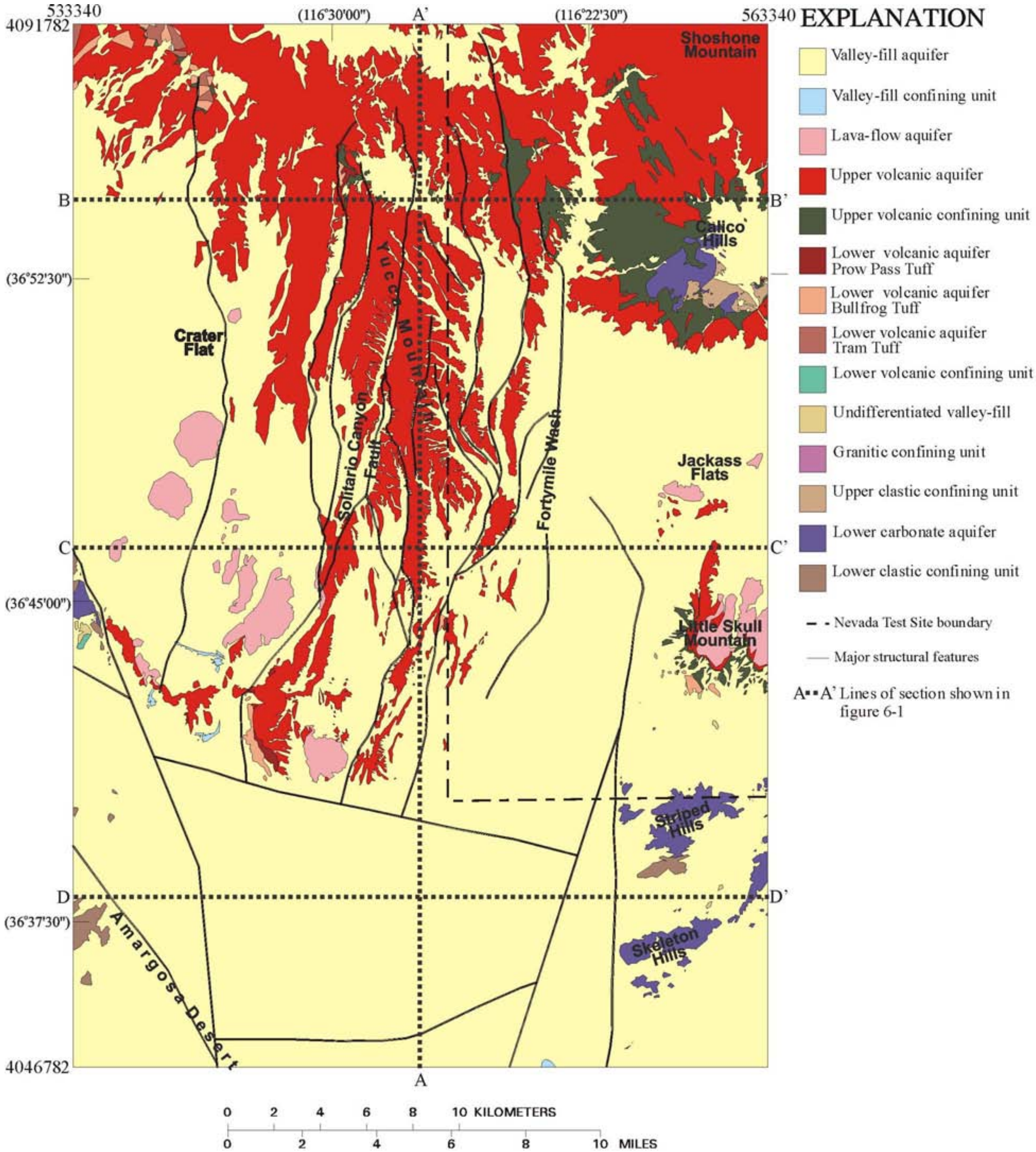
Creation of Alternative Conceptual Model hydrogeologic framework model (27 layer) (HFM-27)—The regional scale hydrogeologic framework model was updated with new data to "Hydrogeologic Framework Model for Site and Regional Saturated Groundwater Flow Models" (Scientific Notebook) (Faunt 2002 [DIRS 171040], pp. 29 to 31 and 49 to 61), which influences the site-scale HFM at the lower boundary and in the area of the Nye County Wells. In the immediate area of the site but at shallower depths, the GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]) has been revised to GFM2000 (BSC 2004 [DIRS 170029]; DTN: MO0012MWDGFM02.002 [DIRS 153777]). To assess the impact of GFM2000 on the site-scale HFM, an alternative HFM was created that included an increase in the number of hydrogeologic layers at shallow depths. This alternative HFM, called HFM-27, is discussed in Section 6.4.2 and Appendix B1 where the justification of GFM 3.1 for use in the HFM-19 of this report is discussed.

The site-scale SZ flow and transport models use HFM-19 as the base-case definition of hydrogeology. The HFM-27 (DTN: GS021008312332.002 [DIRS 164363]) is used for alternate conceptual models, and as such, incorporates the new regional HFM [(Faunt 2002 [DIRS 171040]), GFM2000 (BSC 2004 [DIRS 170029]; and Nye County well data (Section 6.4.2)]. Alternate models using new data are used to evaluate the impact of new data on the HFM-19 and flow results (Section 6.4.2). Differences between the base-case (using HFM-19) and alternate models (using HFM-27) and their impact on flow modeling results are detailed in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]). Transport results are discussed in *Site-Scale Saturated Zone Transport* (BSC 2004 [DIRS 170036]). None of the changes in this model report, qualification actions, or new data availability change the HFM-19 documented as the output DTN for this report (Section 9.5).



Source: All input data in Table 4-1 except water level data, for illustration of data type relative to domain area.

Figure 4-1. Locations for Geologic, Geophysical, and Borehole Data Listed in Table 4-1 Used in the Construction of the Site-Scale Hydrogeologic Framework Model



DTN: GS010908314221.001 [DIRS 162874].

NOTE: Coordinates in meters (UTM, Zone 11, North American Datum 27).

Figure 4-2. Generalized Surface Outcrop Map of Hydrogeologic Units with Major Structural Features and Lines of Cross Sections Specific to the Site-Scale SZ Flow Model Area

4.2 CRITERIA

The general requirements to be satisfied by the total system performance assessment (TSPA) are stated in 10 CFR 63.114 (10 CFR Part 63 [DIRS 156605]). Technical requirements to be satisfied by the TSPA are identified in the Yucca Mountain *Projects Requirements Document* (Canori and Leitner 2003 [DIRS 166275]). The acceptance criteria that will be used by the U.S. Nuclear Regulatory Commission (NRC) to determine whether the technical requirements have been met are identified in the *Yucca Mountain Review Plan, Final Report* (YMRP) (NRC 2003 [DIRS 163274]). The pertinent requirements and criteria for this model report are summarized in Table 4-3. The TWP (BSC 2004 [DIRS 171421], Section 3.5) also lists requirement number PRD-002/T-014 *Performance Objectives for the Geologic Repository After Permanent Closure* that is not addressed in the report. The performance objectives defined in 10 CFR 63.113 (10 CFR Part 63 [DIRS 156605]) are related to the engineered barrier system and the human intrusion scenario. The engineered barrier system and human intrusion may include aspects of the geologic framework model, but are not directly related to the HFM-19 defined in this report. Thus, requirement number PRD-002/T-014, identified generically in the TWP (BSC 2004 [DIRS 171421], Section 3.5), is not addressed in this report.

Table 4-3. Project Requirements for This Model Report

Requirement Number*	Requirement Title*	10 CFR 63 Link	YMRP Acceptance Criteria†
PRD-002/T-015	Requirements for Performance Assessment	10 CFR 63.114 [DIRS 156605]	Section 2.2.1.3.8.3 Criteria 1-4

Source: * Canori and Leitner 2003 [DIRS 166275].

† NRC 2003 [DIRS 163274]

In this section, the acceptance criteria identified in Section 2.2.1.3.8.3 of the YMRP (NRC 2003 [DIRS 163274]), are given below. In cases where subsidiary criteria are listed in the YMRP for a given criterion, only the subsidiary criteria addressed by this model report are listed below. Where a subcriterion includes several components, only some of those components may be addressed. How these components are addressed is summarized in Section 8.3 of this report.

It should be noted that assessment of which YMRP criteria apply has changed since publication of the TWP for this report (BSC 2004 [DIRS 171421]), thus acceptance criteria listed here do not exactly match those in the TWP. Specifically, it has been determined that Acceptance Criterion 5 is not applicable to this report. In addition, Acceptance Criterion 3 “Data Uncertainty is Characterized and Propagated Through the Model” and Acceptance Criterion 4 “Model Uncertainty is Characterized and Propagated Through the Model Abstraction” are added because uncertainty in the HFM is addressed in this report and later propagated through the site-scale SZ flow model, SZ transport model, and SZ flow and transport model abstraction as summarized in Figure 1-1.

Acceptance Criterion 1: System Description and Model Integration Are Adequate.

(1) Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent

and appropriate assumptions, throughout the flow paths in the SZ abstraction process.

(2) The description of the aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings, that may affect flow paths in the SZ, is adequate. Conditions and assumptions in the abstraction of flow paths in the SZ are readily identified, and consistent with the body of data presented in the description.

(4) Boundary and initial conditions used in the total system performance assessment abstraction of flow paths in the SZ are propagated throughout its abstraction approaches. For example, abstractions are based on initial and boundary conditions consistent with site-scale modeling and regional models of the Death Valley groundwater flow system.

(6) Flow paths in the SZ are adequately delineated, considering natural site conditions.

(10) Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2: Data Are Sufficient for Model Justification.

(1) Geological, hydrological, and geochemical values used in the license application to evaluate flow paths in the SZ are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

(2) Sufficient data have been collected on the natural system to establish initial and boundary conditions for the abstraction of flow paths in the SZ.

(3) Data on the geology, hydrology, and geochemistry of the SZ used in the total system performance assessment abstraction are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses, used to support the U.S. Department of Energy total system performance assessment abstraction, are adequate to determine the possible need for additional data.

(4) Sufficient information is provided to substantiate that the proposed mathematical groundwater modeling approach and proposed model(s) are calibrated and applicable to site conditions.

Acceptance Criterion 3: Data Uncertainty Is Characterized and Propagated through the Model Abstraction.

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate.

(3) Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models, considered in developing the abstraction of flow paths in the SZ. This may be done through either sensitivity analyses or use of conservative limits. For example, sensitivity analyses and/or similar analyses are sufficient to identify SZ flow parameters that are expected to significantly affect the abstraction model outcome.

Acceptance Criterion 4: Model Uncertainty Is Characterized and Propagated through the Model Abstraction.

(2) Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed. For example, uncertainty in data interpretations is considered by analyzing reasonable conceptual flow models that are supported by site data, or by demonstrating through sensitivity studies that the uncertainties have little impact on repository performance.

(3) Consideration of conceptual model uncertainty is consistent with available site characterization data, laboratory experiments, field measurements, natural analog information and process-level modeling studies; and the treatment of conceptual model uncertainty does not result in an under-representation of the risk estimate.

(4) Appropriate alternative modeling approaches are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations, using tests and analyses that are sensitive to the processes modeled.

Additional criteria listed in Section 3 of the TWP includes "Completion Criteria" (BSC 2004 [DIRS 171421], Section 3.4), which states that the scope of work should be in accordance with the scope of the work identified in the following TWPs: *Technical Work Plan for: Regulatory Integration Evaluation of Analysis and Model Reports Supporting the TSPA-LA* (BSC 2004 [DIRS 169377], Section 1) and *Technical Work Plan for: Data Confirmation Project–Technical Product Review Process* (Jaeger 2004 [DIRS 169937]). BSC (2004 [DIRS 169377]) was revised to BSC (2004 [DIRS 169653]), however Section 1 of the document remained unchanged. Thus, the revision did not impact the "Completion Criteria" listed in Section 3.4 of *Technical Work Plan for: Natural System - Saturated Zone Analysis and Model Report Integration* (BSC 2004 [DIRS 171421]). These two TWPs also cover work required to enable the closure of condition reports assigned to specific reports. Boundary conditions are not discussed in this report as identified in Section 3.5 of the TWP (BSC 2004 [DIRS 171421], Section 3.5) because boundary conditions do not apply to this model. As required per Section 3.3 of the TWP (BSC 2004 [DIRS 171421]), the adequacy, precision and representativeness of the HFM-19 is provided through the justification of the input data used, see Sections 4.1 and 6.1, and the uncertainties associated with the model development are described in Section 6.4.3.

4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulation requirements other than those identified in the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], Table 2-3) and determined to be applicable (Table 4-3) were used in this model report.

5. ASSUMPTIONS

This section includes a description of assumptions used, in the absence of direct confirming data or evidence, to build the HFM-19. Other model assumptions in the conceptual model development are described in Section 6. The assumptions underlying the construction of the HFM-19 are methodological in nature and are imposed by the use of standard geologic gridding techniques using 3-D geometric elements to conceptualize stratigraphic and structural features.

Hydrogeologic units are a simplification of geology done for inclusion into the database and mapping system and to accommodate groupings of geologic units thought to have similar hydrologic properties, see Section 6.1. Methods, based on the definition of hydrogeologic unit tops using surface, borehole, and geophysical data, are used to generate structure contour maps, which are the fundamental building blocks of the HFM-19. Specific techniques that are assumed to be applicable include the construction of model grids by interpolation and extrapolation with the use of minimum-curvature and first-order least-squares methods. The use of these techniques is described in Section 6 of this model report. The applicability of these techniques to the development of the HFM-19 is supported by the information currently available pertaining to the geologic setting of the Yucca Mountain site and region as described in the *Yucca Mountain Site Description* (BSC 2004 [DIRS 169734]) and require no further confirmation.

In addition to the above general methodological assumptions, the following specific assumptions apply to the construction of the HFM-19:

1. A grid spacing of 125 meters provides adequate spatial resolution for the intended application of the HFM-19 as a conceptual hydrogeologic representation for site-scale SZ flow and transport models (Section 4.1).

   The 3-D site-scale flow model described in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037], Section 6.5.3.2) is based on a numerical spacing of 500 meters. The HFM-19 grid must have 500-meter spacing or smaller to accurately map the shape of hydrogeologic units in the HFM-19 to the computational flow grid. Therefore, the HFM-19 grid provides sufficient resolution to permit the configuration of hydrogeologic units to be represented within the 3-D flow-model computational grid. This assumption does not require further confirmation.

2. The spatial resolution of the DEM used to define the lateral extent of hydrogeologic units exposed at land surface provides a suitable degree of accuracy (Section 4.1).

   The DEM is defined on a rectangular grid with a nodal spacing of 90 m, which is well within the 125-meter nodal spacing of the grid used to construct the HFM-19. This assumption does not require further confirmation.

3. High-angle faults included with the HFM-19 (Section 6.3.3) were represented as vertically oriented planar surfaces.

   Vertical faults are implemented in the HFM-19 to vertically offset hydrogeologic units. The need to represent faults at their appropriate angle or vertical is an issue of scale. The flow model has a horizontal resolution of 500-m, too coarse to capture the inclination of faults in this domain that mostly all dip at angles greater than 60 degrees. For faults with a dip of 60 degrees (generally the shallowest dip of faults in the area), the horizontal displacement over 200 meters is only 115 meters, much less than the horizontal grid spacing of 500 meters used in the flow model. The flow model parameters are homogeneous within a grid cell and the vertical fault assumption is acceptable because it does not significantly impact parameters within a flow model cell. Because the dips available for faults vary within the domain and many have dips that change at an unknown rate with depth (Geologic Map of the Yucca Mountain Region, Nye County, Nevada (Potter et al. (2002 [DIRS 160060])), this is considered an acceptable simplification. Additionally, this representation is consistent with the site-scale SZ flow model, which represents faults explicitly as vertical features (BSC 2004 [DIRS 170037], Section 6.3.2.2). Thrust faults (discussed in Section 6.3.3) are excluded in assumption concerning verticality. This assumption provides an adequate representation of faults within the HFM-19 for its intended use and requires no further confirmation.

6. MODEL DISCUSSION

The HFM-19 is a 3-D static and geometric representation of the location and distribution of hydrogeologic units in the SZ of the Yucca Mountain area, developed for use in site-scale SZ flow and transport models. It is a conceptual model of the hydrogeology at Yucca Mountain, which describes a series of alternating volcanic aquifers and confining units above the regional carbonate aquifer. These hydrogeologic layers consist of one or more contiguous, geologically defined stratigraphic unit(s) that can be grouped into hydrogeologic units based on measured or inferred common hydrologic properties (BSC 2004 [DIRS 170037], Section 6.5.2). The HFM-19 is assembled by using standard gridding techniques to fill the domain area with geometric elements corresponding to the hydrogeologic units. The locations and extent of the represented hydrogeologic units are determined from the input data. The gridding process uses interpolation and extrapolation to relate the geometrical elements to the controlling data within the domain. The result is generalized mapping of input data into a 3-D, volume filled grid with deformed cube shaped elements associated to their corresponding units with identification numbers 2 through 20 (Table 4-2 and Table 6-1).

The HFM-19 is a conceptual model consistent with the definition in AP-SIII.10Q, Section 3.9. It is classified as a conceptual model based on the fact that: (1) it is a set of hypotheses consisting of assumptions, simplifications, and idealizations that describe the hydrogeology and structure within the site-scale SZ flow model (BSC 2004 [DIRS 170037]) and the site-scale SZ transport model (BSC 2004 [DIRS 170036]) domain; and (2) this model consists of concepts related to geometrical elements of the model domain (size and shape) and to, dimensionality (3-D), and lack of time dependence (static model). This product does not provide any hydraulic parameters and cannot approximate a system behavior, process, or phenomenon. Though interpolation methods and calculations were used to describe the HFM-19, the resulting grid is static and fixed and cannot perform any of these functions. The site-scale SZ flow and transport models assign hydrogeologic properties to nodes in a coarser (500-meter resolution) SZ computational flow model grid. The site-scale SZ flow model grid is then combined with boundary conditions and other parameters for groundwater flow simulations. Sections 6.1 through 6.3 discuss the representation of geology, methods, and simplifications, used to build this conceptual model. Section 8 confirms that this is a representation of the hydrogeology. Section 6.5.3 of *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]) describes how the HFM-19 and other inputs were used to assign hydrogeologic units and features, recharge fluxes, hydrogeologic properties, and boundary conditions to node points on a computational grid for the flow modeling process.

As a conceptual model, HFM-19 does not consider alternate conceptual models, though the site-scale SZ flow model report (BSC 2004 [DIRS 170037]) does evaluate this conceptual model and alternate conceptual models used in the SZ flow model studies (see flowchart in Figure 1-1). This report does not discuss results of model testing, sensitivities, or calibration activities as these attributes do not apply to the HFM-19. Mathematical implementation of the HFM-19 occurs when it is used within the flow and transport models for which it is intended. For discussion of the implementation, see the *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]).

6.1 HYDROGEOLOGIC REPRESENTATION

The geologic setting, geologic history, stratigraphy, and structure of Yucca Mountain as represented in HFM-19 are summarized in *Status of Understanding of the Saturated-Zone Ground-Water Flow System at Yucca Mountain, Nevada, as of 1995* (Luckey et al. 1996 [DIRS 100465], pp. 7 to 13). Yucca Mountain (Figure 1-2) is located in the Great Basin section of the basin and range physiographic province, and consists of a group of north-south-trending block-faulted ridges (Figure 4-2) that are composed of volcanic rocks of Tertiary age that may be several kilometers thick. Crater Flat, the basin to the west of Yucca Mountain, contains a thick sequence (about 2,000 m) of Tertiary volcanic rocks, Tertiary and Quaternary alluvium, and small basaltic lava flows of Quaternary age. The Solitario Canyon fault separates Crater Flat from Yucca Mountain (Figure 4-2). West of Crater Flat is Bare Mountain (Figure 1-2), which is composed of Paleozoic and Precambrian sedimentary and crystalline rocks. Fortymile Wash (Figure 4-2), a prominent topographic feature and an inferred structural trough, delimits the eastern extent of Yucca Mountain. East of Fortymile Wash are the Calico Hills, an assemblage of altered Tertiary volcanic rocks and Paleozoic sedimentary rocks. Yucca Mountain terminates to the south in the Amargosa Desert, which contains near-surface deposits of interbedded Quaternary and Tertiary alluvial, paludal, and tuffaceous sediments.

The basic hypothesis used to construct the HFM-19 is that the hydrogeologic units at Yucca Mountain form a series of alternating volcanic aquifers and confining units above the regional carbonate aquifer. The volcanic rocks can be either aquifers or confining units depending on their properties. Hydrologic properties of the volcanic rocks are governed by the mode of eruption and cooling, by the extent of primary and secondary fracturing, and by the degree to which secondary alteration has affected primary permeability (Laczniak et al. 1996 [DIRS 103012]). Dense rocks with abundant fractures are characteristic of the volcanic-rock aquifers. These aquifers consist of welded-tuff sheets outside the calderas and lava flows and thick welded-tuff bodies within the calderas. The ability of these fractured rocks to form aquifers depends on the interconnectedness of these fractures. Generally, the confining units are formed by zeolitically altered nonwelded tuffs (Laczniak et al. 1996 [DIRS 103012]). These have eroded significantly since deposition. The volcanic rocks generally thin toward the south, away from their eruptive source areas in the vicinity of Timber Mountain (Figure 1-1). The volcanic aquifers and confining units are intercalated with undifferentiated valley-fill and the valley-fill aquifer to the south and southeast. Structural features define the eastern, western, and portions of the southern boundaries of Yucca Mountain (Figure 4-2). Depending upon the length of time between major volcanic eruptions, the volcanic rocks and valley-fill materials could have been deposited either on a planar surface unaffected by erosion and structural deformation, or on a preexisting topographic surface. Depositional units that are quickly buried by subsequent deposits generally have planar upper surfaces.

In order to represent geologic heterogeneity introduced by stratigraphy in a groundwater flow system, geologic units traditionally are simplified into hydrogeologic units on the basis of similar hydrologic properties (Winograd and Thordarson 1975 [DIRS 101167]; and Laczniak et al. 1996 [DIRS 103012]). The identification of hydrogeologic units for site-scale flow began in 1995 and started with large-scale regional scale domain encompassing an irregular shaped area in southern California and southern Nevada. Out of the defined hydrogeologic units in the region, some units did not occur in the study area and others were grouped with other units, resulting in

10 hydrogeologic units to coarsely represent groundwater flow in the area. Where possible, hydrogeologic units identified by previous investigators (Luckey et al. 1996 [DIRS 100465; Winograd and Thordarson 1975 [DIRS 101167]; and Laczniak et al. 1996 [DIRS 103012]) were used. The formation of these hydrogeologic groupings is discussed by Faunt (2002 [DIRS 171453], pp. 42 to 45 and 61). The decision was made to build a site-scale HFM with the same depth in units, but with boundaries closer to Yucca Mountain. The site-scale domain was selected to include hydrogeologic units relevant to flow from the repository to a compliance point about 18 km south of Yucca Mountain, near the Amargosa area. The units were regrouped to capture relevant hydrogeology within the small domain, but selected to be consistent with the previous set of investigators. This new domain was grouped into 15 units (Faunt 2002 [DIRS 171453], pp. 122 to 125). Over the years and through iterations of data analysis, evaluations, and reviews of the constructed representation, the HFM evolved to the current version with 19 units (Table 4-1 and Table 6-1). The site-scale domain and the units occurring at the land surface are illustrated in the map of outcrop geology in Figure 4-2. The design of the HFM evolved to look at more detail in the volcanic aquifers at Yucca Mountain. In particular, the Crater Flat tuff was split into its members (Prow Pass, Bullfrog, and Tram). In addition, more detail was added to the basement rocks to separate competent crystalline rocks from clastic rocks. As new information was developed to quantify the thrust fault geometry, the faulting there was incorporated by separating a thrusted carbonate block. Nineteen hydrogeologic units (model units 2 through 20 and base 1) are present in the model area (Figure 6-1; Table 6-1), though some cover only a small portion within the site-scale domain. Table 6-1 summarizes the hydrogeologic units and their correlation with the different hydrogeologic units in the model area. Figure 6-1 illustrates, by way of a fence diagram, the complex 3-D spatial relation among these units within the SZ of the model area.

The geologic relations, both actual and inferred, are simplified in order to accommodate computer mapping, framework modeling, and groundwater flow modeling limitations. In simplifying units, emphasis was placed on maintaining a highly generalized structural and stratigraphic framework that incorporated previously described hydrogeologic units. The following criteria were used as guidelines in the simplification process:

- Major high-angle faults were simplified and represented as individual vertical fault planes (thrust faults are not included as vertical faults and are constructed similar to material units)

- Geologic units were grouped into the hydrogeologic units (Table 6-1)

The site-scale domain was selected based on groundwater flow and radionuclide transport considerations as described in the site-scale SZ flow model (BSC 2004 [DIRS 170037], Section 6.5.3.2). The HFM-19 represents the hydrogeologic setting for the Yucca Mountain area that covers about 1,350 km^2 and includes a saturated thickness of about 2.75 km.

Table 6-1. Hydrogeologic Units (HFM-19), Equivalent Investigated Units, and Associated Lithologies in the Vicinity of Yucca Mountain

Hydrogeologic Unit number and name in HFM-19 (Age)	Equivalent Units from Previous Investigations			
	Winograd and Thordarson (1975 [DIRS 101167])	**Laczniak et al. (1996 [DIRS 103012]) Table 1**	**Luckey et al. (1996 [DIRS 100465])**	**Type of Deposit or Lithology**
20 - Valley-fill aquifer (Q, T)	Valley Fill (Valley-fill aquifer)	Alluvial deposits (Valley-fill aquifer)	Alluvium	Alluvial fan, fluvial, fanglomerate, lakebed, eolian and mudflow deposits
19 - Valley-fill confining unit (Q, T)	Valley Fill (Valley-fill aquifer)	Alluvial deposits (Valley-fill aquifer)	Alluvium	Playa deposits
18 - Limestone aquifer (T)	–	–	–	Lacustrine limestones, calcareous spring deposits
17 - Lava-flow aquifer (Q,T)	Basalt of Kiwi Mesa Basalt of Skull Mountain (Lava-flow aquifer)	Basalt	–	Basalt flows, dikes and cinder cones, latite dikes
16 - Upper volcanic aquifer (T)	Timber Mountain Tuff Paintbrush Tuff (Welded-tuff aquifer)	Thirsty Canyon Group Timber Mountain Group Paintbrush Group (Welded-tuff and lava-flow aquifers)	Paintbrush Group (Upper volcanic aquifer)	Variably welded ashflow tuffs and rhyolite lavas (nonwelded tuffs)
15 - Upper volcanic confining unit (T)	Wahmonie Formation Salyer Formation Rhyolite flows and tuffaceous beds of Calico Hills (Lava-flow aquitard - Tuff aquitard)	Volcanics of Area 20 Wahmonie Formation (Lava-flow aquifers)	Calico Hills Formation (Upper Volcanic Confining Unit)	Rhyolite lavas, volcanic breccias, nonwelded to welded tuffs, commonly argillaceous or zeolitic
14 - Lower volcanic aquifer – Prow Pass Tuff (T)	Grouse Canyon Member Tuff of Crater Flat (Tuff aquitard)	Crater Flat Group Belted Range Group (Welded-tuff and lava-flow aquifers)	Crater Flat Group (Lower Volcanic Aquifer)	Variably welded ashflow tuffs and rhyolite lavas

Table 6-1. Hydrogeologic Units (HFM-19), Equivalent Investigated Units, and Associated Lithologies in the Vicinity of Yucca Mountain (Continued)

Hydrogeologic Unit number and name in HFM-19 (Age)	Equivalent Units from Previous Investigations			
	Winograd and Thordarson (1975 [DIRS 101167])	**Laczniak et al. (1996 [DIRS 103012]) Table 1**	**Luckey et al. (1996 [DIRS 100465])**	**Type of Deposit or Lithology**
13 - Lower volcanic aquifer – Bull Frog Tuff (T)	Grouse Canyon Member Tuff of Crater Flat (Tuff aquitard)	Crater Flat Group Belted Range Group (Welded-tuff and lava-flow aquifers)	Crater Flat Group (Lower Volcanic Aquifer)	Variably welded ashflow tuffs and rhyolite lavas
12 - Lower volcanic aquifer - Tram Tuff (T)	Grouse Canyon Member Tuff of Crater Flat (Tuff aquitard)	Crater Flat Group Belted Range Group (Welded-tuff and lava-flow aquifers)	Crater Flat Group (Lower Volcanic Aquifer)	Variably welded ashflow tuffs and rhyolite lavas
11 - Lower volcanic confining unit (T)	Local informal units of Indian Trail Formation (Tuff aquitard)	Tunnel Formation (Tuff confining unit)	Flow Breccia Lithic Ridge Tuff (Lower Volcanic Confining Unit)	Nonwelded tuff, commonly zeolitized
10 - Older volcanic aquifer (T)	Tub Spring Member (Tuff aquitard)	Volcanics of Big Dome (Lava-flow and welded-tuff aquifer)	–	Variably welded ashflow tuffs, rhyolite lavas
9 - Older volcanic confining unit (T)	? (Tuff aquitard)[1]	Older Volcanics (Tuff confining unit)	–	Nonwelded tuff, commonly zeolitized
8 - Undifferentiated valley-fill (T)	Rocks of Pavits Spring Horse Spring Formation (Tuff aquitard)	Pavits Spring Formation Horse Spring Formation Paleocolluvium	–	Tuffaceous sandstone, tuff breccia, siltstone, claystone, conglomerate, lacustrine limestone, commonly argillaceous or calcareous. Sedimentary breccia.
7 - Upper carbonate aquifer (Pz)	Tippipah Limestone (Upper carbonate aquifer)	Bird Spring Formation (Upper carbonate aquifer)	–	Limestone
5 - Upper clastic confining unit (Pz)	Eleana Formation (Upper clastic aquitard)	Eleana Formation (Eleana confining unit)	–	Siliceous siltstone, sandstone, quartzite, conglomerate, limestone

Table 6-1. Hydrogeologic Units (HFM-19), Equivalent Investigated Units, and Associated Lithologies in the Vicinity of Yucca Mountain (Continued)

Hydrogeologic Unit number and name in HFM-19 (Age)	Equivalent Units from Previous Investigations			
	Winograd and Thordarson (1975 [DIRS 101167])	Laczniak et al. (1996 [DIRS 103012]) Table 1	Luckey et al. (1996 [DIRS 100465])	Type of Deposit or Lithology
4 - Lower carbonate aquifer and 6 - Lower carbonate aquifer thrust (Pz)	Devils Gate Limestone Nevada Formation Ely Springs Dolomite Eureka Quartzite Pogonip Group Nopah Formation Dunderberg Shale Bonanza King Upper Carrara Formation (Lower carbonate aquifer)	Guilmette Formation Simonson Dolomite Sevy, Laketown, and Lone Mountain Dolomite Roberts Mountain Formation Dolomite of the Spotted Range Ely Springs Dolomite Eureka Quartzite Pogonip Group Nopah Formation Bonanza King Formation Upper Carrara Formation (Lower carbonate aquifer)	Lone Mountain Dolomite Roberts Mountain Dolomite (Carbonate Aquifer)	Dolomite and limestone, locally cherty and silty
3 - Lower clastic confining unit (Pz, pC)	Lower Carrara Formation Zabriskie Quartzite Wood Canyon Formation Stirling Quartzite Johnnie Formation (Lower clastic aquitard)	Lower Carrara Formation Zabriskie Quartzite Wood Canyon Formation Stirling Quartzite Johnnie Formation Noonday (?)[2] Dolomite (Quartzite confining unit)	–	Quartzite, siltstone, shale, dolomite
2 - Granitic confining unit (T)	Granitic Stocks (A minor aquitard)	Granite	–	Granodiorite and quartz monzonite in stocks, dikes and sills

[1] ? (Tuff Aquitard) - correlation of HFM unit 9 to stratigraphic units in Winograd and Thordarson is not clear, but would correlate with the Tuff Aquitard hydrogeologic unit.

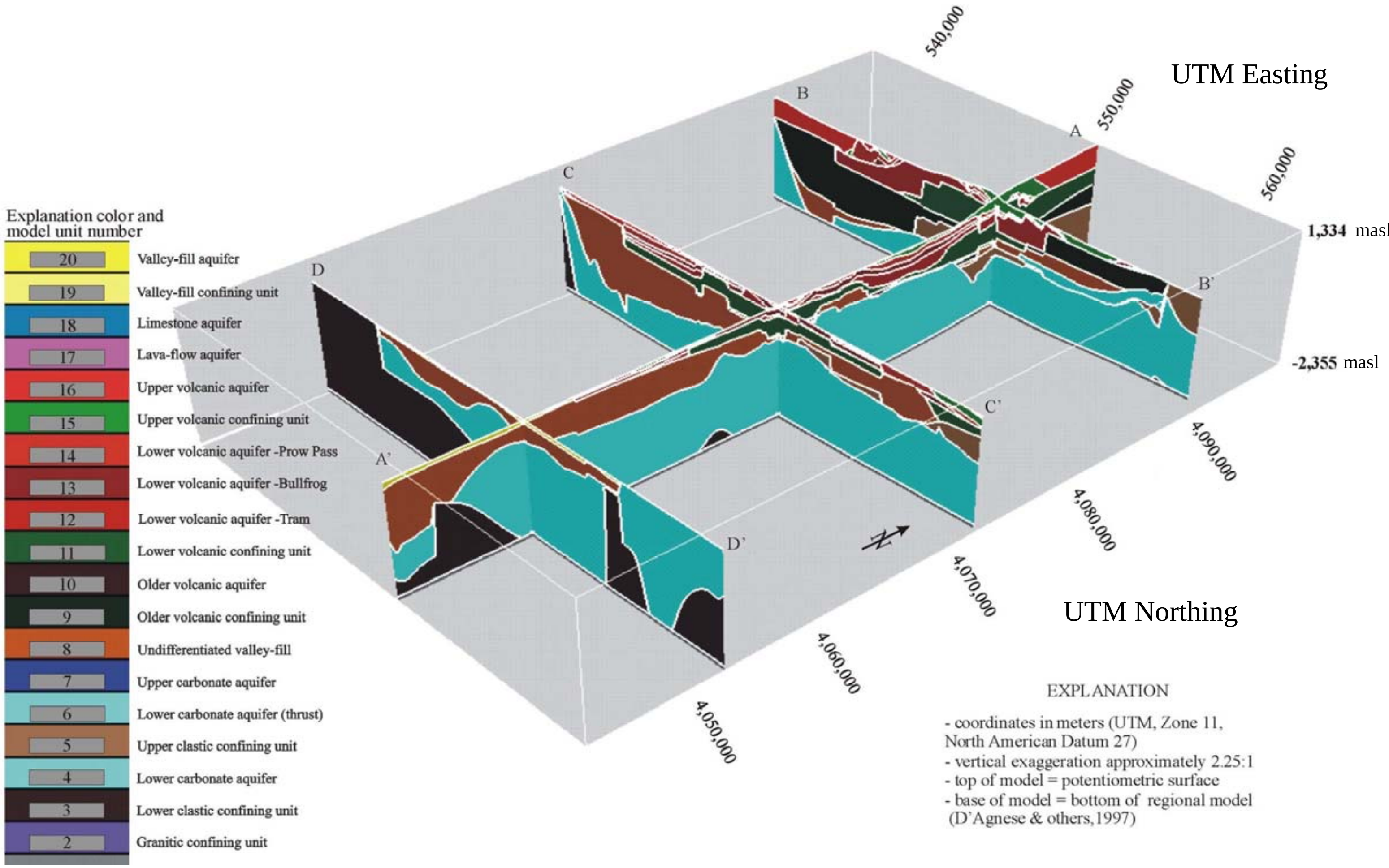
[2] Noonday (?) Dolomite - is identified this way in Winograd and Thordarson (1975 [DIRS 101167], footnote 3 of Table 1) and is reproduced here in the same way.

--, no units identified; hydrologic-unit names listed in parentheses; (Q=Quaternary; T=Tertiary; Pz=Paleozoic; pC=Precambrian); HFM=hydrogeologic framework model

The HFM-19 extends from UTM 533,340 meters to 563,340 meters (west to east) and 4,046,782 meters to 4,091,782 meters (south to north), UTM Zone 11 (Figure 1-1). The base of the model was selected to be consistent with the base of the Death Valley regional groundwater flow model (DTN: GS960808312144.003 [DIRS 105121]) and propagates through the site-scale SZ flow (BSC 2004 [DIRS 170037]) and transport (BSC 2004 [DIRS 170036]) models using HFM-19. The top of the model is ground surface. A smaller version of the HFM-19 is created by clipping the top of the model by a potentiometric surface (Figure 6-2). This was done to satisfy grid size restrictions in the flow codes and has no impact on the flow model since the site-scale SZ domain is below this clipping surface (Faunt 2002 [DIRS 171453], p. 130).

The HFM-19 model documented in this report is built from geologic maps, geologic cross sections, borehole lithologic logs, digital elevation data, and the GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]). Geologic information, geologic cross sections developed for the ERP for the Nevada Test Site (DTN: MO0106STRATHFM.024 [DIRS 155585]), and the results of geologic mapping and subsequent geologic cross section development (DTN: GS010908314221.001.001 [DIRS 162874]) were added to the input set. Data were selected for input into the model upon completion of an extensive literature search. The scientific notebook SN–USGS-SCI-072-V2, V3 (Faunt 2002 [DIRS 171453]) documents the more than 100 references that were examined to determine the most appropriate data for the construction of the HFM-19.

The HFM-19 is assembled by using standard gridding techniques to fill the domain area with 3-D elements corresponding to the hydrogeologic units. The locations and extent of the units are determined from boreholes, surface geologic maps, geologic cross sections, and geophysical surveys. The HFM-19 has 19 unit layers or sequences numbered sequentially from bottom to top starting with a base 1 and the bottom sequence 2. Base 1 is not used in the flow or transport models, but is needed by Stratamodel (USGS 2000 [DIRS 148985]), which requires the specification of a base unit. Each of the sequences (2 through 20) in the model corresponds to a hydrogeologic unit. The numbers representing the stacking order of the units in the site area are listed in Table 6-1 along with the unit names. Figure 6-1 shows these 19 sequences, which will represent the basis for hydrogeologic units in the flow and transport models. The HFM-19 has been clipped for this image.

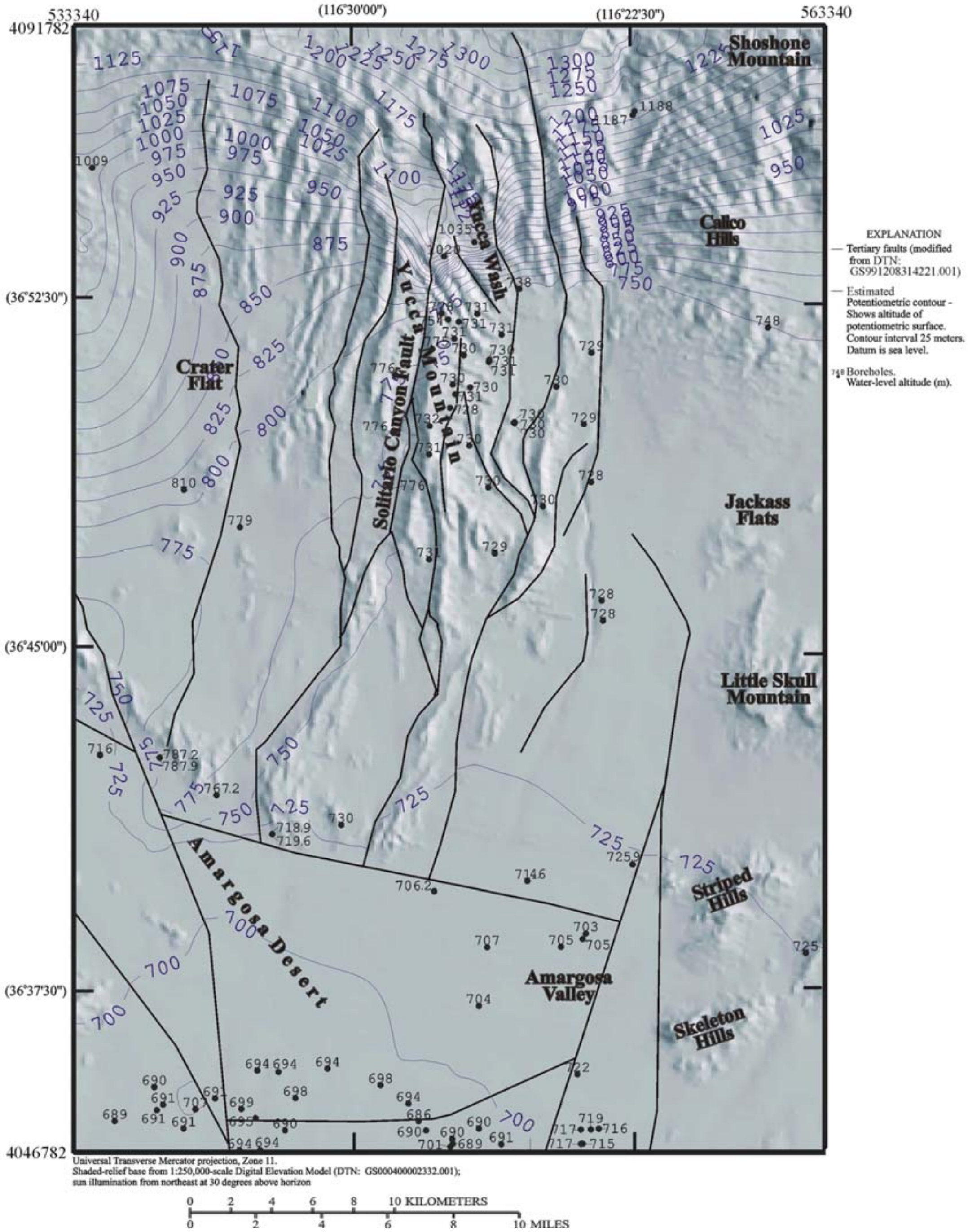


Output DTN: GS030208312332.001.

NOTE: Base of model coincides with bottom of regional model (D'Agnese et al. 1997 [DIRS 100131], p. 2).

UTM=Universal Transverse Mercator; masl = meters above sea level.

Figure 6-1. Fence Diagram Showing Cross-Sections along Dotted Lines Shown in Figure 4-2



Source: DTNs: Water Levels–GS000508312332.001 [DIRS 149947]; DEM–GS000400002332.001 [DIRS 148924]; Faults–GS010908314221.001 [DIRS 162874].

NOTES: Tertiary faults modified from DTN: GS991208314221.001 [DIRS 145263] (this DTN has been updated and is discussed in Section 4.1.1.3). —Estimated potentiometric contour shows altitude of potentiometric surface; contour interval 25 m; datum is sea level. 748 • boreholes = water-level altitude (m). X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-2. Borehole Locations with Water-Level Altitudes, Potentiometric Surface Contours, and Location of Tertiary Faults in Saturated Zone Site-Scale Model Area

6.2 FEATURES, EVENTS, AND PROCESSES CONSIDERED IN THE HYDROLOGIC FRAMEWORK MODEL

As stipulated in the *Technical Work Plan For: Natural System - Saturated Zone Analysis Model Report Integration* (BSC 2004 [DIRS 171421]) this model report addresses the SZ FEPs pertaining to the HFM-19 for the SZ site-scale flow and transport models that are included FEPs for the Total System Performance Assessment for the License Application (TSPA-LA) (Table 6-2). Table 6-2 provides a list of FEPs that are relevant to this model in accordance with their assignment in the license application FEP list (DTN: MO0407SEPFEPLA.000 [DIRS 170760]). Specific reference to the various sections within this document where issues related to each FEP are addressed is provided in the table. Saturated zone FEPs that were excluded from TSPA-LA are described in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]).

Table 6-2. Features, Events, and Processes Included in TSPA-LA and Relevant to this Model Report

FEP No.	FEP Name	Sections Where Disposition is Supported	FEP Topic Addressed in Other SZ Analysis or Model Reports
1.2.02.01.0A	Fractures	6.1, 6.3, 6.3.3, 6.3.4, 6.4	Upstream Feeds[a] – N/A Corroborating[b] – *Saturated Zone In-Situ Testing* (BSC 2004 [DIRS 170010]); *Saturated Zone Site-Scale Flow Model*, (BSC 2004 [DIRS 170037]) Expanded Discussion[c] – *Probability Distribution for Flowing Interval Spacing*, (BSC 2004 [DIRS 170014])
1.2.02.02.0A	Faults	4.1, 6.1, 6.3.3, 6.3.4, 6.3.5, 6.3.6, 6.4, 8.0	Upstream Feeds – N/A Corroborating – *Saturated Zone In-Situ Testing* (BSC 2004 [DIRS 170010]); Expanded Discussion[c] – *Saturated Zone Site-Scale Flow Model*, BSC 2004 [DIRS 170037]
2.2.03.01.0A	Stratigraphy	5.0, 6.1, 6.3.2, 6.3.4, 6.3.5, 8.0	Upstream Feeds – N/A Corroborating – *Saturated Zone In-Situ Testing* (BSC 2004 [DIRS 170010]); *Probability Distribution for Flowing Interval Spacing*, (BSC 2004 [DIRS 170014]) Expanded Discussion[c] – *Saturated Zone Site-Scale Flow Model*, (BSC 2004 [DIRS 170037])

Table 6-2. Features, Events, and Processes Included in TSPA-LA and Relevant to this Model Report (Continued)

FEP No.	FEP Name	Sections Where Disposition is Supported	FEP Topic Addressed in Other SZ Analysis or Model Reports
2.2.03.02.0A	Rock properties of host rock and other units	1.0, 6.1, 6.3.3	Upstream Feeds[a] – N/A Corroborating[b] – *Saturated Zone In-Situ Testing* (BSC 2004 [DIRS 170010])
2.2.07.13.0A	Water conducting features in the SZ	6.1, 6.3.3, 6.3.6	Upstream Feeds – N/A Corroborating – *Saturated Zone In-Situ Testing* (BSC 2004 [DIRS 170010]): Expanded Discussion[c] – *Saturated Zone Site-Scale Flow Model*, (BSC 2004 [DIRS 170037])
2.2.12.00.0B	Undetected features in the SZ	6.3.2, 6.3.3, 8.0	Upstream Feeds – N/A Corroborating – *Saturated Zone In-Situ Testing* (BSC 2004 [DIRS 170010]); *Probability Distribution for Flowing Interval Spacing*, (BSC 2004 [DIRS 170014])

Source: SZ report: BSC (2004 [DIRS 170010]).

[a] Upstream Feeds – Aspects of the SZ FEP screening position adopted in this report are a result of SZ analyses performed in a directly upstream SZ model or analyses. N/A indicates no upstream feeds. Note: Figure 1-1 does not indicate any upstream feeds to this report.

[b] Corroborating – Corroborative aspect(s) of the FEP topic is (are) discussed in a relevant SZ analysis or model report.

[c] Expanded Discussion – The primary discussion of the FEP topic is discussed in the referenced SZ report.

6.3 METHODS USED TO DEVELOP THE HYDROLOGIC FRAMEWORK MODEL

The conceptual model was constructed to provide a characterization of the complex 3-D, heterogeneous, porous, and fractured media beneath Yucca Mountain for the site-scale SZ flow and transport models. The HFM-19 was developed to locate hydrogeologic units on a 500-meter computation grid used in site-scale SZ flow modeling (BSC 2004 [DIRS 170037]). As a result, the HFM-19 has simplifications that may restrict its use for other applications. These simplifications are documented in Section 6.4.

The HFM-19 model domain is encompassed within the Death Valley regional flow model (DTN: GS960808312144.003 [DIRS 105121]). The site-scale covers a larger area than that of the 3-D GFM (DTN: MO9901MWDGFM31.000 [DIRS 103769]) (Figure 4-1), developed to support the Yucca Mountain unsaturated-zone flow and transport models, and extends deeper into the SZ than the GFM. The conceptual model evolved based on the needs of the site-scale SZ flow model (Faunt 2002 [DIRS 171453], p. 176), to include more detail within the Crater Flat tuff at Yucca Mountain that was split into its members (Prow Pass, Bullfrog, and Tram). In addition, more detail was added to the basement rocks to separate out competent crystalline rocks from clastic rocks. As new information was developed to quantify the thrust fault geometry, the faulting in deep units was incorporated by separating out a thrusted carbonate block. These new surfaces resulted in the current version HFM with 19 hydrogeologic units.

Development of an HFM began with the assembly of primary data: geologic maps and cross sections, borehole lithologic logs, and topography DEM. The merging of these diverse data types to form a single coherent 3-D digital representation was done using specialized geologic modeling software (discussed in Section 3). Software such as Stratamodel were used for the regional model studies, and the output files were converted for use by the flow model codes, and helped provide consistency between the SZ hydrologic framework and the site-scale SZ flow model (BSC 2004 [DIRS 170037]). The methods used successfully and those that were discarded are discussed throughout the scientific notebook SN-USGS-SCI-072-V2, V3 (Faunt 2002 [DIRS 171453]).

The input data evolved in a similar fashion over time, through an iterative process of gridding, visualization, analysis, and review as outlined in Section 4.1.1. Duplicate data and obviously unreasonable values were removed from the input data set. In general, the latest data are used as it is almost always based on the most recent and accumulated amounts of data. The data and resulting representation were reviewed and each iteration of the 3-D framework was built. The comments generated during these reviews helped identify software interpolations and techniques that needed adjustments. Each iteration and review is documented in the scientific notebook and includes reviews written by R.W. Spengler and J.B Czarnecki (Faunt 2002 [DIRS 171453], pp. 107 to 109 and p. 110). The pages following the review include responses and changes made for the next iteration of development. Each iteration of analysis and review increases confidence in the accuracy of the hydrogeologic representation (see Section 4.1.1 for more on this iterative process).

The following seven steps were used to build the final HFM-19. The first step was discussed in detail previously, while the last six steps are detailed in Section 6.3.

1. Geologic units are classified into hydrogeologic units based on their hydraulic properties and lateral extent. In this study, the hydrogeologic units described by previous investigators were used, as shown in Table 6-1.

2. DEM data are combined with hydrogeologic maps to provide a series of points in 3-D space locating outcrops of individual hydrogeologic units.

3. Geologic cross sections and borehole lithologic logs are used to locate hydrogeologic units in the subsurface.

4. Geologic maps and geologic cross sections are used to locate selected faults (discussed in Section 6.3.3).

5. Structure contour maps for each hydrogeologic unit are developed by interpolating both surface and subsurface positions with Petrosys, which incorporates offsets of units across faults.

6. An HFM is developed when the structure contour maps for the individual hydrogeologic units are combined, utilizing appropriate stratigraphic principles to control their sequence, thickness, and lateral extent.

7. The potentiometric surface (DTN: GS000508312332.001 [DIRS 149947]) is used to clip the HFM-19.

6.3.1 Surface Information

The geologic map of Potter et al. (2002 [DIRS 160060]; DTN: GS010908314221.001 [DIRS 162874]) for the site model area was available in digital form. The geologic units were combined into hydrogeologic units (Faunt 2002 [DIRS 171453], p. 242) and a new 2-D hydrogeologic map was created in ARC/INFO for visual aid. The surface hydrogeologic map (Figure 4-2) was created by lumping Potter's geologic map into hydrogeologic units as described in the scientific notebook SN-USGS-SCI-072-V2, V3 (Faunt 2002 [DIRS 171453], p. 242) and was used for outcrop data and as a guide for the model building activities.

To define the surficial 3-D extent of units exposed at the ground surface, the hydrogeologic map and the DEM were integrated. The digital elevation data are from 1:250,000-scale topographic maps with a grid spacing of approximately 90 meters (DTN: GS000400002332.001 [DIRS 148924]). The DEM defined an array of points in which each point was located by its planar (x, y) coordinates and altitude (z). Points falling within each outcrop area were tagged with the corresponding hydrogeologic unit code, because the outcrop is the observed surface of that hydrogeologic unit.

6.3.2 Subsurface Information

The geologic cross sections (Table 4-1 and Figure 4-1) used to construct the HFM-19 were all at a scale of 1:100,000 or larger. The detailed stratigraphy was simplified into the appropriate hydrogeologic units (Table 6-1). The simplified geologic cross sections were then digitized, merged, scaled, warped to fit their digitized traces, and accurately placed in 3-D space. A database was populated with the different hydrogeologic units. This database was then linked to the cross sections by pointing to each hydrogeologic unit top and keying in the appropriate hydrogeologic unit (Faunt 2002 [DIRS 171453], pp. 113 to 120, pp. 248 to 251).

Lithologic data for boreholes in the area (Table 4-1 and Appendix A) were used as the primary data set while the geologic cross sections were used to correlate and fill between the data points. Borehole lithologic units were grouped into the appropriate hydrogeologic units (Table 6-1). In order to be consistent with the other altitude data being used, the altitude of the top of each hydrogeologic unit was determined by subtracting its depth from the altitude interpolated from the DEM at the borehole location. Where necessary, units of feet were converted to meters using the following formula:

$$\text{Distance (ft)} \times 0.3048 \text{ (m/ft)} = \text{Distance (m)} \qquad \text{(Eq. 1)}$$

In the area covered by the site GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]) (Figure 4-1), the HFM-19 and the GFM 3.1 are reasonably consistent considering differences in size and control point spacing, (Section 4.1.1.2). The GFM was resampled to the coarser grid resolution of the HFM-19 and only the units corresponding with the tops of the HFM-19 were used (Table 4-2). The GFM surfaces for the Calico Hills formation, and the Prow Pass, Bullfrog, and Tram tuffs were used to refine the HFM-19 grid in the area covered by the site 3-D GFM (Table 6-1 and Table 4-2). For each group of units in a particular hydrogeologic unit, the highest altitude from each grid was taken to represent the top of the corresponding hydrogeologic unit for that cell. The GFM contains a surface representing the older volcanic rocks (see Faunt 2002 [DIRS 171453], p. 189 for a listing of GFM 3.1 surfaces included in the HFM-19). In some areas, this unit appears to equate with the older volcanic confining unit of the HFM-19, while in other areas it appears to be a different surface. As a result, these data are not incorporated.

Although the GFM contains gravity data to help define the top of the Paleozoic rocks, the lower carbonate aquifer is not augmented by the data from the GFM. During the analysis of the input data, the version of the GFM did not agree with the seismic data (Faunt 2002 [DIRS 171453], p. 154). This was a different interpretation than what the USGS had published for the top of the basement (lower carbonate aquifer in this area). The interpretations of the seismic line were chosen to use data that were continuous with regional interpretations (Faunt 2002 [DIRS 171453], pp. 204 to 205). Because of the depth of the lower carbonate aquifer and lower clastic confining unit, the amount of data available for determining the location of these units was based more on geologic interpretations incorporated into cross sections and less on actual map outcrops and well logs (Figures 6-6o and 6-6p).

6.3.3 Representation of Faults and Structures

Information on faults used in the development of the HFM-19 includes fault trace maps showing where faults intersect the land surface, and faults shown on geologic cross sections. The trace of a fault is shown on a map and shows the surface exposure of a fault or where it is interpreted to project to the surface. A cross section indicates the dip, the trace of the fault with depth and how the feature is thought to change at depth. Faults in the model area can dip at almost any angle, but most are high-angle faults (greater than 60). Given software constraints for building features such as faults, and the flow model resolution of 500 meters (BSC 2004 [DIRS 170037], Section 6.5.3.2), the faulting and structures in the area were simplified.

Faulting and fracturing at Yucca Mountain may act as preferred conduits or barriers to groundwater flow. Faults in relative tension are more likely to be conduits for groundwater, and faults in shear or compression are more likely to deflect or block groundwater movements. Due to the large number of faults in the modeled area and limitations in modeling technology, guidelines are needed to select the faults that can realistically be modeled. Selection of representative subsurface features included an understanding on how the various fault in the domain might impact the flow model. Juxtaposition by faulting or folding of low-permeability rocks against relatively high-permeability rocks often forms barriers to groundwater flow and prominent hydraulic discontinuities. In general, a fault can be a barrier to flow for two reasons: (1) juxtaposition of low-permeability materials against relatively high-permeability materials and (2) low permeability material (fault gouge) in the fault zone itself forming a barrier to flow across the fault. The first of these features is generally represented in the unit geometry defined in the HFM-19. Barriers, represented by low-permeability nodes, are the second type of feature.

The faults selected to juxtapose units and form offsets in the structure contour maps are shown explicitly as major structural features in Figure 6-3. Faults and other structures used in the construction of the HFM-19 (by being used for offsets in structure contour map gridding) were taken as a subset of the faults identified by Potter et al. (2002 [DIRS 160060], Map I-2755). This subset was subjective and done based on knowledge gained by field geologists familiar with the study area (Potter et al. 2002 [DIRS 160060]). Decisions on selection of faults were noted in the scientific notebook and include criteria based on offsets, length, and discussions with professional hydrogeologists (Faunt 2002 [DIRS 171453], pp. 128, 172, 242 to 243, and 251). C. Potter was included in these discussions (Faunt 2002 [DIRS 171453], p. 172) and provided the map used to define the fault locations for both the HFM-19 and the flow model (DTN: GS010908314221.001 [DIRS 162874]) by Potter et al (2002 [DIRS 160060]). They were also selected based on coincidence with hydrologic changes that include water level offsets across a feature (Solitario Canyon) and hydrochemical changes (Crater Flat) as shown in Figure 6-3. The vertical faults were not included as a geometric defined space as the units are, they were represented as planer surfaces that extend from the bottom of the model to the top surface. These vertical features act as interfaces that create unit offsets. A number of faults were selected to use for offsets on the grids (Figure 6-3).

Vertical low-permeability geologic features are assumed to impede the horizontal flow of groundwater. In the flow model calibration, the barriers have a significant effect on heads and flows in that they support the hydraulic gradients implied by the hydraulic head observations. Other potential barriers may be found to be unimportant or adequately represented by the juxtaposition of hydrogeologic units. For example, if faulting results in highly permeable rock being truncated by low-permeability rock, the barrier to flow will be represented by this juxtaposition of the units and a separate low permeability feature is not necessary.

Thrust faults are another subsurface feature that are a type of fault but treated separately from vertical faults. An area in the southwest corner of the model domain influenced by thrusting was identified (Figure 6-3). This area is coincident with an area of highly fractured carbonate rock and an area of high hydraulic conductivity and high flow rates in the Death Valley regional flow model (DTN: GS960808312144.003 [DIRS 105121]). Thrust faults were represented by repeating hydrogeologic units where these structural features were thought to be hydrologically important. This method is discussed in Section 6.3.4.

Information on faults used in the development of the HFM-19 includes fault trace maps showing where faults intersect the land surface (Figure 6-3) (Potter et al. 2002 [DIRS 160060]). The Solitario Canyon, Crater Flat, Windy Wash, and Bare Mountain faults (Figure 6-3) are identified as major faults in the site-scale model region and are thought to affect groundwater flow. Other faults were represented implicitly by unit offsets and features such as thrusting (Faunt 2002 [DIRS 171453], p. 251). In addition to faults built into the HFM-19, faults can be included as discrete features in the site-scale SZ flow and transport models. The site-scale SZ flow model calibration and alternate model studies add faults to the flow model as geometrically-defined explicit zones with distinct hydrological properties and complementary to the HFM-19. These include Crater Flat fault, Solitario Canyon fault, and U.S. Highway 95 fault (BSC 2004 [DIRS 170037], Table 6-17 and Figure 6-37).

6.3.4 Construction of Hydrogeologic Unit Contour Maps

The HFM-19 is essentially a 3-D map of selected hydrologic units, whose fundamental building blocks are structure contour maps. To construct these maps, the different hydrogeologic unit tops must be interpolated and extrapolated from the available land-surface data and throughout the subsurface between the cross sections and boreholes. The emphasis in this step was to create structure contour maps in a consistent manner by interpolating and extrapolating from available data points. These data points included: (1) topographic elevations derived from DEM data within the outcrop areas of each hydrogeologic unit; (2) separate files defining the tops of each hydrogeologic unit supplied from the geologic cross sections; (3) altitudes of hydrogeologic unit tops from borehole lithologic logs; (4) geophysical evidence of unit tops from published sources; and (5) grid points from the GFM. The distribution of geologic, geophysical, and borehole-data locations is shown in Figure 4-1. The data sources for developing the structure contour maps are shown in Table 6-3. Maps showing the data used to construct each unit, as well as the distribution of the units, are presented in Figures 6-6a through 6-6q. The distribution of the valley-fill aquifer and confining unit is based only on the surface-based hydrogeologic map data shown in Figure 4-2. Figure 6-7 shows the top of the HFM-19 after the top has been clipped by the water table surface, note the actual distribution of the upper units in the HFM-19 are smaller after being clipped.

Gridding fills space in the domain by creating a surface grid across an area based on the distributed input data Petrosys software, gridding techniques and fault-handling package was used to interpolate the hydrogeologic surfaces between existing geologic cross sections, borehole unit tops, surface exposure points, and points from the GFM. A grid design congruent with the computational grid of the regional groundwater flow model (DTN: GS960808312144.003 [DIRS 105121]) was used. The HFM-19 grid, therefore, consists of a rectangular array of nodes with a nodal spacing of 125 m, which was chosen on the basis of flow modeling requirements (less than or equal to a 500-meter flow grid) as opposed to the best increment to accurately represent the data. This selection resulted in grids with 240 columns and 360 rows. This grid spacing simplifies the available data near the repository and extrapolates from very widely spaced data in other areas of the model domain. See Section 4.1 for more on grid resolutions.

Many methods (both mathematical and interpretive) are available for use in creating geometric grids. This method uses a projected distance weighted average to obtain initial grid estimates for the input data. Once the initial estimation has been completed, the grid is allowed to converge to an optimum solution. This converging process (described below) fills in the missing values in the grid. Hence, the gridding process is a convergent technique that can be summarized in the following steps:

1. The input data set to the gridding is extracted from the available information, taking only data that lies in the model domain.

2. The specified grid cell size is doubled until the numbers of rows or columns in the area of interest is less than eight. This number is determined efficient and is part of the recommended gridding techniques in Petrosys software.

3. The sampled data are used to derive values at each grid node using a projected distance weighted technique. Only values within one-half a grid cell size to the node are used in the calculation. If there are no data values within this distance, no value is assigned to the node. This forms the "forced grid."

4. The values at all the grid nodes are calculated using the hybrid grid algorithm (described below) and are placed in the "working grid."

5. The computed value is compared to the value in the "forced grid." The difference between the two values is the difference between the input data and computed grid. Nodes, where there are no forced grid values, are ignored in this calculation. For comparison, the root-mean-square-error in DEM values as presented in Section 4.1.1.4 is on the order of one-third the contour interval and no errors are greater than two-thirds the contour interval. For contour intervals of 30 or 60 m, the DEM root-mean-square-error values range from 10 to 40 meters.

6. For all grid nodes, where there are values in the "forced grid," the "working grid" is modified and the values changed to match those in the "forced grid."

7. The gridding iterates until the change in grid values becomes insignificant or a total of 200 iterations are reached, whichever is less. This ends the first gridding pass.

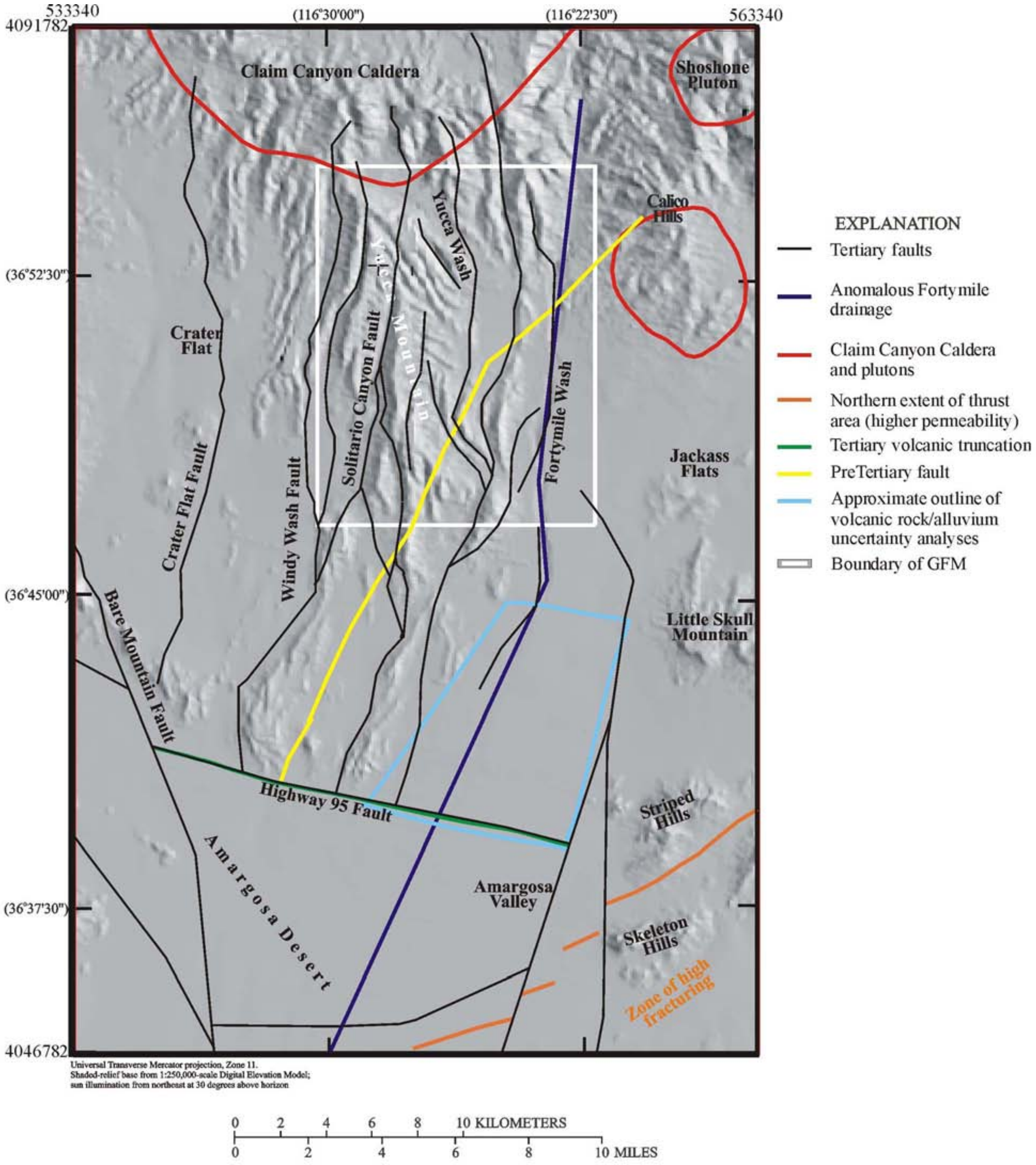
8. The grid cell size is halved, and the sampled data are again used to derive values at each grid node using a projected distance weighted technique. The slopes derived from the previous gridding pass are used in the calculation so that the slopes are preserved. These values then form the new "forced grid."

9. The working grid is updated with the information from the new "forced grid." Gridding continues until the required cell size has been achieved (125 meters in this case).

As mentioned in the steps above, a hybrid gridding technique, which uses two gridding methods, was used to construct a continuous grid or surface for each hydrogeologic unit with a set of points in x, y, z space. The hybrid method is a combination of the minimum curvature and a first order least squares. It uses first order least squares method within one grid cell of a fault and minimum curvature method to calculate all other nodes away from the fault. The minimum curvature method fits a minimum curvature spline through the data points either side of the point being determined. Hence, it preserves the rate of change of slope. The minimum-curvature method is commonly used with good results in geologic modeling, but in areas where faults are treated as opaque barriers between units, this method results in a spiked appearance. The first order least squares method appears to reduce the number of spikes near the faults, resulting in a more realistic looking surface. In regions of heavy faulting, such as Yucca Mountain, a combination of the methods appears to honor the data more accurately (USGS 2001 [DIRS 148306]). In all cases, the preferred gridding method will depend on the data set and on the desired result. The final grid using one algorithm may "look better" to one interpreter, while another person may prefer the result obtained using another algorithm. In these heavily faulted datasets, the results of the hybrid grid algorithm appear to look better than those obtained using minimum curvature alone.

Using a fault-handling package built into the gridding software, the fault traces (Figure 6-3) were used during the gridding procedure so that the altitude of a unit was not translated across a fault (Table 6-4). Where the grid crosses a fault, the grid is offset by the appropriate amount. The offset on the faults varies with location. Inherent in using fault traces is the simplification of these faults being traces of a vertical fault plane. Hence, the resulting structure contour maps contain a series of undulating surfaces broken by faults (Figures 6-6a through 6-6q). Because of the scale of the model, the intended use of the model, and data availability, grids of individual fault surfaces were not constructed. Even less is known about the dip and location of faults below the water table than the stratigraphy. Some of the offsets on the faults are preserved through changes in altitude of a given hydrogeologic unit. Given the depth and area over which the HFM-19 extends, and the lack of information in most of the modeled volume, this simplification provides a reasonable and usable framework for the flow and transport models.

Though most selected faults are treated as vertical, there are types of fault features that, for gridding purposes, are treated similar to hydrologic units. Thrust faults are low angle reverse faults that can cause repeating hydrogeologic units that occur in the model area, but are difficult to represent in the software because geologic, structural, or stratigraphic surfaces stored as arrays cannot have multiple vertical coordinate (z) values. In order to deal with this difficulty, some simplifying techniques were used. Where units were repeated by thrust faults, such as the lower carbonate aquifer, two different grids were created for the same hydrogeologic unit. Repeating hydrogeologic structural unit altitude values were treated as defining unique additional hydrogeologic unit(s). A unit boundary map was then added to define an outline for the perimeter of the thrust sheet. Within this boundary, hydrogeologic structural elevation values were treated as defining unique additional hydrogeologic units. Where units were continuous across this boundary, values are the same on each side, making the boundary invisible for modeling purposes.



Modified from DTN: GS010908314221.001 [DIRS 162874].

NOTE: X axis=longitude and UTM Easting in meters.
Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-3. Site Saturated Zone Model Extent and Locations of Proposed Hydrogeologic Zones and Faults

Table 6-3. Data Sources for Hydrogeologic Units

Hydrogeologic Unit	Data Sources					
	Geologic Cross Section[1]	Lithologic Log[2]	Geologic Map[3]	GFM 3.1[4]	ERP Geologic Cross Section[5]	Geophysical Data[6]
Valley-Fill Aquifer			X			
Valley-Fill Confining Unit			X			
Limestone Aquifer		X				
Lava-Flow Aquifer	X	X	X			
Upper Volcanic Aquifer	X	X	X			
Upper Volcanic Confining Unit	X	X	X	X		
Lower Volcanic Aquifer –Prow Pass Tuff	X	X	X	X		
Lower Volcanic Aquifer –Bullfrog Tuff	X	X	X	X		
Lower Volcanic Aquifer –Tram Tuff	X	X		X		
Lower Volcanic Confining Unit	X	X	X			
Older Volcanic Aquifer		X				
Older Volcanic Confining Unit	X	X				
Undifferentiated Valley-Fill	X	X	X			
Upper Carbonate Aquifer					X	
Lower Carbonate Aquifer (Thrust Plate)	X		X			
Upper Clastic Confining Unit	X	X	X		X	
Lower Carbonate Aquifer	X	X	X		X	X
Lower Clastic Confining Unit	X		X		X	
Granitic Confining Unit	X					

[1] See Appendix A.
[2] See Appendix A.
[3] DTN: GS000400002332.001 [DIRS 148924]; DTN: GS010908314221.001 [DIRS 162874]
[4] DTN: MO9901MWDGFM31.000 [DIRS 103769]
[5] DTN: MO0106STRATHFM.024 [DIRS 155585]
[6] DTN: MO0106STRATHFM.025 [DIRS 155586] and DTN: MO0106STRATHFM.026 [DIRS 155587]

NOTE: GFM=geologic framework model; ERP=Environmental Restoration Program

Table 6-4. Gridding Parameters

Hydrogeologic Unit	Clipping Distance (m)[1]	Faults included in gridding
Valley-Fill Aquifer	62.5	No
Valley-Fill Confining Unit	62.5	No
Limestone Aquifer	2,000	No
Lava-Flow Aquifer	2,000	Yes
Upper Volcanic Aquifer	5,000	Yes
Upper Volcanic Confining Unit	5,000	Yes
Lower Volcanic Aquifer –Prow Pass Tuff	7,500	Yes
Lower Volcanic Aquifer –Bullfrog Tuff	10,000	Yes
Lower Volcanic Aquifer –Tram Tuff	7,500	Yes
Lower Volcanic Confining Unit	7,500	Yes
Older Volcanic Aquifer	5,000	Yes
Older Volcanic Confining Unit	10,000	Yes
Undifferentiated Valley-Fill	10,000	Yes
Upper Carbonate Aquifer	2,000	Yes[2]
Lower Carbonate Aquifer (Thrust Plate)	7,500	Yes[3]
Upper Clastic Confining Unit	2,000	Yes[2]
Lower Carbonate Aquifer	None	Yes[2]
Lower Clastic Confining Unit	None	Yes[2]
Granitic Confining Unit	6,000	Yes

Output DTN: GS000508312332.002.

Source: Figures 6-6a through 6-6q

[1] Clipping distance is the distance beyond the data points which grid nodes are set to null values.
[2] Paleozoic fault was also included.
[3] Thrust fault unit extent was used.

Where little data are available to determine the altitude of a hydrostratigraphic unit, the altitude of the unit top was extrapolated from the existing data points. The location of the data can be seen relative to each unit in Figures 6-6a through 6-6q. The white areas in the figures show where the grid values are null, and the unit does not exist. Boreholes, cross section data, GFM extent, and geologic map data are shown relative to the unit where they were used. Areas close to the repository and at shallower depths show good definition, areas beyond the GFM boundary and in the deeper units show sparse data distribution. The extrapolation is based on the hybrid gridding algorithm described above.

The quality of individual structure contour maps depends on the quantity of the data points used to define them. Some of these hydrogeologic surfaces, such as that for upper volcanic aquifer, were relatively well defined by more than one data set (derived from surface information, lithologic logs, and geologic cross sections). Other structure contour maps, especially those for units with fewer outcrops, were less well defined and were extrapolated from sparse, interpretive data such as published geophysical interpretations. In areas with little or no data, gridding algorithms sometimes extrapolate unreasonably. Where no geologic interpretations were available to augment the data, the problems were handled in two ways: (1) a clipping distance (Table 6-4) was instituted that allowed the grid values to be null where the unit was thought not to exist, and (2) gaps that were filled between data extrapolations were kept. These areas were evaluated in the alternate HFM (HFM–27) and are discussed in Section 6.4. Confidence in the resulting representation was established by the iterative process of data analysis during gridding and evaluation of the contour maps.

6.3.5 Assembling the Hydrogeologic Framework Model

The 3-D HFM-19 was constructed by combining the set of interpolated structure contour maps representing the tops of individual hydrogeologic units. Stratamodel stratigraphic geocellular modeling (USGS 2000 [DIRS 148985]) is a geologic modeling software product that uses its own "geologic rules" to help define the geographic extent and intersection of surfaces. The stratigraphic geocellular modeling (Stratamodel) software has been developed for modeling a sedimentary basin environment. It allows for the specification of sedimentary depositional units (onlap and proportional units), as well as the truncation of units and faulting. Although Stratamodel allows the incorporation of faults as individual surfaces in the sequence of events, because of the lack of geologic information at depth and complexity of the model area, this feature was not incorporated in the construction of the HFM-19. The sequence presented below describes the geologic rules used with this software. Basically, the HFM-19 is a 3-D cellular framework that defines the structural and stratigraphic nature of rock formations. The stratigraphic nature is defined by depositional pattern and cell layer resolution. Examples of the stratigraphic and structural complexities include: proportionally varying cell thickness, onlap or baselap, truncation, and faulting.

Stratamodel was not designed to handle the time stratigraphic emplacement of intrusions. To include intrusions, they must be inserted into Stratamodel out of their correct stratigraphic order. The youngest intrusion must represent the oldest deposition surface. Therefore, the youngest intrusion is the first event sequence included in Stratamodel. While this does not affect the resulting model, it does affect the order the units are put into the model. The following sequence was used to build the 3-D HFM-19 for the site-scale SZ flow and transport models:

1. To maintain consistency among the SZ models, the base is selected to be coincident with the base of the Death Valley regional flow model set at 2,750 meters below a smoothed version of the potentiometric surface (D'Agnese et al. 1997 [DIRS 100131], pp. 2 and 75). This selected base is deep enough to encompass the flow model boundary set at 2,200 meters below the water table (BSC 2004 [DIRS 170037], Section 6.4.6.2.1).

2. The granitic intrusions were input as the first geologic unit.

3. The lower clastic confining unit was input. Where the granitic intrusions were above this grid, the unit was truncated.

4. The remaining units (lower carbonate aquifer, upper clastic confining unit, upper carbonate aquifer, undifferentiated valley-fill unit, volcanic aquifers and confining units, basalt flows, and limestone aquifer) were entered in order by an onlap process onto the lower clastic confining unit and intrusions. Because the volcanic and sedimentary units fill in topographic lows, the onlap process of Stratamodel (USGS 2000 [DIRS 148985]) simulates this process. A special surface was placed at

an appropriate location within the above general sequence to represent the thrust-faulted geometries.

5. The valley-fill aquifer and confining units were emplaced in the valleys.

6. The potentiometric surface (Figure 6-2) was then used as a truncation surface to clip the top of the HFM-19.

The HFM-19 has volumetric units defined by the structure contour maps of individual hydrogeologic units. The hydrogeologic units are numbered consecutively in stratigraphic order from bottom to top (Table 6-1), beginning with sequence number 2 (Sequence 1 is the base and corresponds to the base of the larger SZ regional model). Only the hydrogeologic units and structures occurring above the bottom of the Death Valley regional SZ flow model and below the potentiometric surface are included in the HFM-19. Although the cells have uniform horizontal dimensions throughout the HFM-19, the number of cell layers may be controlled. In many locations, hydrogeologic units have a large thickness.

The stratigraphy and structure represented in the HFM-19 are shown in a fence diagram view of the clipped site model (Figure 6-1). The resulting HFM-19 does not represent many small and even intermediate-scale features within the subsurface, which cannot be resolved within the 125-meter grid spacing. It does, however, represent the site-scale features accurately given the grid resolution, and captures details such as fault-induced truncation of hydrogeologic units providing substantial constraints for flow model development.

6.3.6 Potentiometric Surface

The potentiometric-surface map presented does not strictly represent the water table; it is used for HFM-19 only as a clipping surface of the top of the SZ flow model. Water level data are used differently in the flow model as important calibration targets, and to derive horizontal and vertical hydraulic gradients. The site-scale SZ flow model report (BSC 2004 [DIRS 170037], Sections 6.4.4 and 6.4.5) discusses various interpretations (including perched) and use of water level data within the flow model. However, the potentiometric surface presented here is a reasonable representation of the water table for the following reasons: (1) at Yucca Mountain, water levels at most boreholes were measured in Tertiary volcanic rocks in the uppermost part of the SZ (Graves et al. 1997 [DIRS 101046], p. 1); (2) south of Yucca Mountain, boreholes penetrate the SZ to varying depths dependent upon the total depth of the borehole, but in this area most groundwater flow is believed to be nearly horizontal and available data indicate negligible vertical-head gradients; and (3) for the case of boreholes having multiple piezometers, only water levels from the uppermost saturated interval were used in the construction of the potentiometric-surface map.

Because the potentiometric data dictate a complex 3-D flow system, a number of different conceptual models of the flow system are possible, as discussed in *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (BSC 2004 [DIRS 170009], Section 6.5). In particular, the interpretation of the water table selected assumes a continuous system as opposed to one where the water levels are not well connected. Specifically, in this type of system, some of the water levels could be from a separated perched system or possibly even a more compartmentalized system (by faults or other features). Although the boreholes are open at different depths below the water table and are open to different geologic zones, water levels in most of the boreholes seem to represent a laterally continuous aquifer system (i.e., perched or semi-perched conditions are absent). This portrayal of the potentiometric surface at Yucca Mountain (Figure 6-2) is consistent with those referenced consequent to and including the early work by Robison in *Ground-Water Level Data and Preliminary Potentiometric-Surface Maps, Yucca Mountain and Vicinity, Nye County* Nevada (Robison 1984 [DIRS 144849]), which implies a hydraulically well-connected flow system within the SZ. The well-connected system may result from the presence of many faults and fractures in the volcanic part of the flow system (Tucci and Burkhardt, 1995 [DIRS 101060], p. 7). At the scale of the site model, the groundwater flow system behaves as a porous medium. Flow in the volcanic rocks occurs primarily in fractures and secondarily in the matrix of the rock. Therefore, the uppermost aquifer may be unconfined or confined depending upon the areal location of the point being measured (Tucci and Burkhardt 1995 [DIRS 101060], p. 7).

The potentiometric surface was gridded using these water level data, then resampled to 125-meter spacing coincident with the HFM-19. The borehole locations from which potentiometric data were used in contouring are shown in Figure 6-2, which also shows the borehole elevations. For the case of boreholes having multiple piezometers, only data from the uppermost-completed borehole interval were used. Most of the boreholes are partially penetrating. No attempt was made to segregate and analyze water-level measurements associated with specific hydrogeologic units or fracture zones. Some water levels represent composite heads from multiple hydrogeologic units and fractures. Figure 6-2 shows the top of the HFM-19 as represented by the computer-generated potentiometric surface over the model area in which data from all available boreholes in and around the model area were used. The input water-level data used to construct the surface are discussed in the water level data analysis (USGS 2001 [DIRS 154625]), and were used as calibration targets in the development of the site-scale SZ flow model (BSC 2004 [DIRS 170037], Section 6.4.4).

6.4 RESULTS AND DISCUSSION

The HFM-19 is a conceptual model that provides a static representation of the geometry internal to the volume encompassed by the 3-D model domain of the site-scale SZ flow and transport models for the Yucca Mountain site. The HFM-19 is a conceptual model, not a numerical predictive model, so validation is achieved through the SZ flow and transport models that implement it. All appropriate data that were available to define the geometric relationships within the HFM-19 model domain are used in constructing the HFM-19. The hydrogeologic units consist of contiguous, geologically defined stratigraphic units that are grouped into 19 hydrogeologic units based on measured or inferred common hydrologic properties as shown in Table 6-1. The HFM-19 is assembled from the hydrogeologic units by using standard and acceptable techniques (Section 5) to interpolate and extrapolate the locations and extent of the hydrogeologic units based on data from boreholes, surface geologic maps, geologic cross sections, and geophysical surveys.

Evaluation of the HFM-19 consists of comparing it to data and model sources, and checking that the representation is adequate for its intended use in flow and transport modeling (Faunt 2002 [DIRS 171453], pp. 240 and 241). The accuracy of the HFM-19 is checked by comparing the model against the input data used to build it (Section 6.4.1). New data were added to HFM-19 and the resulting HFM-27 can be used to evaluate the impact of this new data. Accuracy is checked by comparing changes in the source data and their impact on the reinterpreted HFM-27 and on the flow and transport models results (Section 6.4.2). Section 6.4.3 discusses uncertainties in the HFM-19 and how they propagate to the flow and transport models. Adequacy for intended use is checked by evaluating data accuracy and the results from flow and transport modeling using the HFM-19 and the HFM-27 (Section 6.4.4).

6.4.1 Evaluation of HFM-19 Construction and Data

The model construction process can be checked by comparing input data (geologic cross section unit tops, unit tops from borehole lithologic logs, and geologic map unit tops) with grids representing tops of hydrogeologic units in the HFM-19. Specifically, a grid representing the top of a hydrogeologic unit was taken from the HFM-19. This grid was visually compared to the input data. Because of the inconsistent distribution of data, values of approximation varied over the model area. The unit tops of the HFM-19 and input data were checked to see if:

1. Grid values approximated input data
2. Extrapolation from data values is reasonable
3. Grids were not clipped by another surface unreasonably where input data exist.

These checks took place during reviews and confirm that the HFM-19 closely approximates the input data, as documented in the scientific notebook SN-USGS-SCI-072-V2, V3 (Faunt 2002 [DIRS 171453]). These reviews are outlined in Section 4.1.1. The model is more accurate (near the repository and near the land surface) where more data exist. There is less control on extrapolation values further from data control points. The hydrogeologic unit tops have some truncations that result from lack of data and where search distances are exceeded in the gridding algorithms. These truncations and extrapolation effects are a part of the HFM-19 and should be taken into consideration by uncertainty analyses in flow modeling. Specifically, the contact between the volcanic rocks and the alluvium down gradient (south) from the repository should be examined as part of the flow modeling process. The approximate location of this uncertainty zone is shown in Figure 6-3 and is discussed in further detail in Section 6.4.3.

Within the immediate repository area, the site GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]) 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 (Table 6-3). For these units, the GFM is effectively embedded within the HFM-19. However, because of differences between extrapolation techniques and data coverage, the process of embedding the GFM within the HFM-19 introduced discontinuities in some unit thicknesses across the GFM model boundaries. These discontinuities do not affect the flow model in any significant manner (see further discussion in Section 6.4.2 and Appendix B1).

In areas where geologic data are sparse, the gridded surfaces cannot be checked against data. To resolve some of the extrapolation effects, resulting from structural control and depositional heterogeneity, the model was examined for geologic inconsistencies. The maps showing the distribution of the hydrogeologic units (Figures 6-6a through 6-6q) were inspected to determine whether the gridded surfaces were consistent with the input data and the site-scale geologic setting. These figures are a good tool for visually checking that the units of the HFM-19 are a reasonable representation. The units show a recognizable shape and topology that can be compared visually to revisions and similar views of related geologic models. Examination of Figures 6-6a through 6-6q and the actual HFM-19 show that in many areas the lack of hydrogeologic data or the presence of faulting causes a blocky or choppy appearance in the model. Where data show good coverage, units between models compare very closely; where data are sparse, units vary somewhat according to technique and interpretation. These sparse areas include the alluvium uncertainty zone and the deeper units representing the carbonate aquifers and the clastic confining units.

Structures that are a part of the volcanic rocks within the HFM-19 include the Claim Canyon caldera and the Shoshone pluton, shown in Figure 6-3 (Faunt 2002 [DIRS 171453], p. 251). These may be associated with zones of hydrothermally altered rocks having distinctly different hydrologic properties from those nominally associated with the volcanic rocks. These altered zones, therefore, may be hydrologically significant in controlling groundwater flow and recharge in the northern part of the model domain. At the time this model was constructed, available data were not sufficient to assess the potential effects of these zones of altered rocks and to incorporate these zones explicitly within the HFM-19. Similarly, the anomalous Fortymile Wash drainage shown in Figure 6-3 may be indicative of a structural feature that may affect groundwater flow and recharge but was not incorporated explicitly in the HFM-19. However, allowance for the potential effects of these features is incorporated into the site-scale SZ flow model (BSC 2004 [DIRS 170037], Section 6.5.3.4).

By inspecting the HFM-19, it is determined that the grid conforms to input data in the area of the repository, with negligible grid effects along boundaries between dense and sparse data distributions. As the distance from the repository increases (both horizontally and vertically), the grid increment is much finer than the data resolution, so accuracy is difficult to measure. Inspections during the construction of the model and review by Wilson (2001 [DIRS 155614], p. 110) indicate that the HFM-19 agrees with the input data and is suitable for its intended use. The HFM-19 was examined and corrected for geologic inconsistencies; however, the model is not intended for precise geologic unit locations but does satisfy the intent to provide a reasonable and generalized representation that captures major hydrogeologic units affecting flow in the SZ within a resolution used by the SZ flow and transport models.

6.4.2 Impact of New Data and Alternate Models

The development of new geologic models was influenced by geologic observations from Nye County Early Warning Drilling Program (EWDP) wells and made available after HFM-19 was completed. These wells allow a better characterization of the thickness and lateral extent of the alluvial aquifer just north of U.S. Highway 95 (Figure 1-2). A revision to the HFM-19, is a 27-layer HFM-27 (DTN: GS021008312332.002 [DIRS 164363]) incorporating new Nye County data and the updated GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]). The HFM-27 is used for alternate conceptual models in the SZ flow and transport models, and thus enables an evaluation of the impact of new data and the represented hydrogeology. The HFM-19 has not changed as a result of new data and models and remains the base-case conceptual model for the site-scale SZ flow and transport models.

The method to build the HFM-27 is the same as described in this document with some important differences. The units are grouped to resemble the new regional scale HFM2003 resulting in 27-model units instead of 19, and the boundaries are extended vertically (Faunt 2002 [DIRS 171040], pp. 46 to 47). Instead of an altitude near -2,750 m, the base of the regional model and HFM-27 is lowered to an altitude of -4,000 meters. This depth is interpreted to encompass nearly all of the aquifer units in the regional groundwater flow system (Sweetkind et al. 2001 [DIRS 159092]). The top of the HFM-27 is no longer clipped, but continues to the ground surface. The larger vertical representation allows flexibility for flow and transport models in defining the potentiometric and bottom level surfaces for the flow and transport models "Memo Documenting Transmittal of Preliminary Site Saturated Zone Hydrogeologic Framework Model (HFM)" (Faunt 2002 [DIRS 170974]).

The HFM-27 uses new data to establish the thickness and locations of units in the area of the GFM2000 encompassing the repository site and incorporates data from Nye County EWDP boreholes EWDP-2DB and EWDP-19D1 (DTN: GS011008314211.001 [DIRS 158690]); EWDP-01DX, EWDP-02D, EWDP-03D, and EWDP-09SX (DTN: GS000808314211.005 [DIRS 154685]) (blue crosses in Figure 6-4, also used in the flow model). The HFM-27 was made to match well data to within 10 meters and geologic contact data from the Nye County geologic cross sections, NYE-1, NYE-2 and NYE-3 (DTN: GS020208314211.002 [DIRS 158689]), to within 25 meters (Faunt 2002 [DIRS 171040], pp. 53 to 61). Although the Nye County Cross Sections have been revised since development of the HFM-27 (DTN: GS031108314211.005 [DIRS 168526], revised geologic contact information within the cross sections fall within the 25 meters resolution of the HFM-27. Thus, the revision to the Nye County Cross Sections does not impact the HFM-27.

Gridding improvements to the HFM-27, using newly developed hydrogeologic data and the GFM2000, significantly reduce the grid effects seen in the HFM-19, specifically in the Crater Flat Group. These improvements are evident when the HFM unit shapes and thicknesses are compared to the GFM in Figures C-1 through C-5 in Appendix C. These figures demonstrate that that the current revisions of the GFM and HFM resolve the major differences in the thickness of the hydrogeologic units in the northwest corner of the GFM domain.

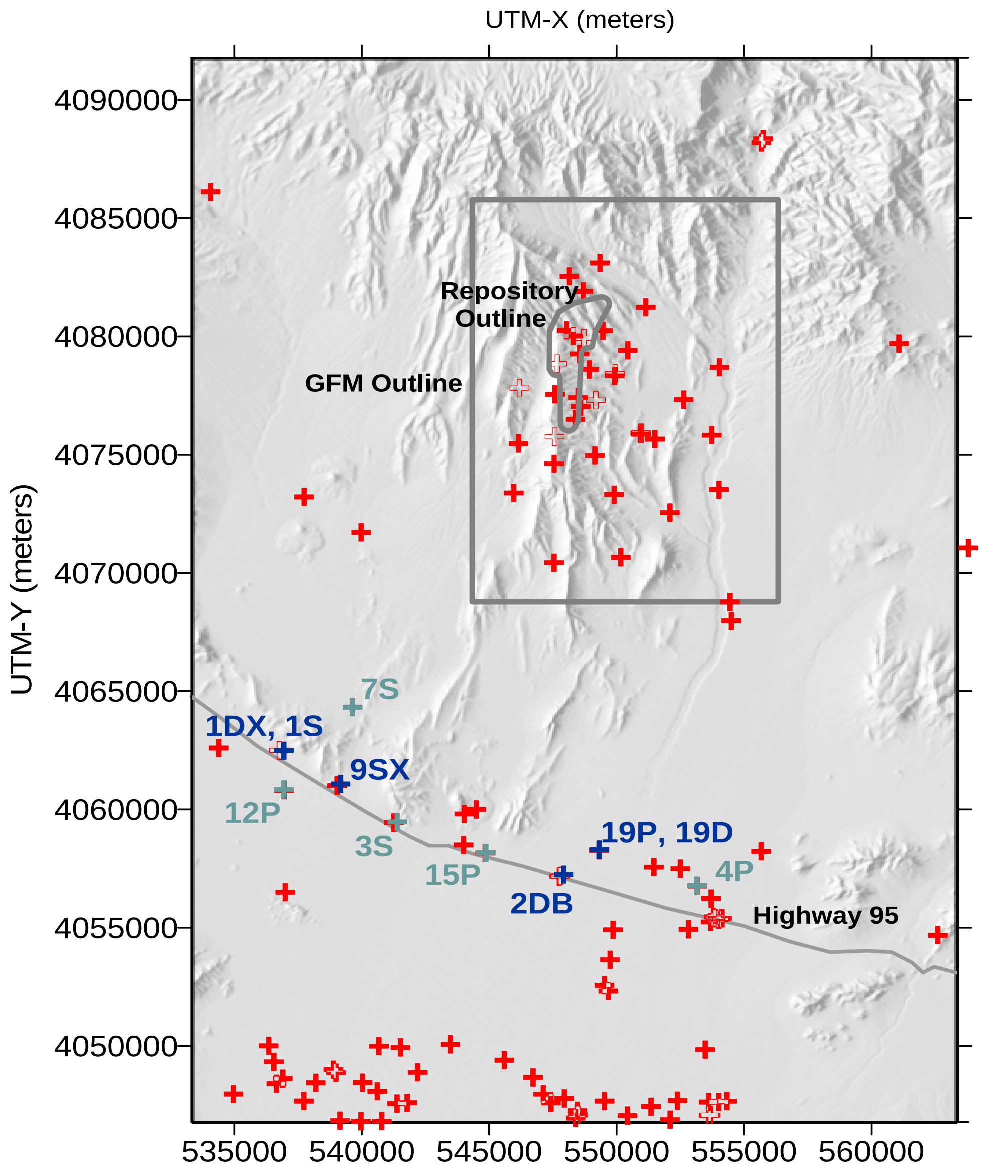
A comparison of the hydrogeologic units used in the computational grids for flow and transport as identified in HFM-19 and HFM-27 are shown in Figure 6-5. This figure shows the computational flow and transport model grids colored by hydrogeologic units using HFM-19 for the base-case model grid and HFM-27 for the alternate model grid. The view is planar with north at the top of the images. Both grids have been clipped at the potentiometric surface and show the hydrogeologic units colored by numbers 2 through 28. The base-case grid has been colored to approximate the units in the alternate grid (HFM-27). The shortened unit names are shown on either side of the color bar and indicate their approximate unit correlation. Three flow paths from each flow model are shown overlaying the top of the model for reference only and indicate the southern direction taken by the flow paths as they leave the repository. Major changes in the southern part of the HFM-27 are the depths and extent of the alluvial layers. The units for the northern part of the HFM-27 domain were changed mainly as a result of reinterpretation of geophysical data regarding the depth of the carbonate aquifer. The carbonate aquifer is no longer believed to intersect the northern boundary of the SZ site-scale flow model. Some units in the HFM-27 have been further subdivided. For instance, the upper volcanic aquifer of HFM-19 is congruent to the HFM-27 Timber Mountain and Paintbrush volcanic aquifers. Therefore, in the north, the Paintbrush volcanic aquifer replaces the similar but differently named upper volcanic aquifer as the dominant unit near the water table. The primary hydrogeologic units for flow remain comprised of the Crater Flat group: Prow Pass, Bullfrog, and Tram units (BSC 2004 [DIRS 170037], Section 6.4.6.2.2.1).

The impact of new data and updated models is evaluated by SZ flow modeling using the updated HFM-27 that incorporates the newer GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]), a new Death Valley regional groundwater model as discussed by Faunt (2002 [DIRS 171040]), EWDP boreholes and cross sections. The flow model uses the HFM-19 as a base-case version flow model, and HFM-27 and explicitly defined geometric “zones” to examine multiple alternate flow models (BSC 2004 [DIRS 170037], Section 6.4). Flow paths in the base-case model using HFM-19 trend in a southeasterly direction from the repository site. Alternate models using HFM-27 trend toward a more southern direction (Figure 6-5). Further analysis of the flow paths indicate that the fluid particles travel in the same units regardless of the underlying hydrogeologic representation. The flow for these models are predominantly to the Bullfrog tuff and the alluvial units, with some difference in degree of southerly direction and speed of flow paths influenced by added complexity and division of nearby units (BSC 2004 [DIRS 170037], Sections 6.4.6.3.5 and 6.8.1). The flow paths do not reach the Carbonate Aquifer due to the effects of the vertical gradient as shown in the calibrated site-scale SZ flow model (BSC 2004 [DIRS 170037], Sections 6.3.1 and 6.3.2.3).

6.4.3 Uncertainties

For the HFM-19, uncertainty is an estimation of how closely the model matches the actual hydrogeologic setting of the site-scale SZ model area and the interpretations of the geologic setting it is built on. The primary factor affecting uncertainty in the HFM-19 is the distance from the grid points to the nearest input data, and the overall distribution of the input data over the site-scale domain. Hydrogeologic units near the surface are constrained by the hydrogeologic map (Figure 4-2). The horizontal distance from a data point shows part of the distribution of uncertainty where data distribution is shown relative to the unit (Figures 6-6a to 6-6q). Most of the borehole data are limited to very shallow depths (corresponding with high unit identification numbers), therefore, uncertainty increases with depth (low unit identification numbers). Hence, interpretations regarding deeper hydrogeologic units have more uncertainty associated with them than that associated with shallower hydrogeologic units.

The sparseness of data contributes to uncertainty in the configuration of the unconformity between Tertiary and Paleozoic rocks. Figure 6-6o shows only limited data were available near the repository at these depths. Only one borehole (UE-25 p#1) in the vicinity of Yucca Mountain penetrates the contact between the Tertiary volcanic and underlying Paleozoic rocks, but Paleozoic rocks crop out in several areas surrounding Yucca Mountain (Figure 4-2). There are alternative interpretations of the location of the carbonate aquifers and clastic confining units in the subsurface between these known points. The configuration of these lower units rely on the gridding techniques outlined in Section 6.3.5 and include evaluations from on-site experts while the HFM-19 is being built (Section 4.1.1).

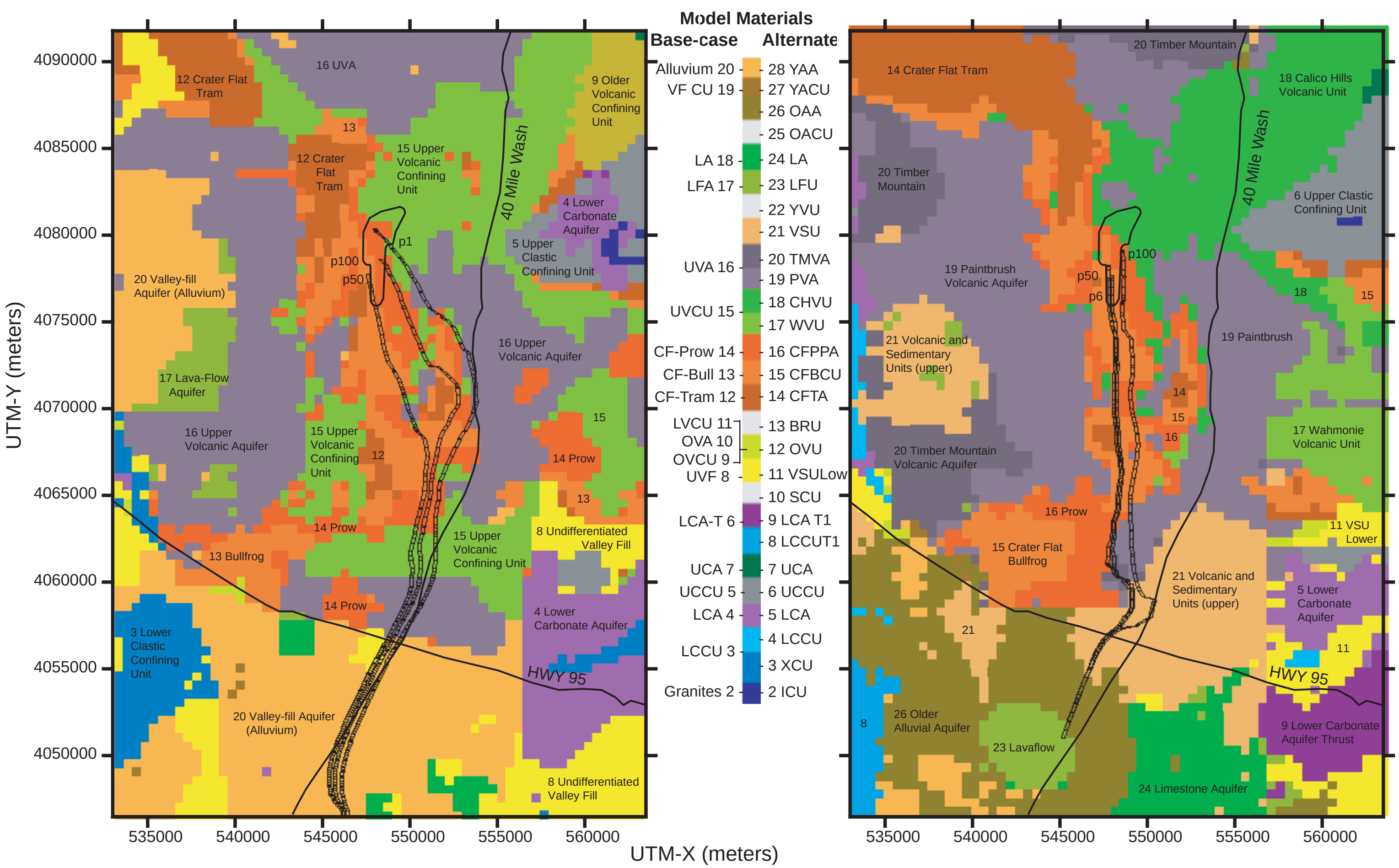


Source: BSC 2004 [DIRS 170037], Table 6-18 and Figure 6-40.

NOTE: This image identifies 3 borehole sets, those used in the HFM-19, HFM-27, and new wells used in the site-scale SZ flow model but not available in time for either HFM. The red crosses are borehole locations used in the SZ flow model and included in both HFMs, blue crosses represent new Nye County wells (NC-EWDP) used in alternate flow models and HFM-27, green crosses are new Nye County wells not in either HFM, but used in the flow and transport models. UTM-X =UTM-Easting and UTM-Y =UTM-Northing.

UTM=Universal Transverse Mercator

Figure 6-4. Site-Scale Map Showing Borehole Locations Used for the Saturated Zone Flow Base-Case (using HFM-19) and Alternate Flow Models (using HFM-27)



Source: Base-case site-scale SZ flow model grid (HFM-19) DTN: LA0304TM831231.002 [DIRS 163788] (left), Alternate site-scale SZ flow model AM0 grid (HFM-27) DTN: LA0409GZ831231.001 [DIRS 171605].

NOTES: Selected flow paths. UTM-X =UTM-Easting and UTM-Y =UTM-Northing.

UTM=Universal Transverse Mercator

Figure 6-5. Hydrogeology at the Water Table in Saturated Zone Site-Scale Flow Grids using HFM-19 and HFM-27

Table 6-5. Correlation of Alternate Model HFM-27 and Base-Case HFM-19 Units

	Alternate Model (HFM-27)		Base-Case Model (HFM-19)	
Abbreviation	**Hydrogeologic Name**	**Unit**	**Unit**	**Hydrogeologic Name**
Base	Base (-4000 m)	1	1	Base (bottom of regional flow model)
ICU	Intrusive Confining Unit	2	2	Granitic confining unit (granites)
XCU	Crystalline Confining Unit	3	3	Lower Clastic Confining Unit (lccu)
LCCU	Lower Clastic Confining Unit	4	3	Lower Clastic Confining Unit (lccu)
LCA	Lower Carbonate Aquifer	5	4	Lower Carbonate Aquifer (lca)
UCCU	Upper Clastic Confining Unit	6	5	Upper Clastic Confining Unit, Upper Clastic Confining Unit – thrust 2 (uccu,uccut2)
UCA	Upper Carbonate Aquifer	7	7	
LCCU_T1	Lower Clastic Confining Unit - thrust	8		Lower Clastic Confining Unit - thrust 1 (lccut1)
LCA_T1	Lower Carbonate Aquifer - thrust	9	6	Lower Carbonate Aquifer thrusts 1 and 2 (lcat1, lcat2)
SCU	Sedimentary Confining Unit (none in site area)			
VSU Lower	Lower Volcanic and Sedimentary Units	11	8	Undifferentiated valley-fill (leaky)
OVU	Older Volcanic Units	12	9,10, 11	Older Volcanic Confining Unit, Older Volcanic Aquifer, Lower Volcanic Confining Unit (lvcu,lva,mvcu)
BRU	Belted Range Unit (none in site area)			
CFTA	Crater Flat - Tram Aquifer	14	12	Lower Volcanic Aquifer –Tram Tuff (tct)
CFBCU	Crater Flat - Bullfrog Confining Unit	15	13	Lower Volcanic Aquifer –Bullfrog Tuff (tcb)
CFPPA	Crater Flat - Prow Pass Aquifer	16	14	Lower Volcanic Aquifer –Prow Pass Tuff (tcp)
WVU	Wahmonie Volcanic Unit	17	15	Upper Volcanic Confining Unit (uvcu)
CHVU	Calico Hills Volcanic Unit	18	15	Upper Volcanic Confining Unit (uvcu)
PVA	Paintbrush Volcanic Aquifer	19	16	Upper Volcanic Aquifer (uva)
TMVA	Timber Mountain Volcanic Aquifer	20	16	Upper Volcanic Aquifer (uva)
VSU	Volcanic and Sedimentary Units	21	8	Undifferentiated valley-fill (leaky)
YVU	Young Volcanic Units (none in site area)			
LFU	Lava flow Unit	23	17	Lava-flow Aquifer (basalts)
LA	Limestone Aquifer	24	18	Limestone Aquifer (amarls)
OACU	Older Alluvial Confining Unit (none in site area)			
OAA	Older Alluvial Aquifer	26	20	Valley-fill Aquifer (alluvium), Undifferentiated valley-fill (leaky)
YACU	Young Alluvial Confining Unit	27	19	Valley-fill Confining Unit (playas)
YAA	Young Alluvial Aquifer	28	20	Valley-fill Aquifer (alluvium)

Source: BSC 2004 [DIRS 170037], Table 7.5-2.

NOTE: These units do not have a one-to-one correlation. This table approximately relates HFM-27 hydrogeologic units to the base-case HFM-19.

HFM=hydrogeologic framework model

An important consideration in understanding the SZ flow system is the relationship between flow in the fractured tuff aquifers immediately beneath and down gradient from Yucca Mountain, and the alluvial aquifer from which groundwater discharges in the Amargosa Valley. The approximate outline of the uncertainty zone associated with the contact between the volcanic rock and alluvium downgradient (south) from the repository is shown in Figure 6-3. Investigations performed as part of the Nye County EWDP better constrain the location of the tuff-alluvium contact and better characterize the thickness and lateral extent of the alluvial aquifer north of U.S. Highway 95 (BSC 2004 [DIRS 170042], Section 6.5.2.2). More discussion of the impacts on groundwater flow paths due to uncertainty in the hydrogeologic conceptual model (for example the Large Hydraulic Gradient region) are presented in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037] Sections 6.7 and 6.8).

The site-scale SZ flow and transport models for which this framework is built, provides the best evaluation of uncertainty in the HFM-19. This HFM-19 provides the geologically defined internal geometry for flow and transport models and can be converted into a mesh for use in groundwater flow and transport modeling codes. The sparseness of data, the difference from scale of measurements to scale of model, and permeabilities of various units are inherited through the flow model and propagate to the output breakthrough curves (BSC 2004 [DIRS 170036], Section 6.5). The transport model finds that the radionuclide transit times are most sensitive to groundwater-specific discharge (BSC 2004 [DIRS 170036], Section 6.7.1), which is impacted by the uncertainty in the hydrogeology in the vertical direction inherent in the HFM-19 as discussed in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037], Section 6.8).

The site-scale flow model indicates that as long as the horizontal spatial ambiguity in the location of hydrogeologic contacts is less than 250 meters (one half the horizontal grid cell size), there is essentially no impact on model specific discharge or flux calculations (BSC 2004 [DIRS 170037], Section 6.8.5.1). Because flow leaving the repository area is confined to a few of the most permeable units, the vertical dimension of the computational flow grid deserves special consideration (vertical resolution is variable with the smallest spacing at 10 meters and located in the upper units). As reported in the site-scale SZ flow report (BSC 2004 [DIRS 170037], Section 6.8.5.1), fluid leaves the repository area through the Bullfrog tuff and migrates to the south predominantly in alluvial units. Changing a single flow grid element's hydrogeologic designation, either to or from Bullfrog tuff would result in a change to the local specific discharge by no more than a factor of 50/300 (17 percent). This is well within the overall flow model tolerances. Unfortunately, the thin flow path between UTM northing coordinates 4,070,000 meters and 4,060,000 meters can be problematic. Here the fluid flow is vertically constrained to 100 meters. If the bottom contact of the Bullfrog tuff were to change in altitude (vertically) by 50 m, this could result in a change in the flow model to the specific discharge flux in that area of up to 50 percent. Because of the averaging effect across flow grid elements, a 50 percent regional change in a relatively small portion of the 0-km to 20-km compliance boundary affects model results only moderately and by no more than 25 percent (BSC 2004 [DIRS 170037], Section 6.8.5.1).

Uncertainty is an inherent part of the HFM-19 and its input data. Users of the HFM-19 should consider uncertainty when using the HFM-19 and determine whether the uncertainty described in the HFM-19 is appropriate to specific users. In both the SZ flow and alternate flow models (using HFM-19 and HFM-27 representations) the flow remains southerly and primarily through the Crater Flat units and the alluvium. Evaluations between the site-scale flow model and the alternative flow model indicate that uncertainty is reduced with new data and new framework models, making the HFM-19 the more conservative of the two HFMs.

6.4.4 Adequacy and Intended Use

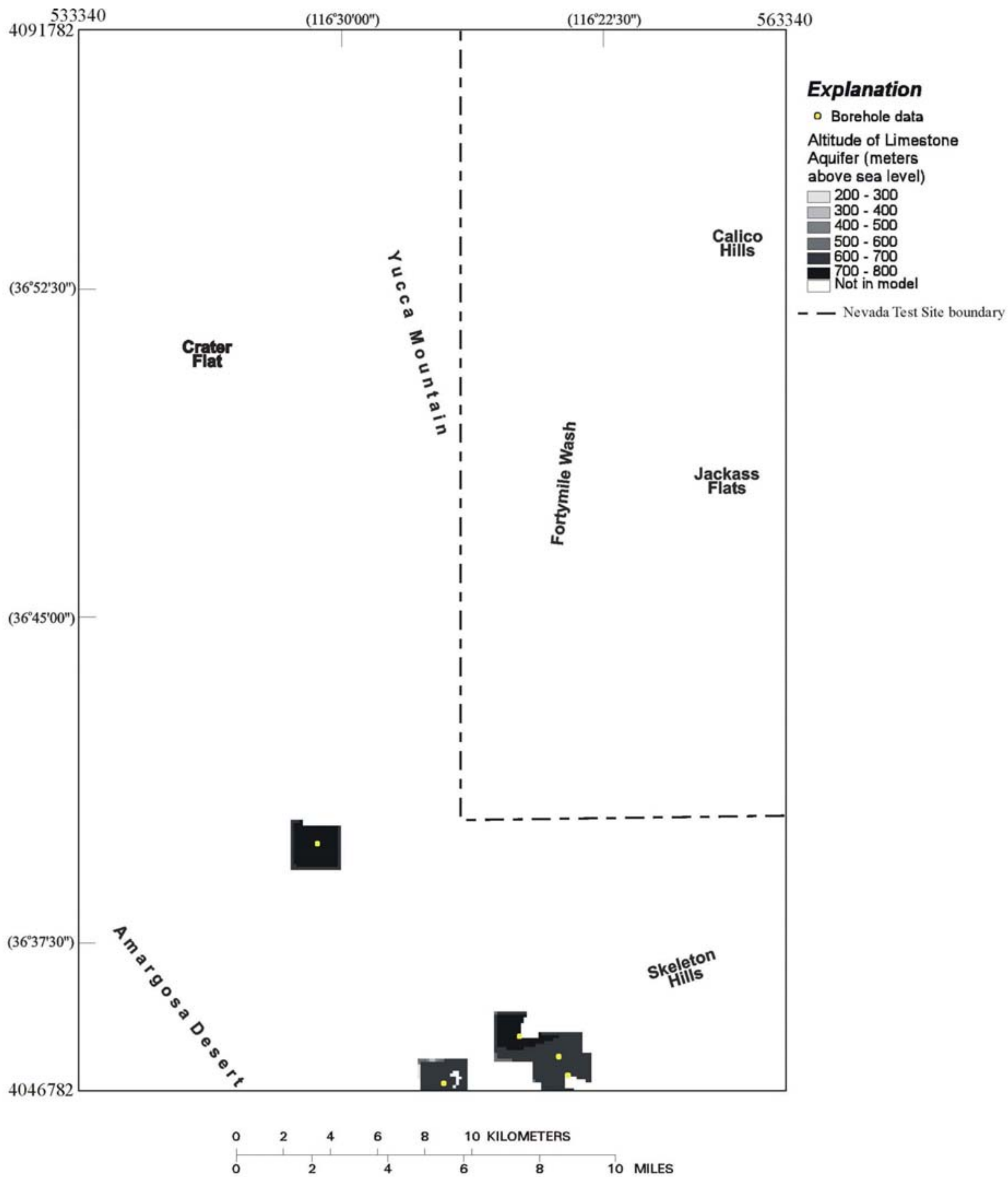
The site HFM-19 is developed specifically as a hydrogeologic framework for the site-scale SZ groundwater flow and transport models. The HFM-19 is utilized in building a groundwater flow model mesh, for use in the flow model using the groundwater flow and transport modeling code, Finite Element Heat and Mass (FEHM) model (Zyvoloski et al. 1997 [DIRS 110491]; Zyvoloski et al. 1999 [DIRS 107889]). FEHM is a general-purpose unsaturated zone and SZ non-isothermal code built around unstructured control volume finite element numerical procedures. The flow and transport models use the one-phase, isothermal flow module and the particle-tracking module. Through the definition and assemblage of the hydrogeologic units integral to its construction, the HFM-19 provides an internally consistent, geometric representation of the spatial distribution of hydrogeologic units within the 3-D SZ flow and transport models domain. The hydrogeologic properties within the 3-D flow and transport model domains are thought, at least partially, to be controlled by the hydrogeologic units. This representation is founded on the underlying geologically defined stratigraphic and structural framework. Spatial resolution obtainable within the HFM-19 is limited by the lack of well-distributed subsurface data over most of the model domain and, consequently, the HFM-19 must be considered to be a coarse-scale approximation rather than an accurate depiction of reality. The impact of course representation of faults on the flow model is discussed in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037], Section 6.8.4).

In the HFM-19 interpretation, the dominant high-angle faults were simplified to be vertical. Some of the offsets on the faults are preserved through changes in altitude of a given hydrogeologic unit. Given the depth to which the model extends and the lack of information in most of the modeled volume, this seems to be a rational simplification. Calibration of the SZ flow model using the HFM-19 results in a better understanding of the adequacy of the HFM-19 for SZ flow modeling. Artificial effects such as blocky edges and discontinuities show little effect on the flow process. These effects are resolved with improved data and techniques in the revised HFM-27 and enhance the applicability of the HFM-19, but of more consequence are the actual definition of units, their thickness and the inclusion of additional faults and structures.

Some of the near surface units that cover most of the model land surface area (Figure 4-2) only account for a small amount of the total model volume. Most of the borehole information is in the upper units and in the area removed from the HFM-19 with the clipping surface. Both of these data sets do, however, help define the areal extent of the hydrogeologic units. The hydrogeologic unit tops have some truncations that result from lack of data and where search distances are exceeded in the gridding algorithms. These truncations have not been removed. This should be taken into consideration by uncertainty analyses in flow modeling. Specifically, the contact between the volcanic rocks and the alluvium down gradient (Figure 6-3) from the repository should be examined.

The significance of the HFM-19 is that it enables the computational grid of the SZ flow and transport models to be populated with an initial set of hydrologic-property values that, subsequently, can be refined through calibration of the flow model. The calibrated property sets are those that are used subsequently to generate the groundwater flow fields on which transport calculations to support TSPA is based. Uncertainties in the HFM-19 relate most importantly to the quantity and location of available data, and secondly to the interpretation of surfaces and the representation of important faults and structures. In the intended context of providing a set of initial approximations for the spatial distribution of hydrologic properties, the HFM-19 is considered to be appropriate and adequate for its intended use. Use of HFM-19 and the revised HFM-27 (DTN: GS021008312332.002 [DIRS 164363]) in site-scale flow and transport studies, has shown the HFM-19 to be a sufficient representation and consistent with expectations that groundwater originating near Yucca Mountain flows primarily through the Crater Flat units (Prow, Bullfrog, and Tram), and through the alluvial units. The use of the more complex representation in HFM-27 does add complexity to the flow system, providing more options for flow in the additional and refined units. This complexity produced slower groundwater flow during the calibration process using HFM-27. This makes the base-case flow model (using HFM-19), the more conservative of the two versions, requiring fewer controls and resulting in faster flow paths in both travel times and distance. These results are summarized in the comparisons of specific discharge discussed in the site-scale SZ flow model (BSC 2004 [DIRS 170037], Sections 6.6 and 7.2).

Figures 6-6a to 6-6q illustrate the general shape and data coverage of units in the HFM-19. For a particular unit construction, the relative location of data sources and data types are shown in the legend (right side of each image). Each unit is viewed from above and is colored by the altitude of the unit top. Blank areas are regions where the grid values are null and the unit does not exist. The result is a recognizable unit shape, that when viewed in other models and grids with similar unit definitions, is a useful tool for visually checking and comparing units. These figures are also used to illustrate the data related to each particular unit and reveal the impact of geometric simplifications and data distribution. These figures provide a resource when calibrating the flow model in providing a sense of the subsurface data and represented hydrogeology. Data sources specific to each unit are listed in Appendix A, Tables A2 to A20. Two units (20 and 19) are not individually shown in the figures, but are shallow enough to be seen in Figure 6-7. Unit 20 is the valley fill aquifer and Unit 19 is the valley-fill confining unit, both list the geologic map in Potter et al. (2002 [DIRS 160060], Tables I-2 and I-3) as a single source. Note that the full list of data sources shown in Figures 6-6a to 6-6q are summarized in Table 4-1.



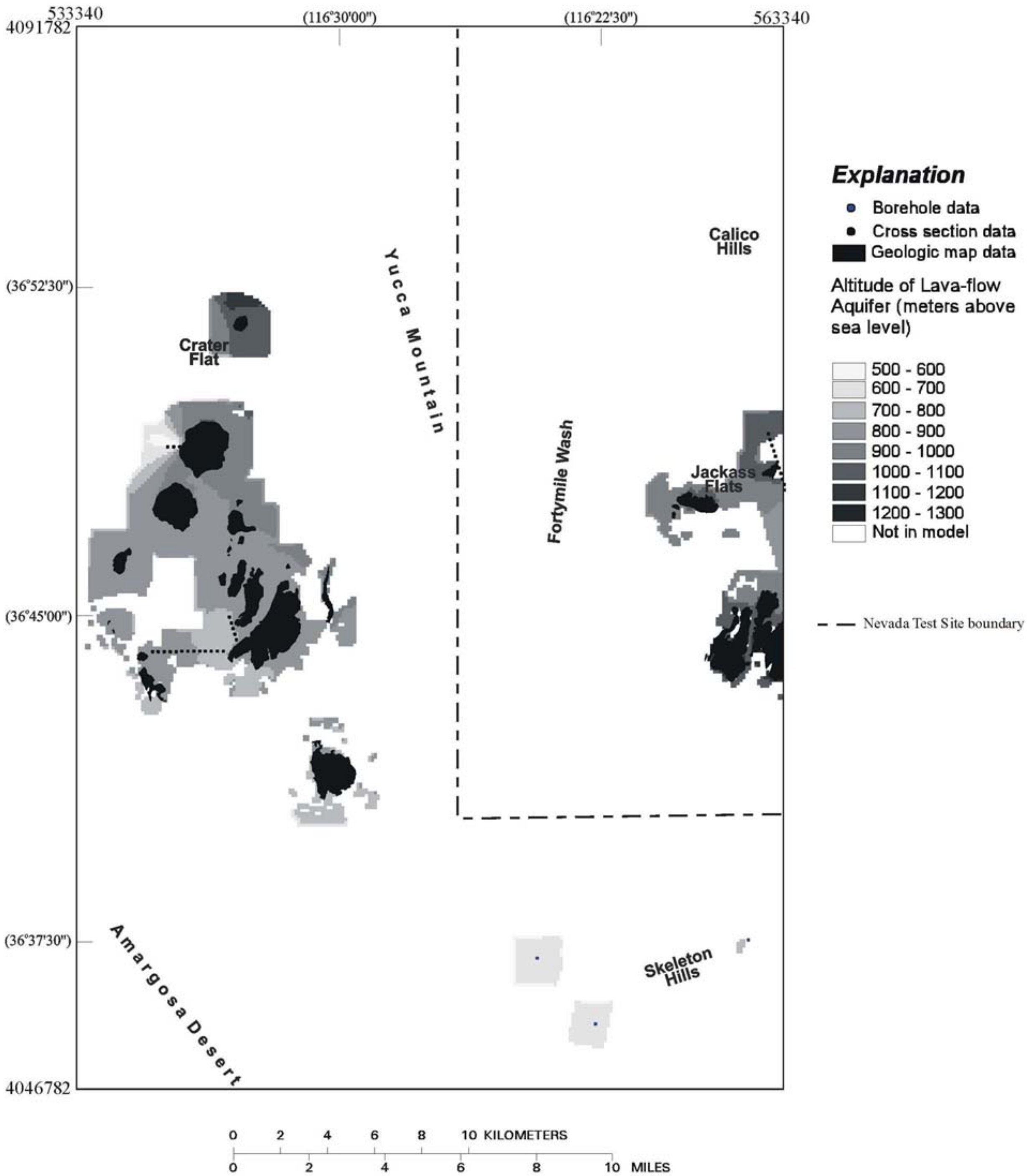
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-4.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6a. Map Showing Distribution of Unit 18 Limestone Aquifer and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



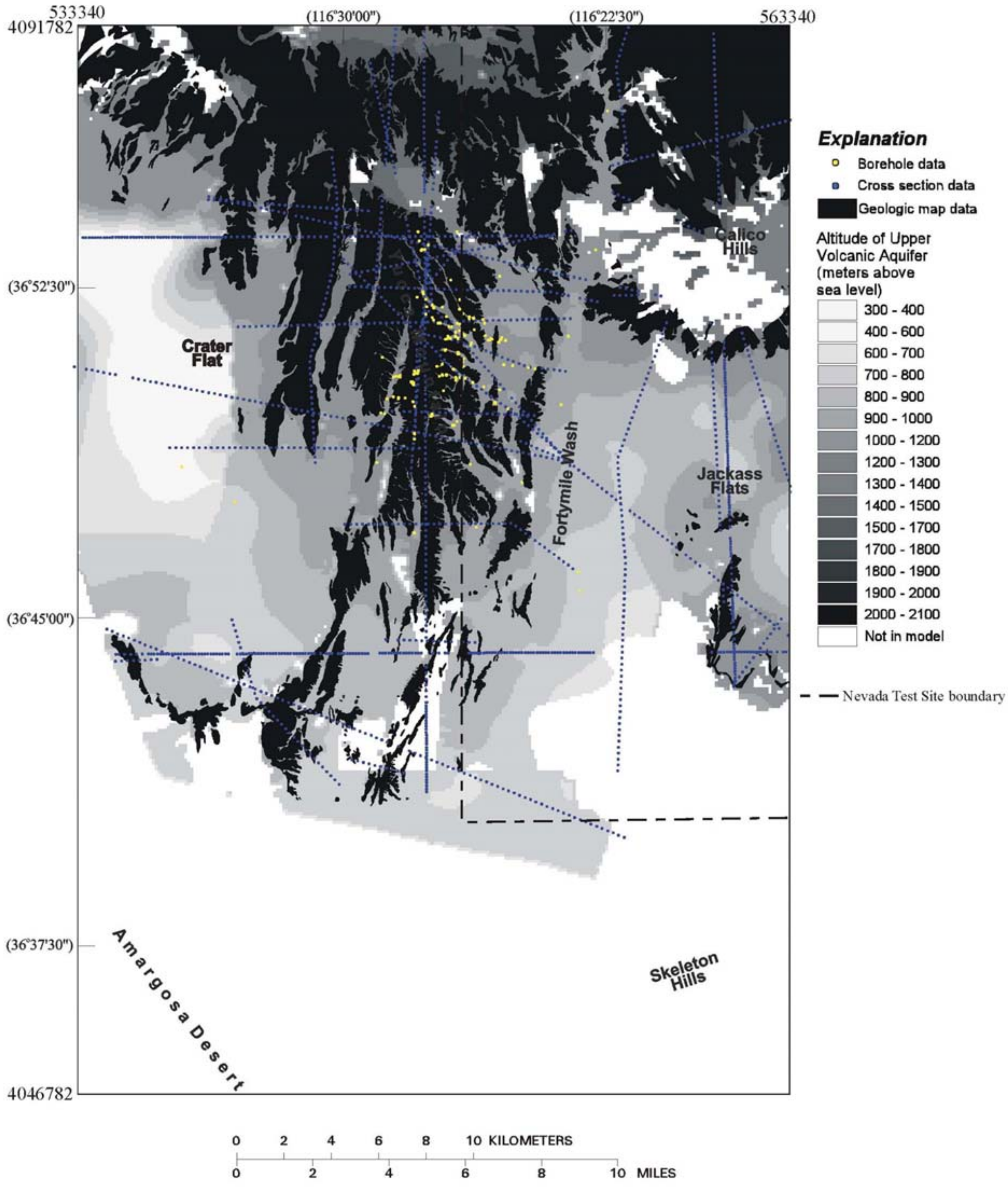
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-5.

NOTES: Altitude shown is for the top surface of the unit.
X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6b. Map Showing Distribution of Unit 17 Lava-Flow Aquifer and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



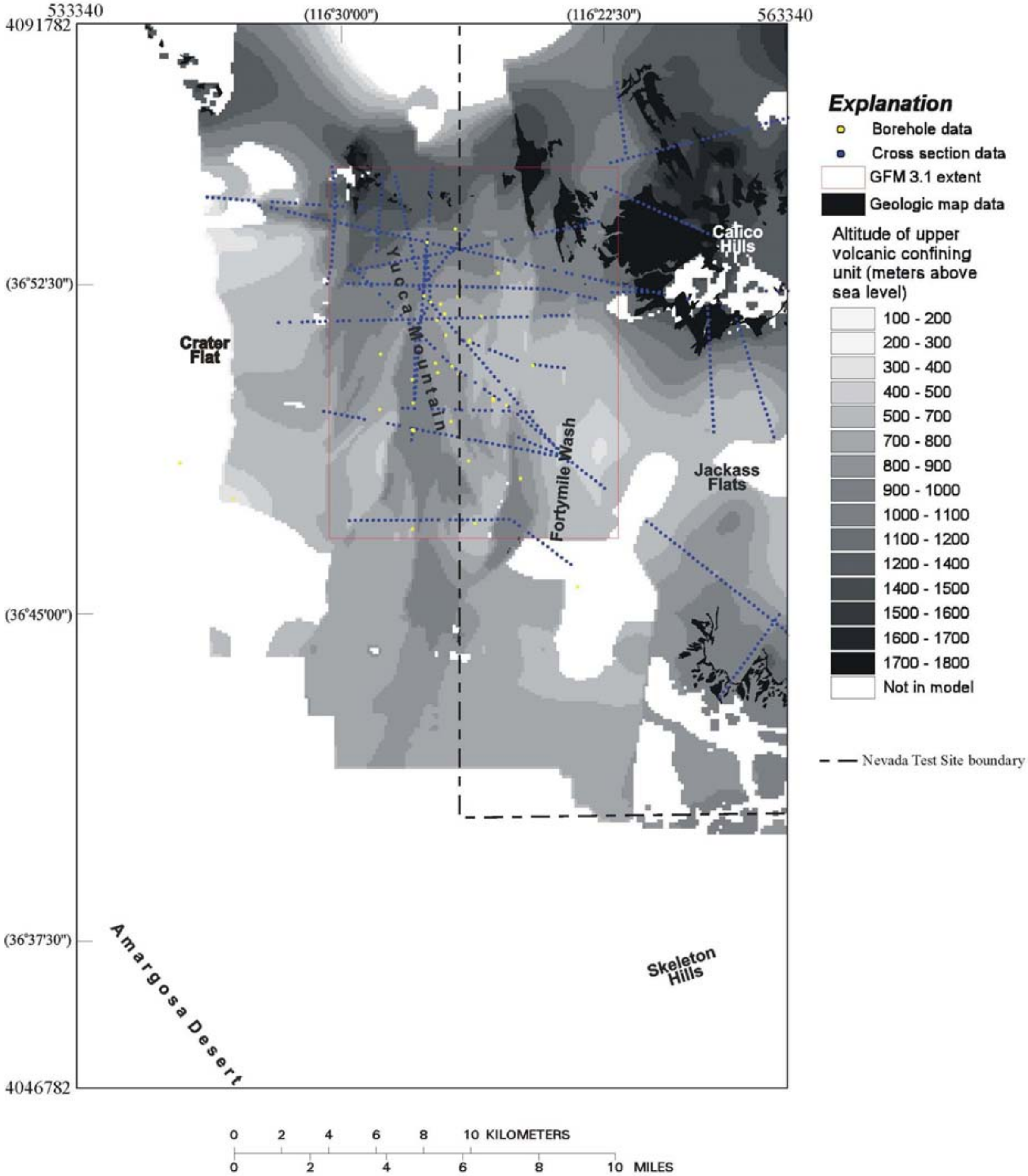
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-6.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6c. Map Showing Distribution of Unit 16 Upper Volcanic Aquifer and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



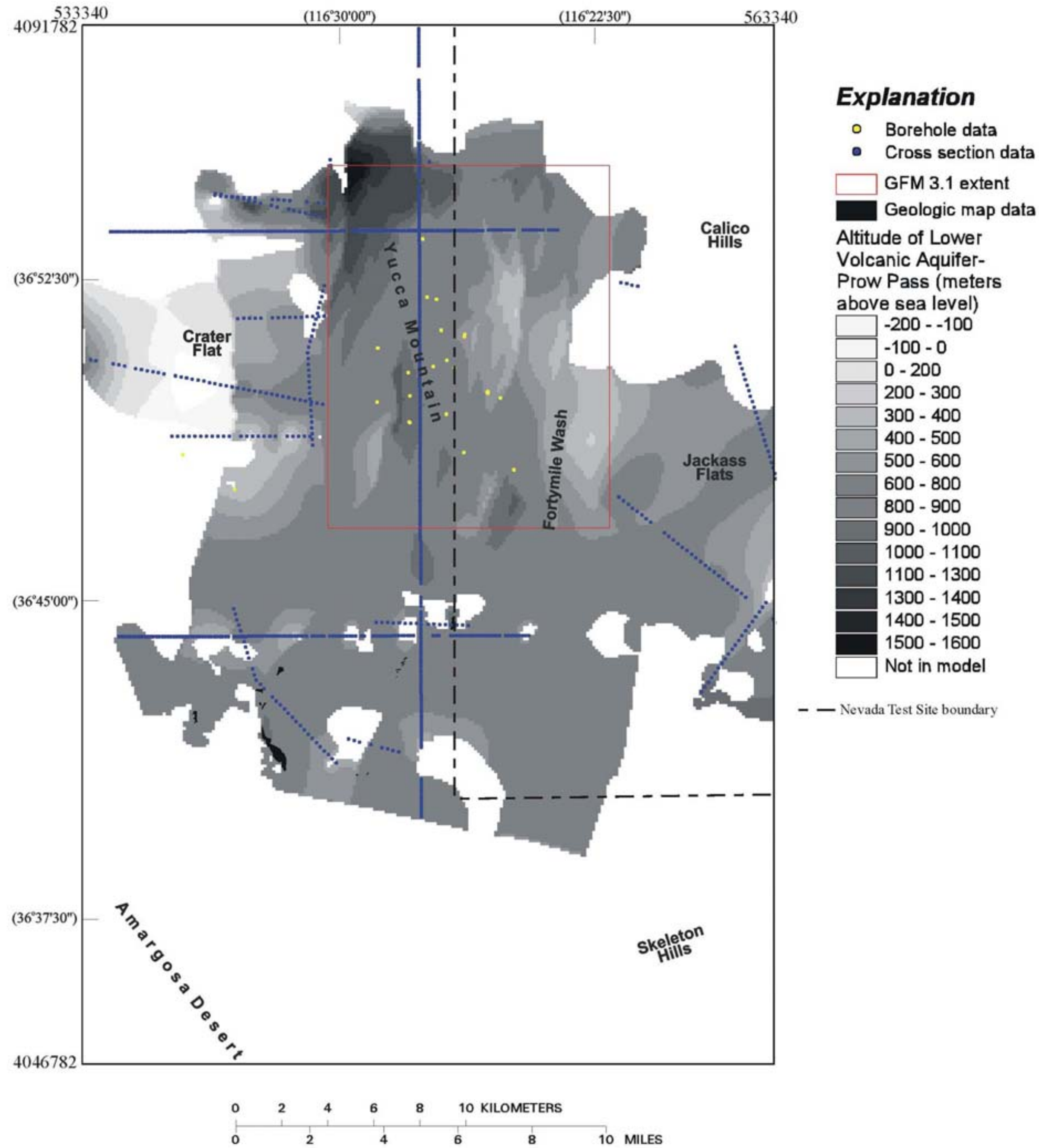
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-7.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator; GFM=geologic framework model

Figure 6-6d. Map Showing Distribution of Unit 15 Upper Volcanic Confining Unit and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



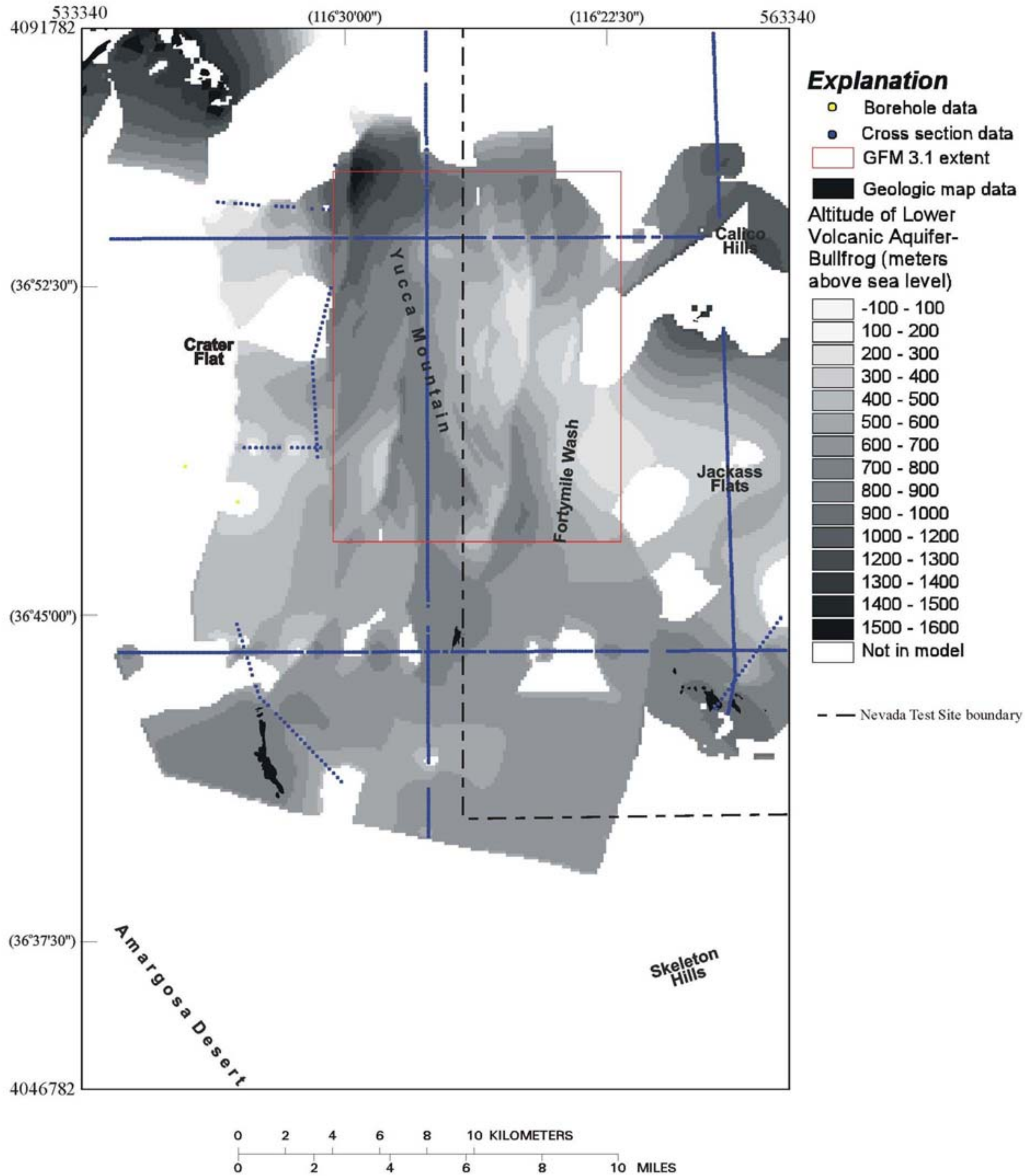
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-8.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator; GFM=geologic framework model

Figure 6-6e. Map Showing Distribution of Unit 14 Lower Volcanic Aquifer (Prow Pass Tuff) and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



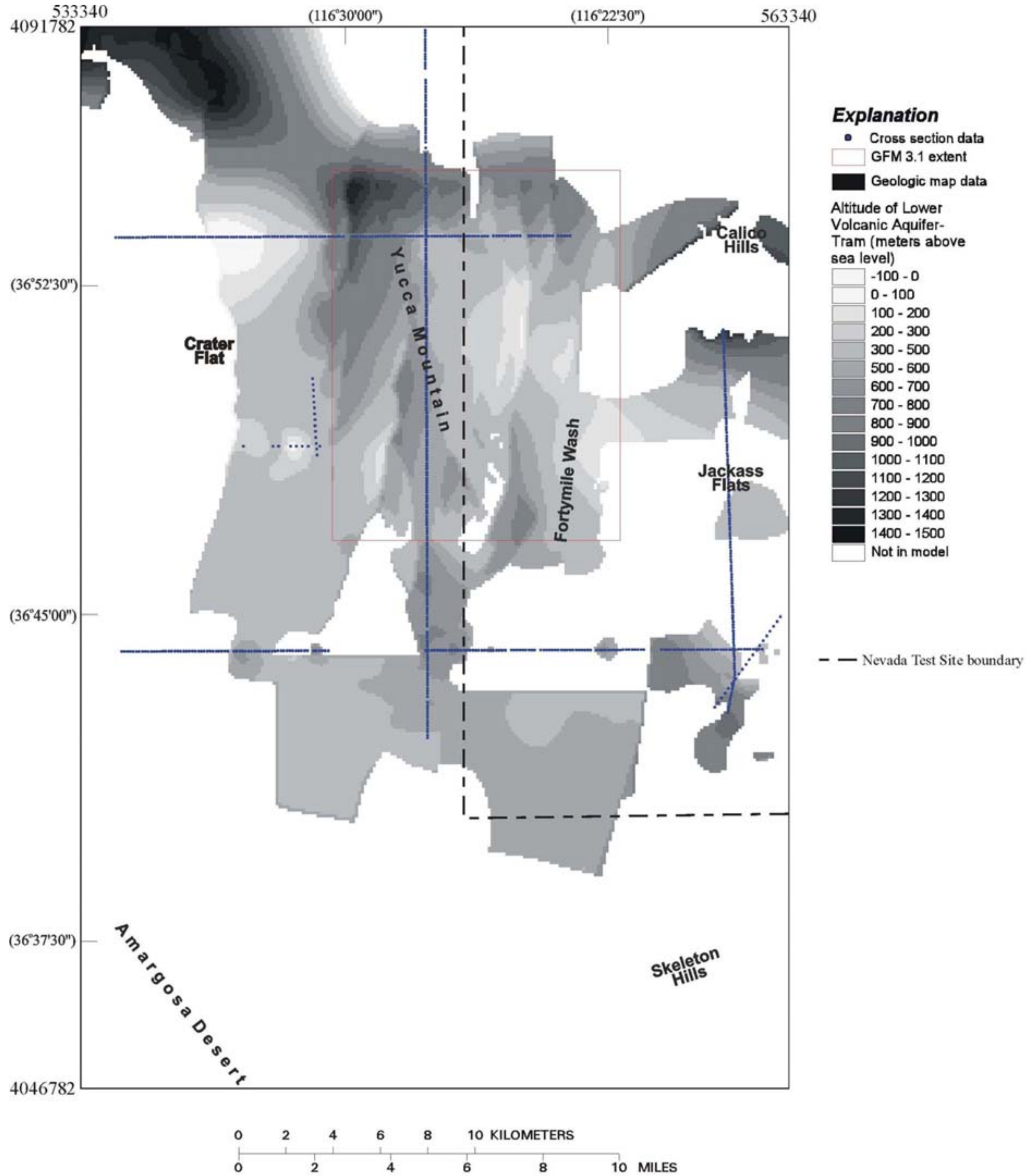
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-9.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator; GFM=geologic framework model

Figure 6-6f. Map Showing Distribution of Unit 13 Lower Volcanic Aquifer (Bullfrog Tuff) and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



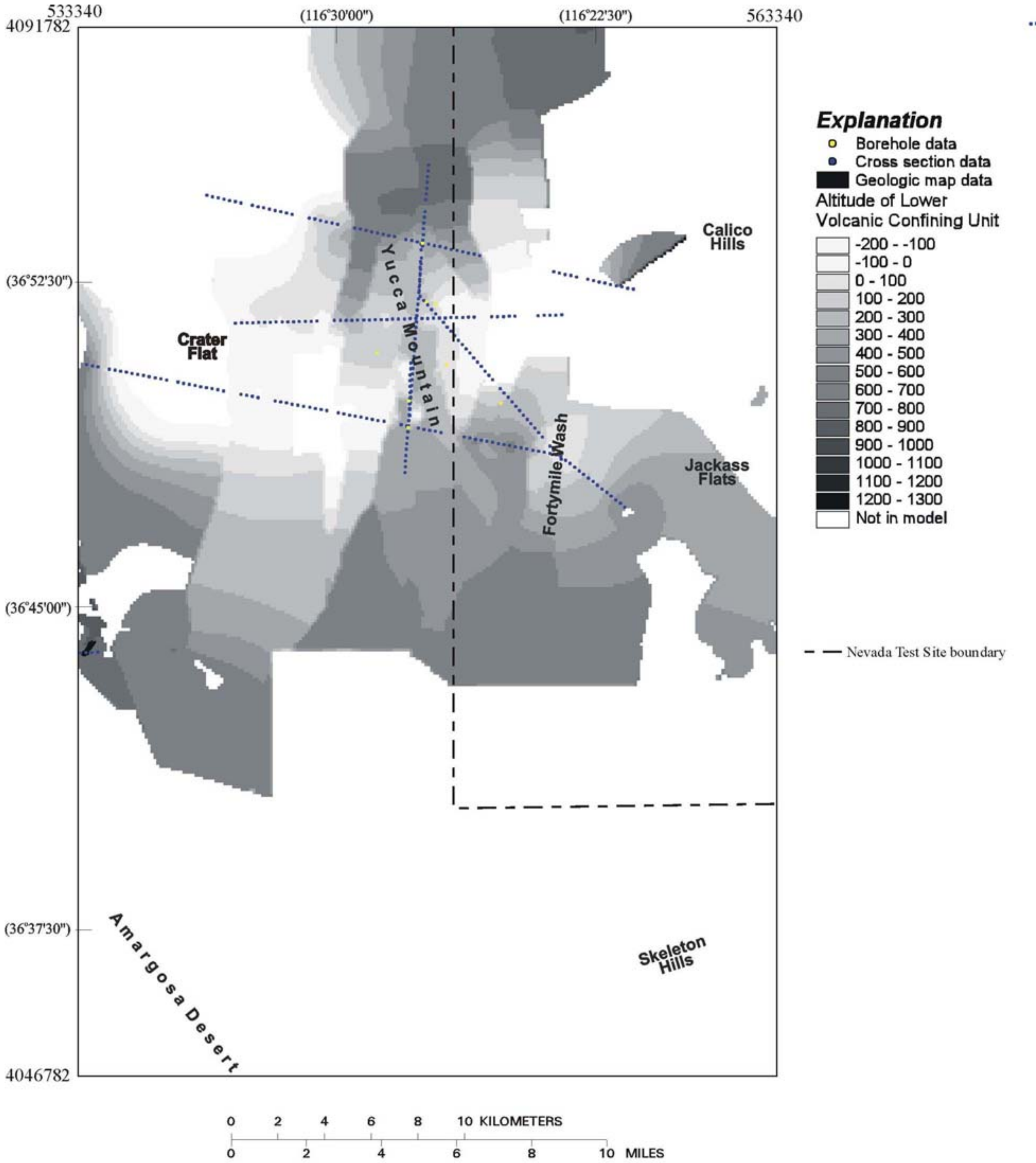
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-10.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator; GFM=geologic framework model

Figure 6-6g. Map Showing Distribution of Unit 12 Lower Volcanic Aquifer (Tram Tuff) and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



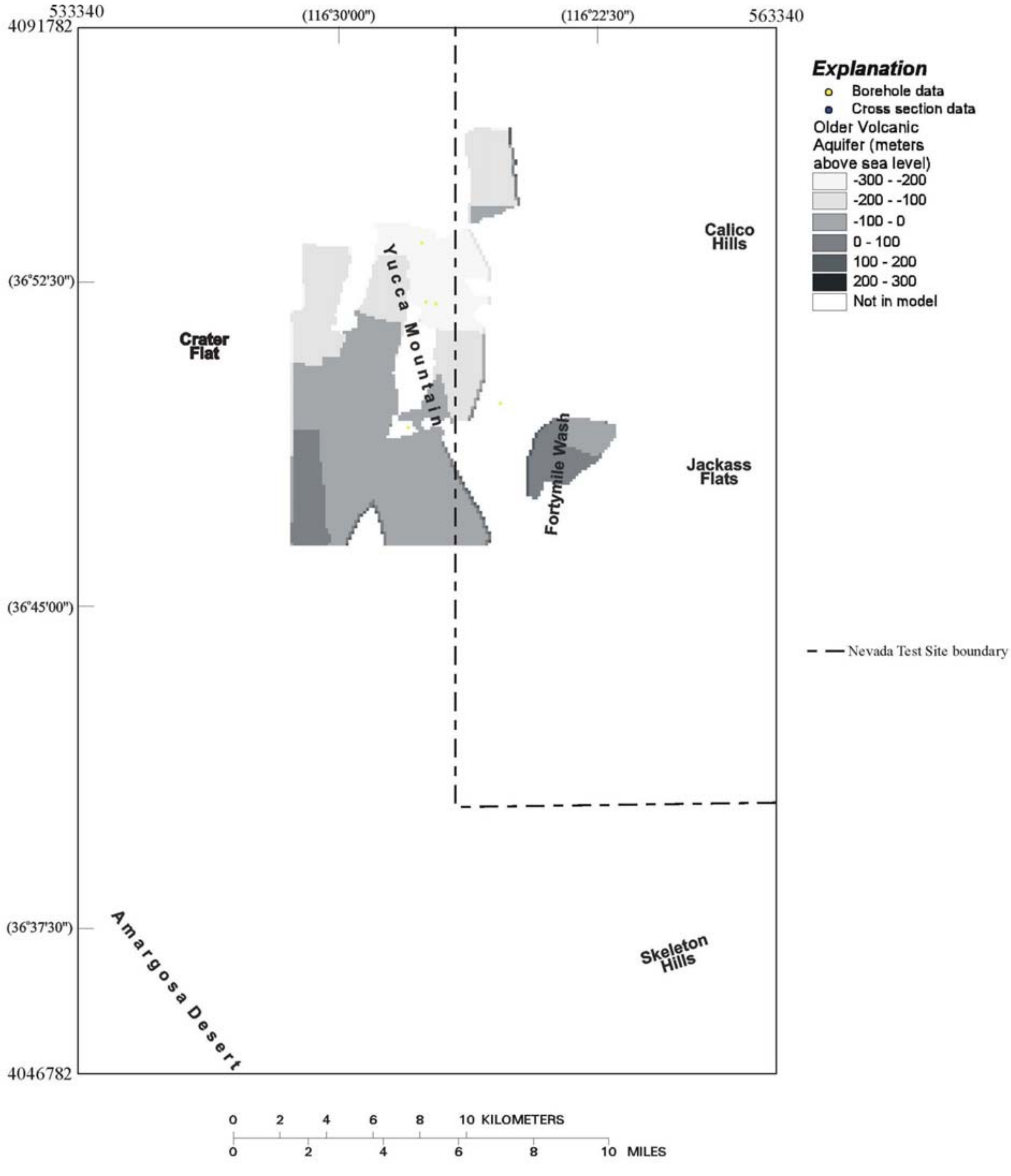
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-11. Altitude shown is for the top surface of the unit.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6h. Map Showing Distribution of Unit 11 Lower Volcanic Confining Unit and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



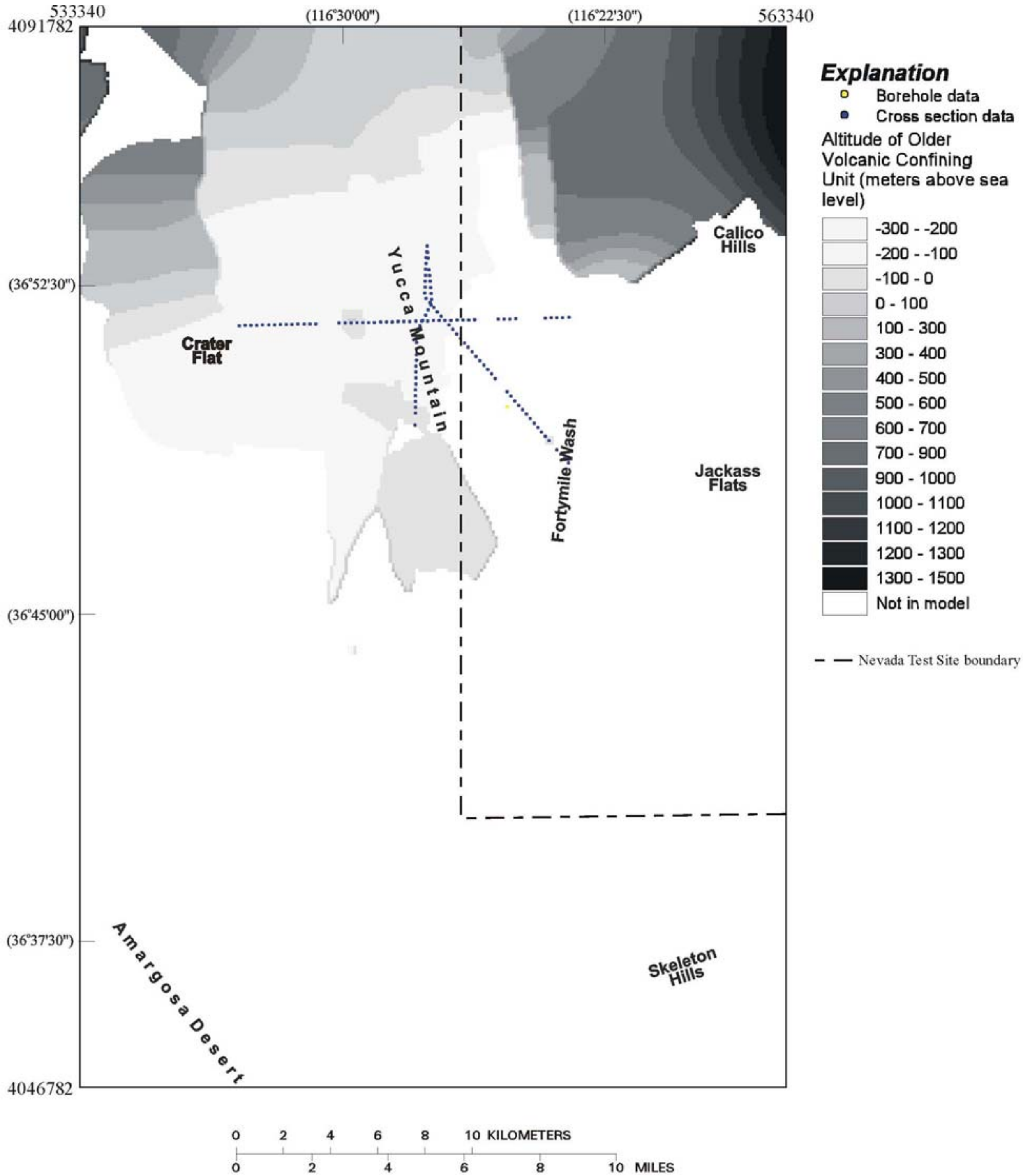
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-12. Altitude shown is for the top surface of the unit.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6i. Map Showing Distribution of Unit 10 Older Volcanic Aquifer and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



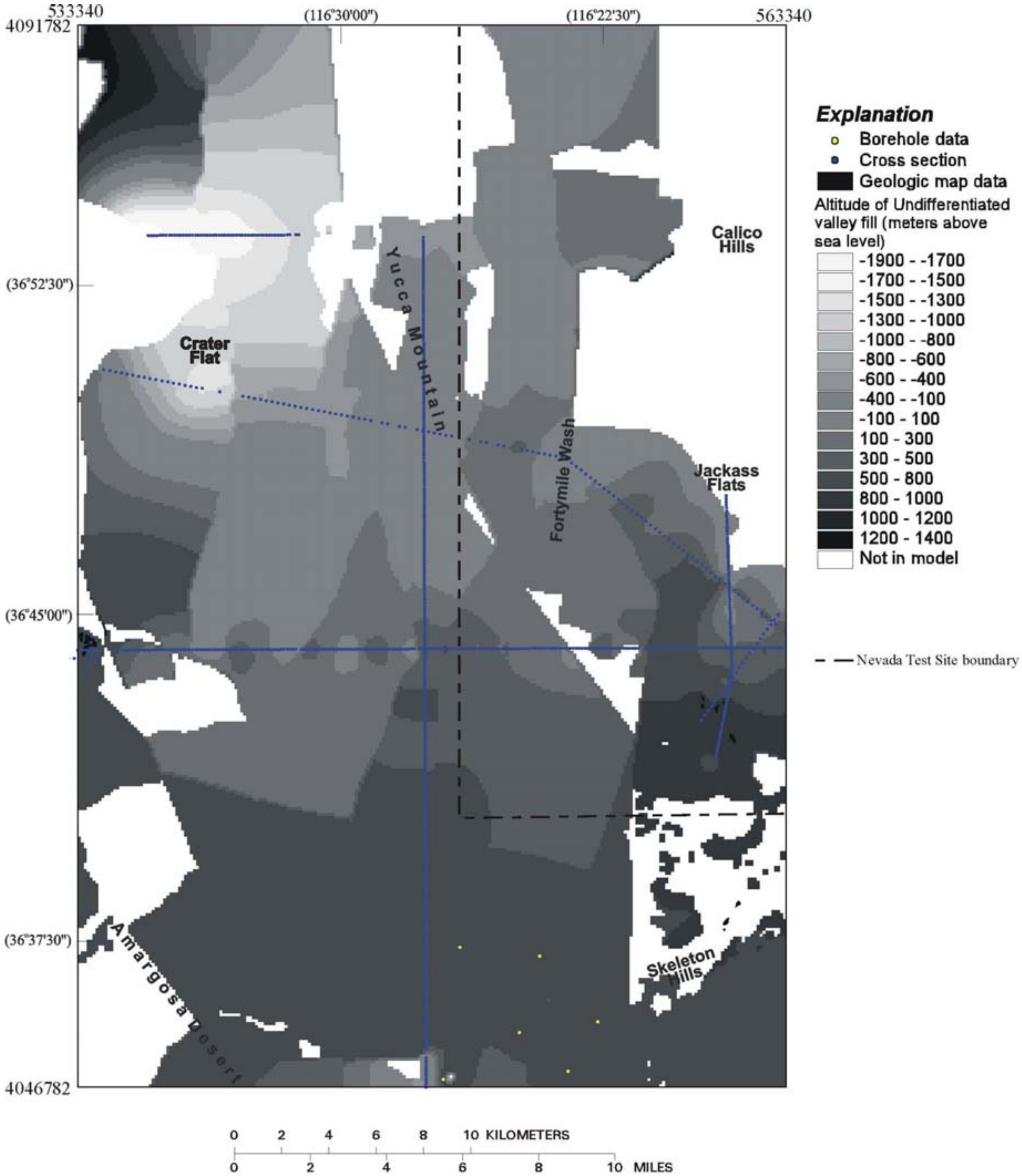
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-13.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6j. Map Showing Distribution of Unit 9 Older Volcanic Confining Unit and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



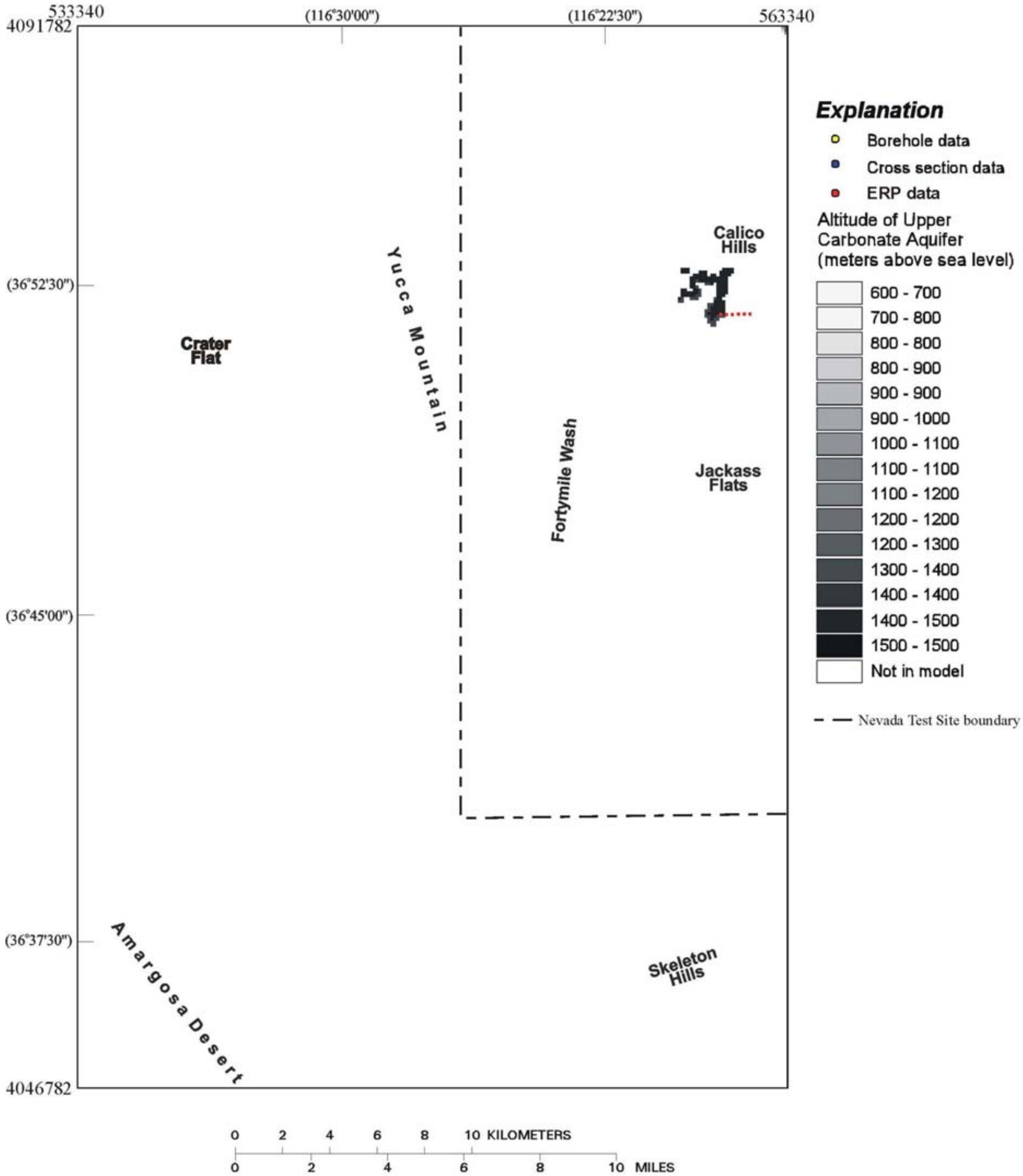
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-14.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6k. Map Showing Distribution of Unit 8 Undifferentiated Valley Fill and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



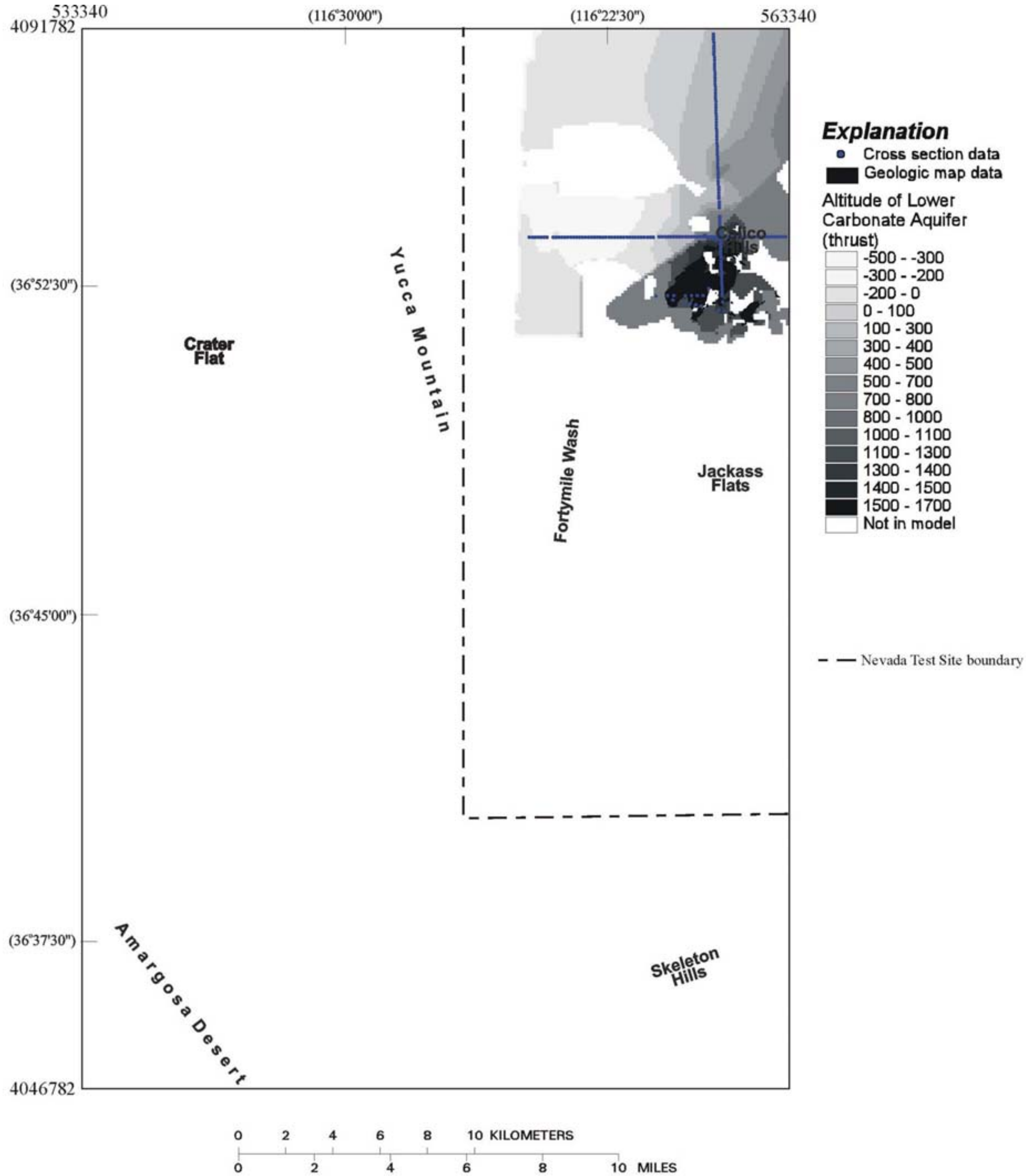
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-15.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator; ERP=Environmental Restoration Program

Figure 6-6l. Map Showing Distribution of Unit 7 Upper Carbonate Aquifer and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



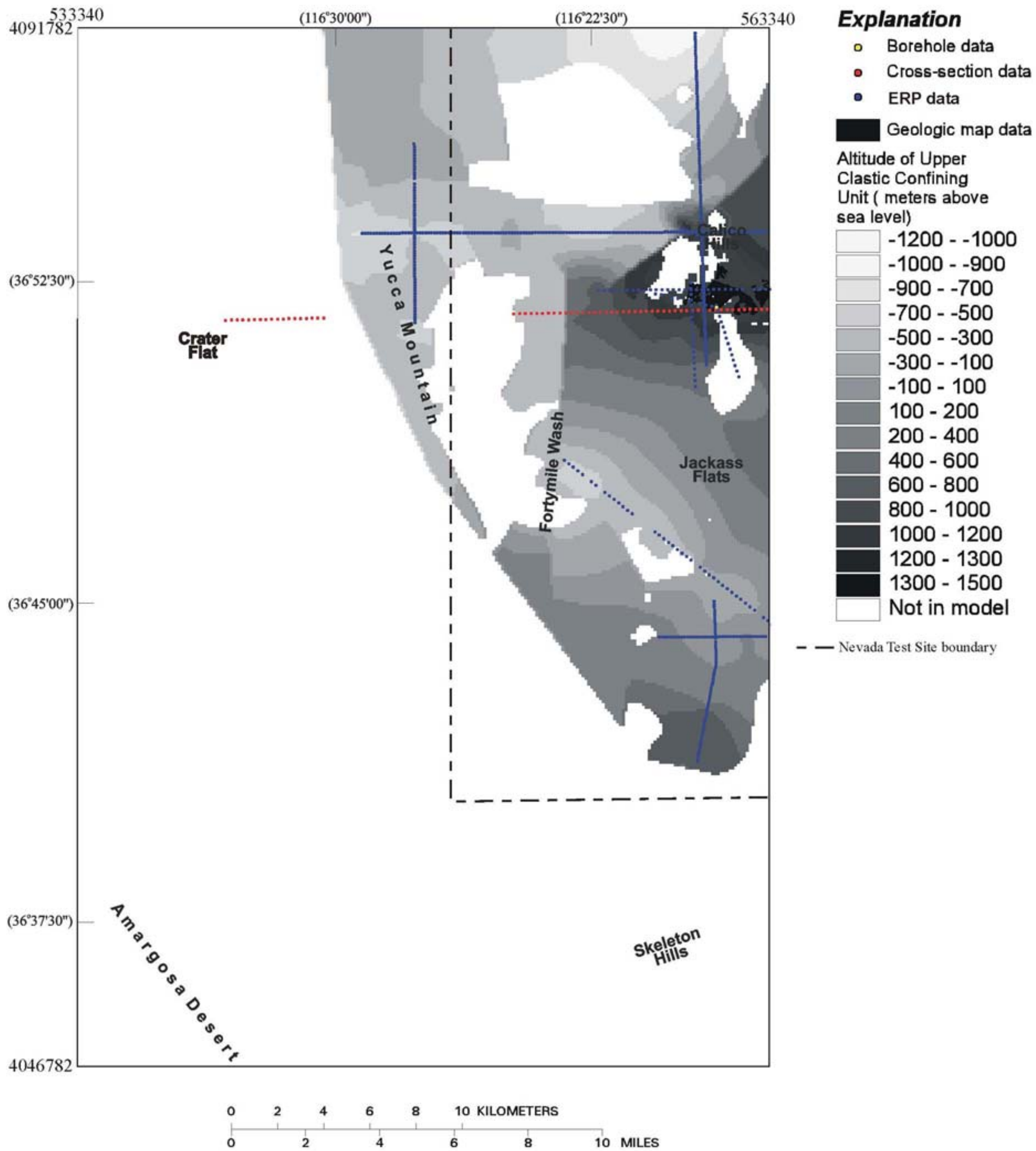
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-18.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6m. Map Showing Distribution of Unit 6 Lower Carbonate Aquifer Thrust and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



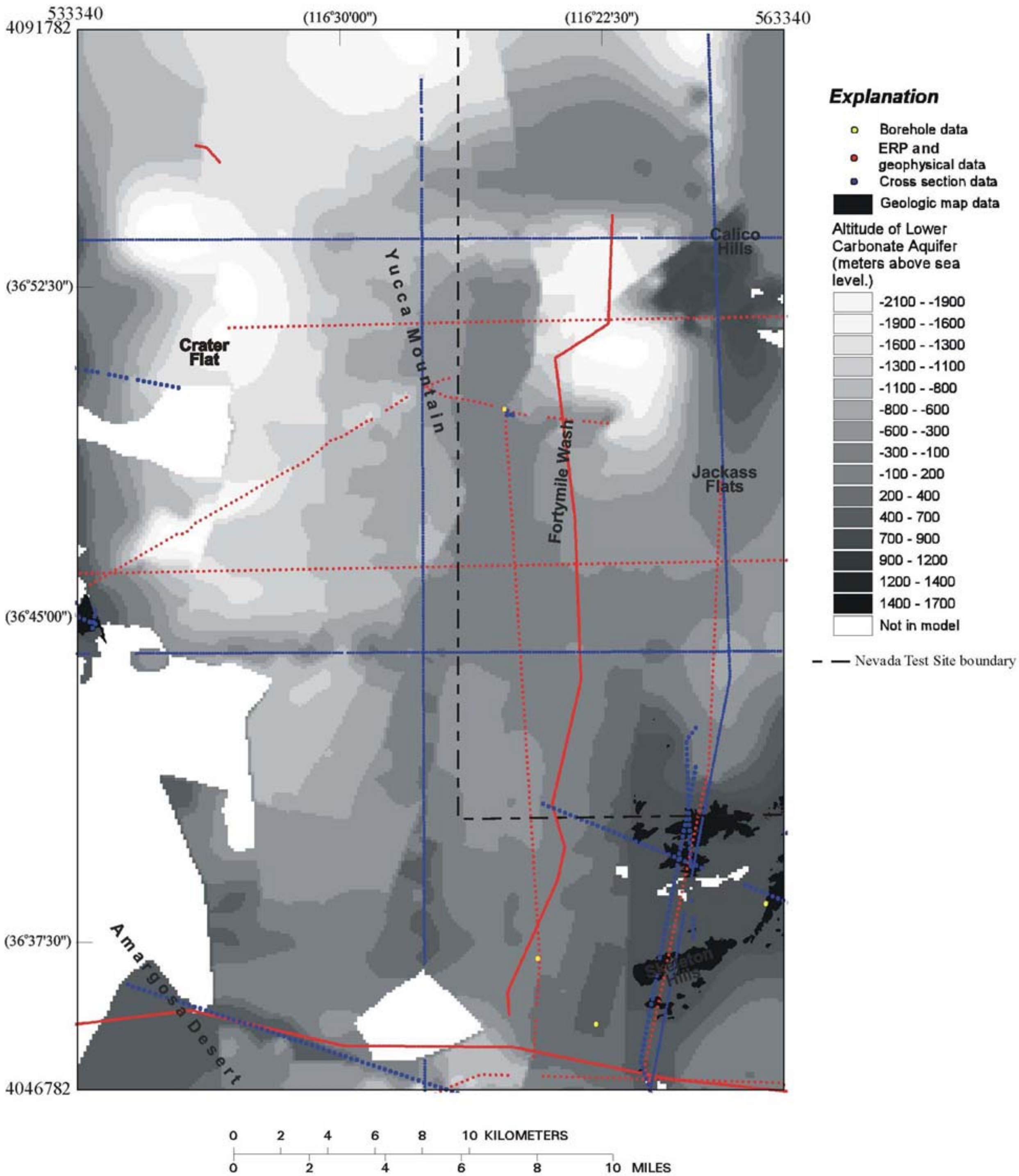
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-16.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator; ERP=Environmental Restoration Program

Figure 6-6n. Map Showing Distribution of Unit 5 Upper Clastic Confining Unit and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



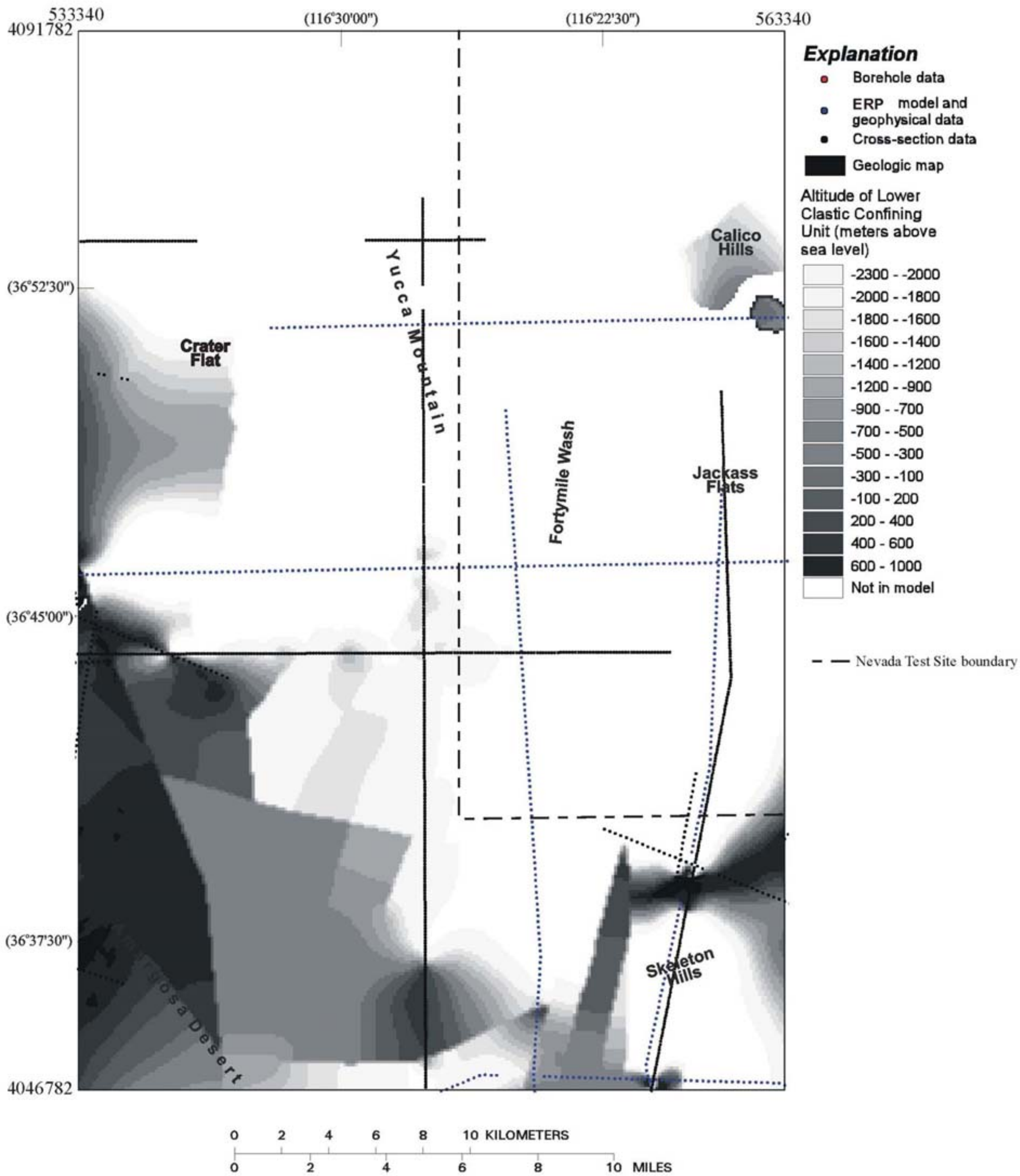
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-17.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator; ERP=Environmental Restoration Program

Figure 6-6o. Map Showing Distribution of Unit 4 Lower Carbonate Aquifer and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



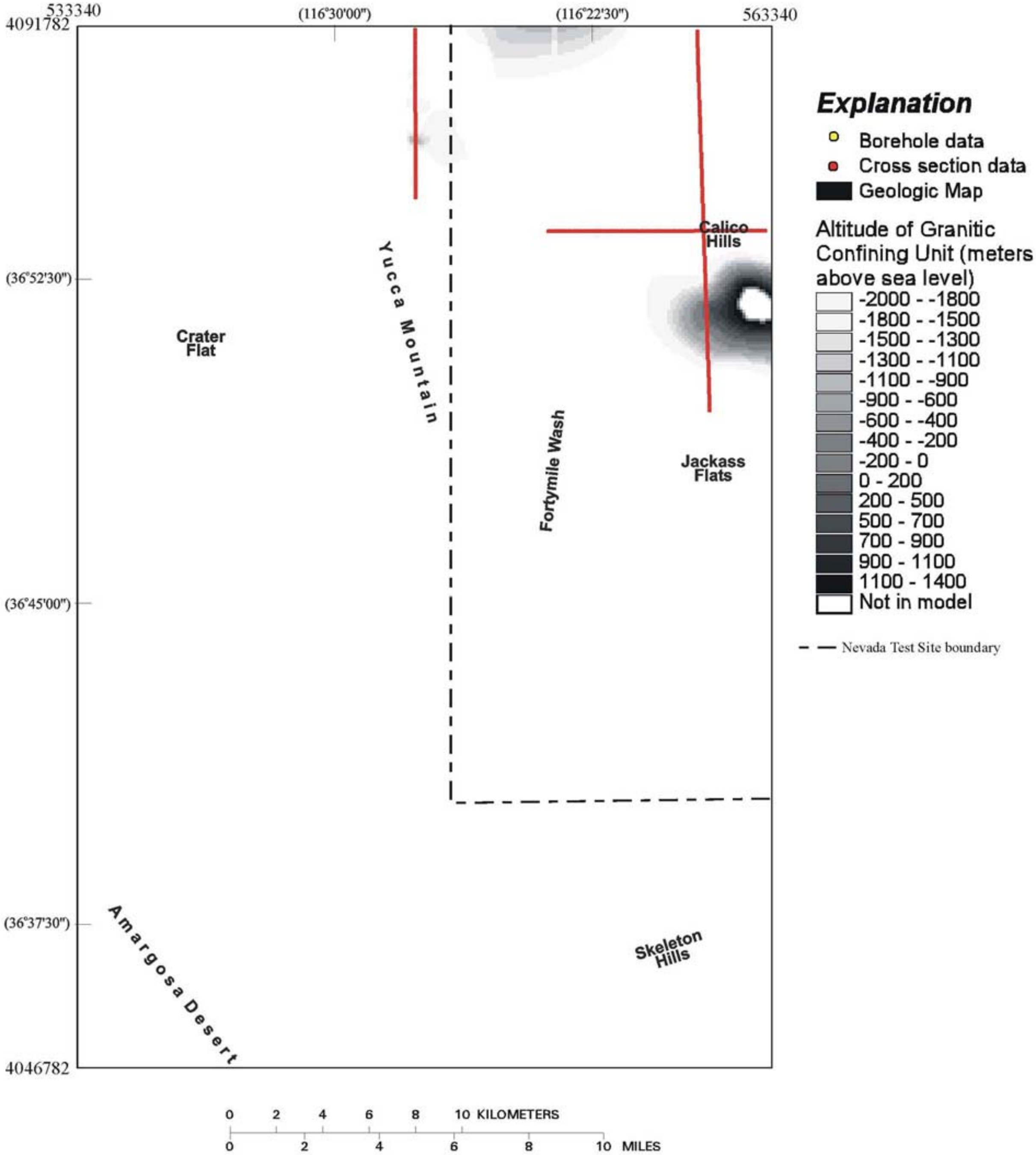
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-19.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator; ERP=Environmental Restoration Program

Figure 6-6p. Map Showing Distribution of Unit 3 Lower Clastic Confining Unit and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



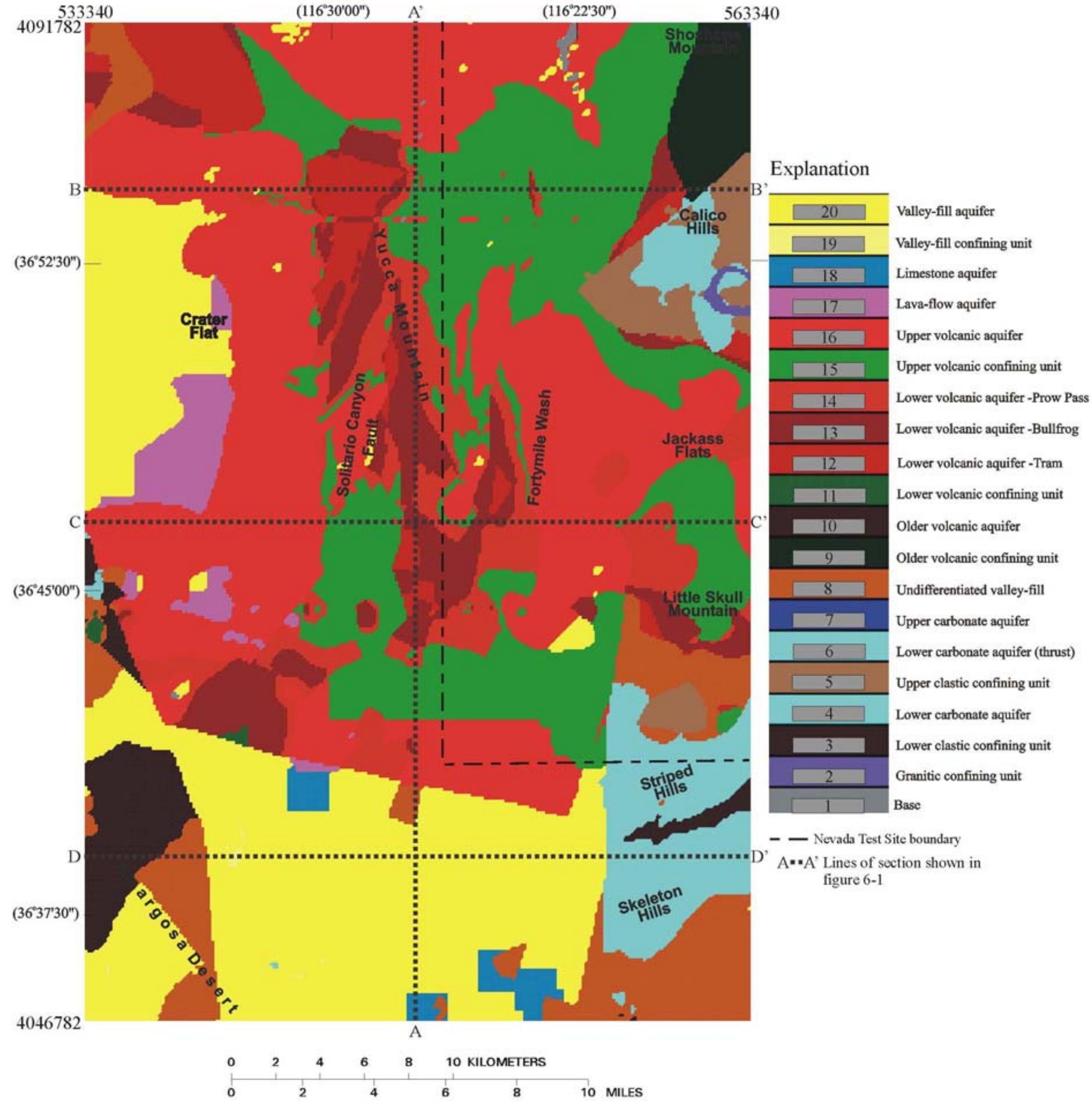
Output DTN: GS000508312332.002.

Source: See Appendix A, Table A-20.

NOTES: Altitude shown is for the top surface of the unit. X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.

UTM=Universal Transverse Mercator

Figure 6-6q. Map Showing Distribution of Unit 2 Granite Confining Unit and Data Distribution Used to Construct Surface (Unit Distribution is before Clipping by Potentiometric Surface)



Output DTN: GS030208312332.001

Source: See Table 4-1.

NOTE: X axis=longitude and UTM Easting in meters. Y axis=latitude and UTM Northing in meters.
UTM=Universal Transverse Mercator

Figure 6-7. Map Showing all Units in the Final Hydrogeologic Framework Model Viewed from above and Clipped by the Potentiometric Surface

7. VALIDATION

The HFM-19 is a conceptual model that provides a static 3-D geometric idealization of the hydrogeologic units in the site-scale SZ domain. It is intended specifically for use in the site-scale SZ flow model (BSC 2004 [DIRS 170037]) and site-scale SZ transport model (BSC 2004 [DIRS 170036]) and is not a numerical predictive model (Section 6). Confidence building and post-development model validation activities of the numerical models that implemented the conceptual model (i.e., the SZ flow and transport models) are described in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]) and *Site-Scale Saturated Zone Transport* (BSC 2004 [DIRS 170036]). The SZ flow and transport models have been previously validated as a Level II model validation as described in Section 2.2.1.1 of the SZ TWP (BSC 2004 [DIRS 171421]). Section 2.1.1.1 and Section 2.2.1.1 of the SZ TWP (BSC 2004 [DIRS 171421]) require the update of the documentation of the development of the HFM-19 and are described in the Section 7.1. Section 2.2.1.1 of the SZ TWP (BSC 2004 [DIRS 171421]) requires additional traceability and transparency of existing model validation and justification that generates confidence in the conceptual model.

7.1 CONFIDENCE BUILDING DURING MODEL DEVELOPMENT TO ESTABLISH THE SCIENTIFIC BASIS AND ACCURACY FOR INTENDED USE

The following documents the decisions or activities that were performed to generate confidence during development of the HFM, per Section 5.3.2(b) of AP SIII.10Q. The development of the HFM-19 has been conducted according to these criteria as follows:

1. Selection of input parameters and/or input data, and a discussion of how the selection process builds confidence in the model [AP-SIII.10 Q, 5.3.2(b) (1) and AP-2.27Q, *Planning for Science Activities*, Attachment 3, Level I (a)].

Data were selected for input into the model upon completion of an extensive literature search. The scientific notebook SN USGS-SCI-072-V2, V3 (Faunt 2002 [DIRS 171453]) documents the more than 100 references that were examined to determine the most appropriate data for the construction of the HFM-19. As discussed in detail in Section 4, inputs to the HFM-19 include borehole lithologic logs, geologic maps, geologic cross sections, topographic information, geophysical data, and the GFM (input model used in this report) (GFM 3.1) (DTN: MO9901MWDGFM31.000 [DIRS 103769]). In addition, geologic cross sections developed for the DOE ERP for the Nevada Test Site (DTN: MO0106STRATHFM.024 [DIRS 155585]) are used as input data. The lower boundary of the HFM-19 is selected to be consistent with the lower boundary of the Death Valley regional groundwater flow model (DTN: GS960808312144.003 [DIRS 105121]). The potentiometric surface (DTN: GS000508312332.001 [DIRS 149947]) is used as a clipping surface to form the top of the HFM-19. These data constitute a necessary and sufficient data set with which to represent the 3-D conceptual model at the designated scale of resolution required for the flow and transport models. The selection of these data and groupings of the hydrogeologic units are addressed in Section 6.1.

The primary input data for the HFM-19 are stratigraphic contact data from boreholes, geologic cross sections, GFM 3.1, and the geologic map of the Yucca Mountain region, as listed in

Table 4-1. The general locations of these input data for the site-scale domain and encompassing regional area are shown in map view in Figure 4-1. The faults and hydrogeologic units that outcrop (at ground surface) in the site-scale area are shown in Figure 4-2. Direct input data sets and associated DTNs are listed in Table 4-1; the qualification statuses of the input sources are indicated in the Automated Technical Data Tracking database. The *Data Qualification Report: Stratigraphic Data Supporting the Hydrogeologic Framework Model for Use on the Yucca Mountain Project* (Wilson 2001 [DIRS 155614]) qualifies and provides analysis for hundreds of stratigraphic data points used as inputs for the HFM-19. The selection and use of site-specific information adds confidence in the model. Thus, this requirement can be considered satisfied.

2. Description of calibration activities, and/or initial boundary condition runs, and/or run convergences, simulation conditions set up to span the range of intended use and avoid inconsistent outputs, and a discussion of how the activity or activities build confidence in the model. Inclusion of a discussion of impacts of any non-convergence runs [AP-SIII.10Q, 5.3.2(b)(2) and AP-2.27Q, Attachment 3, Level I (e)].

Sections 1 and 6.1 explain how the boundaries of the HFM were established. The domain was selected based on groundwater flow and radionuclide transport considerations as described in the site-scale SZ flow model (BSC 2004 [DIRS 170037], Section 6.5.3.2). The HFM-19 represents the hydrogeologic setting for the Yucca Mountain area that covers about 1,350 km^2 and includes a saturated thickness of about 2.75 km. The HFM-19 extends from 533,340 meters to 563,340 meters (west to east) and 4,046,782 meters to 4,091,782 meters (south to north), UTM Zone 11 (Figure 1-1). The base of the model is selected to be consistent with the base of the Death Valley regional groundwater flow model (DTN: GS960808312144.003 [DIRS 105121]) and will propagate through the flow (BSC 2004 [DIRS 170037]) and transport (BSC 2004 [DIRS 170036]) models using HFM-19. The top of the model is ground surface. A smaller version of the HFM-19 is created by clipping the top of the model by the potentiometric surface (Figure 6-2). This was done to satisfy grid size restrictions in the flow codes (Faunt 2002 [DIRS 171453], p. 130) and has no impact on the flow model since the site-scale SZ domain is below this clipping surface.

This model is static and provides a hydrogeologic definition that propagates through the abstraction process as part of the flow modeling process. A discussion of the convergence process used to develop the geometric grid used in the construction of the hydrogeologic contour maps is provided in Section 6.3.4. Discussion of HFM impact in process models is discussed in the SZ flow and transport models. Discussion about model runs and non-convergence runs are not relevant for this model report.

3. Discussion of the impacts of uncertainties to the model results including how the model results represent the range of possible outcomes consistent with important uncertainties [AP-SIII.10Q, 5.3.2(b)(3) and AP-2.27Q, Attachment 3, Level 1 (d) and (f)].

For the HFM-19, uncertainty is an estimation of how closely the model matches the actual hydrogeologic setting of the site-scale SZ model area and the interpretations of the geologic setting it is built on. The primary factor affecting uncertainty in the HFM-19 is the distance from the grid points to the nearest input data, and the overall distribution of the input data over the site-scale domain. Hydrogeologic units near the surface are constrained by the hydrogeologic map (Figure 4-2). The horizontal distance from a data point shows part of the distribution of uncertainty where data distribution is shown relative to the unit (Figures 6-6a to 6-6q). Most of the borehole data are limited to very shallow depths (corresponding with high unit identification numbers), therefore, uncertainty increases with depth (low unit identification numbers). Hence, interpretations regarding deeper hydrogeologic units have more uncertainty associated with them than that associated with shallower hydrogeologic units. Detailed discussion of model uncertainties are provided in Section 6.4.3. A summary discussion on uncertainties and their impact is given in Section 8.

4. Formulation of defensible assumptions and simplifications [AP-2.27Q, Attachment 3, Level I (b)].

Geologic relations have been simplified in order to accommodate computer mapping, framework modeling, and groundwater flow modeling limitations. In simplifying units, emphasis was placed on maintaining a highly generalized structural and stratigraphic framework that incorporated previously described hydrogeologic units. The following criteria were used as guidelines in the simplification process:

- Major high-angle faults were simplified and represented as individual vertical fault planes (thrust faults are not included as vertical faults and are constructed similar to material units)

- Geologic units were grouped into the hydrogeologic units (Table 6-1).

Discussion of assumptions and simplifications are provided in Section 5 and throughout Section 6 in discussions of data selection and model methods.

5. Consistency with physical principles, such as conservation of mass, energy, and momentum [AP-2.27Q, Attachment 3, Level I (c)].

Model grids were constructed using standard methods to generate structure contour maps, which were converted into a 3-D representation of the hydrogeologic units of the site-scale SZ (the HFM-19) by applying accepted geologic rules. The details of the methods are presented in Section 6.3.

7.2 POSTDEVELOPMENT MODEL VALIDATION TO SUPPORT THE SCIENTIFIC BASIS OF THE MODEL

The HFM is a conceptual model that is considered part of the SZ flow and transport flow model validation. Therefore, a discussion of confidence building of model after development is not included in this section. The site-scale SZ flow (BSC 2004 [DIRS 170037]) and site-scale SZ transport (BSC 2004 [DIRS 170036]) models discuss confidence building after model development as described in the SZ TWP (BSC 2004 [DIRS 171421]).

7.3 VALIDATION SUMMARY

The HFM is a conceptual model that is a part of the SZ site-scale flow (BSC 2004 [DIRS 170037]) and site-scale SZ transport (BSC 2004 [DIRS 170036]) models validation. Requirements for confidence building during model development have been satisfied. The HFM-19 model has been evaluated by comparing it to data and model sources, and checking that the representation is adequate for its intended use in flow and transport modeling (Faunt 2002 [DIRS 171453], pp. 240 to 241). The accuracy of the HFM-19 is checked by comparing the model against the input data used to build it (Section 6.4.1). Accuracy can also be checked by comparing changes in source data and their impact as used in HFM-27 and its use in the flow and transport models (Section 6.4.2). Section 6.4.3 discusses uncertainties in the HFM-19 and how they propagate to the flow and transport models. Adequacy for intended use has been determined by evaluating data accuracy and the results from flow and transport modeling using the HFM-19 and the HFM-27 (Section 6.4.4).

8. CONCLUSIONS

8.1 SUMMARY OF MODELING ACTIVITY

The HFM-19 model is an interpretation of surface and subsurface geologic and geophysical data that is based on fundamental geologic principles and the established geologic history of the Nevada Test Site and surrounding areas. It is an expression of the conceptual understanding of the geology of the Yucca Mountain area, created with the aid of computer software that imposes internal geometric consistency in the interpretations.

The HFM-19 is a conceptual model that provides a static 3-D geometric idealization of the hydrogeologic units in the site-scale SZ domain and is intended specifically for use in the site-scale SZ flow (BSC 2004 [DIRS 170037]) and site-scale SZ transport (BSC 2004 [DIRS 170036]) models. The HFM is not a numerical predictive model (Section 6). Mathematical implementation of the HFM-19 occurs when it is used as a basis for assigning hydrologic properties within the SZ site-scale flow model domain. Therefore, this product does not provide any hydraulic parameters and is intended only to provide a geometric representation of hydrogeology and structure for use as a conceptual model in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]). Validation of the HFM-19 is considered part of the SZ site-scale flow and transport models that have been previously validated as a Level II model validation as described in Section 2.2.1.1 of the SZ TWP (BSC 2004 [DIRS 171421]).

The HFM-19 is appropriate for use in the site-scale SZ flow (BSC 2004 [DIRS 170037]) and site-scale SZ transport (BSC 2004 [DIRS 170036]) models because its development was achieved utilizing standard geologic methods and software based on all appropriate data from the Yucca Mountain area. The locations and extent of the hydrogeologic units are determined from boreholes, surface geologic maps, geologic cross sections, and geophysical surveys. The lower boundary of the model is coincident with that of the regional flow model (DTN: GS960808312144.003 [DIRS 105121]). This boundary is generally consistent with no vertical flow in or out of the base of the site-scale model domain. The top of the HFM-19 is set to an updated potentiometric surface map (DTN: GS000508312332.001 [DIRS 149947]). The gridding process is a simplification and idealization relating geometrical elements to the controlling data within the domain.

The hydrogeologic layers of the HFM-19 form a series of alternating volcanic aquifers and confining units and alluvium above the regional carbonate aquifer. These hydrogeologic regions consist of one or more contiguous geologically defined stratigraphic units that can be grouped into hydrogeologic units based on measured or inferred common hydrologic properties (BSC 2004 [DIRS 170037], Section 6.5.2). The HFM-19 is assembled by using standard interpolation and extrapolation techniques to fill the domain area with elements corresponding to the hydrogeologic units.

8.2 MODEL OUTPUTS

8.2.1 Developed Output

HFM-19 model development and construction is summarized in Section 6 and documented in scientific notebook SN-USGS-SCI-072-V2, V3 (Faunt 2002 [DIRS 171453]). The model files output from this report are available from the Technical Data Management System. The unclipped HFM-19, which is built to the ground surface, is output DTN: GS000508312332.002. The version clipped by the water table and used by the flow and transport models is output DTN: GS030208312332.001. The HFM-19 consists of digital files (*site125.tfm, site125.tfb, site125.scf,* V5-99) in binary Stratamodel format (USGS 2000 [DIRS 148985]). Note that the clipped HFM-19 includes, as its top surface, the water table definition used in the SZ flow and transport models. None of the changes in this report revision change the HFM-19 in these two output DTNs.

8.2.2 Output Uncertainties and Limitations

Geologic relations, both actual and inferred, are simplified in order to accommodate computer mapping, framework modeling, and groundwater flow modeling limitations. As a result, the model contains an inherent level of uncertainty that is a function of data distribution and geologic complexity. The major simplifications include the grouping of geologic units into hydrogeologic units (Table 6-1), and high-angle faults represented as individual vertical fault planes. As a result, many fault offsets are smoothed in the HFM-19. In the area of the GFM, the appropriate offsets on units, based on dipping faults, are retained. Section 5 describes simplifications of features and choices of grid resolution representing these features. These hydrogeological units and major structural features are adequately included in the TSPA through the SZ flow and transport models and SZ flow fields that support the TSPA.

Model uncertainties in the HFM-19 can be attributed to interpretations and simplifications driven by the distribution and availability of data. The data distribution over the SZ area is uneven, much of the volume is unsampled, and many of the input files are interpretations. As a result, the expected error in the HFM-19 varies significantly over the model area. Some of the surfaces, such as that of the upper volcanic aquifer in the area of the repository, are relatively well defined by more than one data set (derived from the surface hydrogeologic unit map, borehole lithologic logs, and geologic cross sections). Others, especially the units that crop out less commonly, are less well defined and are extrapolated from sparse data. In the area of the repository the unit, locations are relatively well known. Even in this area, however, there is only one borehole that penetrates the Paleozoic rocks. Data uncertainty increases with depth and distance from the repository as data become sparse and the effects of faults deeper in the system become unknown. As a result, the model contains an inherent level of uncertainty that is a function of data distribution and geologic complexity. These data errors and limitations include the data poor regions of uncertainty in the deeper Paleozoic carbonate region, and the alluvial uncertainty zone south of the repository.

Additional boreholes have been drilled by Nye County since the development of the HFM-19, primarily to characterize the contact between the valley-fill and the volcanic rocks in the southern portion of the model area. However, these new data did not eliminate all uncertainty in the location and character of this contact. The Nye County boreholes were being drilled at the time the HFM-19 was developed so the stratigraphic data were not available in time for model construction. As a result, generalized units such as “undifferentiated valley-fill”, “valley-fill”, and “volcanic units” are used in HFM-19 to describe near surface units that are particularly variable in lithologic characteristics and hydraulic properties.

Uncertainties due to the development of the hydrogeologic units propagate through the flow and transport model abstraction (BSC 2004 [DIRS 170042]). Uncertainties in the HFM-19 relate most importantly to the quantity and location of available qualified data, and secondly to the interpretation of surfaces and the representation of important faults and structures. Evaluations between the base-case flow and transport models using the HFM-19 and alternate models using HFM-27 indicate that the use of HFM-19 is more conservative than HFM-27, (see Section 6.4.4 of this report and *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037], Section 6.4.7). Considering these constraints, and as shown by the flow and transport results, the HFM-19 is sufficiently accurate and adequate as a conceptual model for SZ site-scale flow and transport models.

8.3 YUCCA MOUNTAIN REVIEW PLAN ACCEPTANCE CRITERIA

The main acceptance criteria identified in the YMRP (NRC 2003 [DIRS 163274]) that are associated with this report are included in this section. A list of the subcriteria relevant to this report, and a discussion of how these subcriteria are addressed, is also provided. Only those acceptance criteria that are applicable to this report (Section 4.2) are discussed. In most cases, the applicable acceptance criteria are not addressed solely by this report; rather, the acceptance criteria are fully addressed when this report is considered in conjunction with other analysis and model reports that describe transport in the SZ.

8.3.1 Flow Paths in the Saturated Zone

This section describes how the acceptance criteria in the YMRP Section 2.2.1.3.8.3, Flow Paths in the Saturated Zone, are addressed by this report.

Acceptance Criterion 1: System Description and Model Integration are Adequate.

Subcriterion (1): Sections 1 and 6 describe the HFM as a conceptual model of the hydrogeologic units and major structural features in the SZ flow system. Section 5 describes simplifications of features and choices of grid resolution representing these features. These hydrogeological units and major structural features are adequately included in the TSPA through the SZ flow and transport models and SZ flow fields that support the TSPA.

Subcriterion (2): Section 6.1 introduces the method and Table 6-1 shows the geologic groupings chosen for representing the geologic heterogeneity, which is introduced by stratigraphy, and influences the modeling of groundwater flow. Sections 3 and 6.3 identify the software and methods used to construct these groupings into the HFM. Section 4 describes the aspects of hydrology and geology that may affect flow paths in the SZ. These descriptions are adequate because they are based on a substantial amount of data.

Subcriterion (4): Sections 1 and 6.1 explain how the boundaries of the model were established. The lower boundary of the model is consistent with the Death Valley regional groundwater flow model and the upper boundary is obtained by truncating the hydrogeologic layers at the potentiometric surface. Section 6.3.5 describes the steps taken to build the model beginning with the base and grid coincident to the regional model, building to the ground surface, and finishing the model with a clipping surface described in 6.3.6. These features propagate through the abstraction process as part of the flow modeling process.

Subcriterion (6): Section 6.4.4 describes how the HFM-19 was developed specifically to support the modeling of flow and transport in the site-scale SZ. Because the HFM-19 adequately addresses natural site conditions, these conditions are adequately delineated in the flow paths in the site-scale SZ.

Subcriterion (10): This model was developed in accordance with the *Quality Assurance Requirements and Description* (DOE 2004 [DIRS 171539]), which commits to these NUREGs, and the associated procedures as discussed in Section 2. Compliance with these procedures was determined through the quality assurance and other review programs.

Acceptance Criterion 2: Data Are Sufficient for Model Justification.

Subcriterion (1): Section 4.1 describes the geological, hydrologic, and geochemical values, which were used in the license application to evaluate flow paths in the SZ, and shows why they are adequately justified. Data include stratigraphic contact data from boreholes, the lithographic logs, geologic cross sections, topographic information, geophysical data, and GFM 3.1. The lower boundary of the HFM-19 is consistent with the lower boundary of the Death Valley regional groundwater flow model. The accuracy of these data is discussed in Section 4.1 and appropriateness of these data is discussed in Section 6.1.

Subcriterion (2): Section 4.1 describes the data collected on the natural system and used to determine the locations of the hydrogeologic surfaces, including the upper and lower boundaries of the SZ. The extent of the data sources listed in Table 4-1 shows that the data are sufficient to establish the boundaries, which support the abstraction of flow paths in the SZ.

Subcriterion (3): Section 4.1 describes the standard and, therefore, appropriate techniques, which were used to develop the data on the geology, hydrology, and geochemistry of the SZ, which were used in the TSPA abstraction.

Subcriterion (4): Section 5 describes the methodological assumptions and suitable grid resolution applied to construction of the HFM-19. Section 6.3 describes the mathematical methods used to substantiate the applicability of the groundwater modeling approach to site conditions. Model grids were constructed using the minimum curvature and first-order squares methods and the interpolation and extrapolation of stratigraphy through the use of borehole lithographic logs, geologic maps, developed geologic cross sections, and geophysical data. Standard methods were used to generate structure contour maps that were converted into a 3-D representation of the hydrogeology of the site-scale SZ and the HFM-19, by applying accepted geologic rules.

Acceptance Criterion 3: Data Uncertainty Is Characterized and Propagated through the Model Abstraction.

Subcriterion (1): Section 6.4.3 explains that as long as the horizontal spatial ambiguity in the location of hydrogeologic contacts is less than 250 m, and given an adequate representation of the hydrogeology, there is essentially no impact on the specific discharge or flux calculations using the site-scale flow model. Section 6.4.3 also discusses the impact on low specific discharge that results from uncertainty in the vertical location of certain strata.

Subcriterion (3): Section 6.4.1 evaluates the agreement between the HFM-19 and input data concluding that the HFM-19 inherits the uncertainty inherent in sparse data coverage at depth and away from the immediate site area. Section 6.4.3 describes how the uncertainty in the HFM-19 is propagated through the flow and transport models to the breakthrough curves used in the TSPA. Section 6.4.4 describes how uncertainty in the initial set of hydrologic property values in the HFM-19 is addressed through the calibration of the flow model when the HFM-19 is used in the calculation of flow fields.

Acceptance Criterion 4: Model Uncertainty Is Characterized and Propagated through the Model Abstraction.

Subcriterion (2): Section 6.4.3 adequately defines and documents conceptual model uncertainties in the HFM-19. The increase in uncertainty about deeper hydrogeologic units with depth, the existence of alternative interpretations of the location of the carbonate aquifers and clastic confining units, and the alluvial uncertainty zone are acknowledged. The effects of these uncertainties on conclusions regarding performance are properly assessed in other reports, which address flow and transport in the SZ.

Subcriterion (3): Sections 6.4.3 and 6.4.4 show that the conceptual model uncertainty is consistent with available site characterization data and field measurements, specifically the regional model and the Nye County data.

Subcriterion (4): Sections 4.1 and 6.4.2 discuss an alternative model. It is consistent with available data and current scientific understanding because it is based on updates in the GFM2000 (BSC 2004 [DIRS 170029]) and regional model and the new data from Nye County EWDP. Because this alternative model was found not to significantly affect the flow paths in the SZ, the results and limitations of this alternative model are appropriately considered in the abstraction.

This report includes the scope of work identified in Section 3.4 of the TWP (BSC 2004 [DIRS 171421]). This scope of work is defined more specifically in action lists particular to this AMR. Successful completion of this work is evaluated during the AP-2.14Q, *Document Review* process.

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MO0007LGLOG251.000. Lithologic and Geophysical Logs from the Felderhof Federal 25-1 Borehole, Amargosa Desert, Nye County, Nevada. Submittal date: 07/11/2000. 152893

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MO0106STRATHFM.006. Lithologic Log for Test Hole USW UZ-7. Submittal date: 06/26/2001. 155541

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MO0106STRATHFM.028. Generalized Lithologic Log for Test Well USW H-1. Submittal date: 06/27/2001. 155589

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MO0407SEPFEPLA.000. LA FEP List. Submittal date: 07/20/2004. 170760

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9.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

GS030208312332.001. HFM Final Output - Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model. Submittal date: 02/10/2003.

GS000508312332.002. Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model. Submittal date 06/01/2000 (This version is before clipping by the potentiometric surface).

9.5 SOFTWARE CODES

CRWMS M&O (Civilian Radioactive Waste Management System Management & Operating Contractor) 2000. *Software Code: ARCINFO.* V7.2.1. SGI Irix. 10033-7.2.1-00. 157019

USGS 2000. *Stratamodel V4.1.1.* 4.1.1. 10121-4.1.1-00. 148985

USGS 2001. *Software Code: ERMA Site Geologist.* V6.0.1. 10210-6.0.1-00. 148986

USGS 2001. *Software Code: Petrosys.* V7.60d. 10168-7.60d-00. 148306

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APPENDIX A

INPUT DATA SOURCES BY HYDROGEOLOGIC UNIT

The following tables show the unit-by-unit data sources for each affected unit. The specific data used are given by description and DTN. These data are summarized in Section 4.1 and listed in Table 4-1. Where data are part of a larger data set (as listed in Table 4-1), the shorthand name of the data set is included as part of the description. Table A-1 lists four data sources that are used throughout the full model and are not specific to a single unit; these are the DEM (DTN: GS000400002332.001 [DIRS 148924]), GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]), Water-Level Data (DTN: GS000508312332.001 [DIRS 149947]), and YMP Boreholes (DTN: MO9906GPS98410.000 [DIRS 109059]). Note that the full list of data sources shown in these tables is summarized in Table 4–1. These tables are summarized from this report, the Scientific Notebook SN-USGS-SCI-072_V2, V3 (Faunt 2002 [DIRS 171453]), and the data qualification report by Wilson (2001 [DIRS 155614]). There is one table for each of the HFM-19 units and each is labeled with the HFM-19 name, unit number, and unit names as used in Table 2 of the Wilson report (note that the Wilson report names the lower volcanic confining unit as MVCU, and older volcanic confining unit as LVCU).

Table A-1. General Input Data

Data Description	Data Tracking Number
Digital Elevation Models Death Valley East Scale 1:250,000	GS000400002332.001 [DIRS 148924]
Geologic Framework Model, GFM 3.1	MO9901MWDGFM31.000 [DIRS 103769]
Water-Level Data Analysis for the SZ Site-Scale Flow and Transport Model	GS000508312332.001 [DIRS 149947]
Yucca Mountain Project (YMP) Borehole Locations (GPS updated x,y coordinates supercede earlier locations in affected DTN's)	MO9906GPS98410.000 [DIRS 109059]

GFM=geologic framework model; GPS=Global Positioning System

Table A-2. Input Data for Valley-Fill Aquifer (Unit 20 Alluvium)

Data Description	Data Tracking Number
Geologic Map of the Yucca Mountain Region in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]

Table A-3. Input Data for Valley-Fill Confining Unit (Unit 19 Playas)

Data Description	Data Tracking Number
Geologic Map of the Yucca Mountain Region in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]

Table A-4. Input Data for Limestone Aquifer (Unit 18 Amarls)

Data Description	Data Tracking Number
Lithologic data for Collins well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]
Lithologic data for Heindel well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]

Table A-4. Input Data for Limestone Aquifer (Unit 18 Amarls) (Continued)

Data Description	Data Tracking Number
Lithologic data for Vassar well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]
Lithologic data for Bettles well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]
Lithologic data for Finch well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]

Table A-5. Input Data for Lava-Flow Aquifer (Unit 17 Basalts)

Data Description	Data Tracking Number
Cross Section b from Faulds et al. (1994 [DIRS 105126])	MO0106STRATHFM.022 [DIRS 155583]
Cross Section a from Swadley and Carr (1987 [DIRS 101300])	MO0106STRATHFM.010 [DIRS 155545]
Cross Section d from Maldonado (1985 [DIRS 104160])	MO0106STRATHFM.011 [DIRS 155546]
Geologic map and Cross Section b in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
Lithologic data for Nye County Land Company well	MO0106STRATHFM.003 [DIRS 155538]
Lithologic data for Felderhoff 5-1 borehole	MO0007LLGLOG51.000 [DIRS 152894]
Lithologic data for Felderhoff 25-1 borehole	MO0007LGLOG251.000 [DIRS 152893]
Locations for the Felderhoff boreholes	MO0007BLFHF525.000 [DIRS 152892]

Table A-6. Input Data for Upper Volcanic Aquifer (Unit 16 UVA)

Data Description	Data Tracking Number
Cross Sections a and b from McKay and Sargent (1970 [DIRS 155611])	MO0106STRATHFM.012 [DIRS 155572]
Cross Sections a and b from Sargent et al. (1970 [DIRS 155615])	MO0106STRATHFM.013 [DIRS 155573]
Cross Sections a, b, and c from Orkild and O’Conner (1970 [DIRS 106459])	MO0106STRATHFM.014 [DIRS 155755]
Cross Sections a and b from McKay and Williams (1964 [DIRS 155612])	MO0106STRATHFM.015 [DIRS 155574]
Cross Sections a, b, and c from Lipman and McKay (1965 [DIRS 104158])	MO0106STRATHFM.016 [DIRS 155575]
Cross sections a and c from Christiansen and Lipman (1965 [DIRS 100566])	MO0106STRATHFM.017 [DIRS 155610]
Cross sections b and d from Maldonado (1985 [DIRS 104160])	MO0106STRATHFM.011 [DIRS 155546]
Cross Sections a and b from Swadley and Carr (1987 [DIRS 101300])	MO0106STRATHFM.010 [DIRS 155545]

Table A-6. Input Data for Upper Volcanic Aquifer (Unit 16 UVA) (Continued)

Data Description	Data Tracking Number
Cross Section a from Byers et al. (1976 [DIRS 103624])	MO0106STRATHFM.018 [DIRS 155579]
Cross Section d from Frizzell and Shulters (1990 [DIRS 105454])	MO0106STRATHFM.019 [DIRS 155580]
Cross Section a from Young (1972 [DIRS 103023])	MO0106STRATHFM.020 [DIRS 155581]
Cross Sections a, b, and c from Scott and Bonk (1984 [DIRS 104181])	GS930283117461.001 [DIRS 107027]
Cross Sections a, b, and c from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Sections a, b, and c from Faulds et al. (1994 [DIRS 105126])	MO0106STRATHFM.022 [DIRS 155583]
Geologic map and Cross Sections a, b, c, and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
Cross Section j from Moench (1965 [DIRS 155613])	MO0106STRATHFM.023 [DIRS 155584]
Lithologic data for borehole UE-25 a#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 a#4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 a#5	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 a#6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 a#7	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 b#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#2	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 J#13	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 NRG#2	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 NRG#2a	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 NRG#2b	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 NRG#2c	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 NRG#2d	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 NRG#3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 NRG#4	MO9901MWDGFM31.000 [DIRS 103769]

Table A-6. Input Data for Upper Volcanic Aquifer (Unit 16 UVA) (Continued)

Data Description	Data Tracking Number
Lithologic data for borehole UE-25 NRG#5	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 p#1	MO0106STRATHFM.029 [DIRS 155590]
Lithologic data for borehole UE-25 RF#1 (RF Boreholes)	MO0106STRATHFM.002 [DIRS 155537]
Lithologic data for borehole UE-25 RF#10 (RF Boreholes)	MO0106STRATHFM.002 [DIRS 155537]
Lithologic data for borehole UE-25 RF#11 (RF Boreholes)	MO0106STRATHFM.002 [DIRS 155537]
Lithologic data for borehole UE-25 RF#2 (RF Boreholes)	MO0106STRATHFM.002 [DIRS 155537]
Lithologic data for borehole UE-25 RF#3 (RF and GFM)	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 RF#4 (RF Boreholes)	MO0106STRATHFM.002 [DIRS 155537]
Lithologic data for borehole UE-25 RF#5 (RF Boreholes)	MO0106STRATHFM.002 [DIRS 155537]
Lithologic data for borehole UE-25 RF#8 (RF and GFM)	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 RF#9 (RF Boreholes)	MO0106STRATHFM.002 [DIRS 155537]
Lithologic data for borehole UE-25 UZ#16	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 UZ#4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 UZ#5	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 UZN #1 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #10 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #12 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #13 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #14 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #18 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #19 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #2 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #20 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #21 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #22 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]

Table A-6. Input Data for Upper Volcanic Aquifer (Unit 16 UVA) (Continued)

Data Description	Data Tracking Number
Lithologic data for borehole UE-25 UZN #23 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #29 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #3 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #30 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #4 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #5 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #56 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #6 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #7 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #8 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #9 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN #97 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN 60 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 UZN#63	GS940308314211.017 [DIRS 155534]
Lithologic data for borehole USW WT-11	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT #5 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 WT#12	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#13	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#14	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#15	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#16	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#17	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#18	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#4	MO9901MWDGFM31.000 [DIRS 103769]

Table A-6. Input Data for Upper Volcanic Aquifer (Unit 16 UVA) (Continued)

Data Description	Data Tracking Number
Lithologic data for borehole UE-25 WT#6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25a #6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW G-1	MO0106STRATHFM.030 [DIRS 155591]
Lithologic data for borehole USW G-2	MO0106STRATHFM.031 [DIRS 155592]
Lithologic data for borehole USW G-3	MO0106STRATHFM.004 [DIRS 155539]
Lithologic data for borehole USW G-4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW GU-3	MO0106STRATHFM.004 [DIRS 155539]
Lithologic data for borehole USW H-1	MO0106STRATHFM.028 [DIRS 155589]
Lithologic data for borehole USW H-3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-5	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW NRG-6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW NRG-7/7a	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-12	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-7	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-13	MO0106STRATHFM.005 [DIRS 155540]
Lithologic data for borehole USW UZ-14	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-6s (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-7	MO0106STRATHFM.006 [DIRS 155541]
Lithologic data for borehole USW UZ-N11	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N15	GS940308314211.019 [DIRS 145591]
Lithologic data for borehole USW UZ-N16	GS940308314211.019 [DIRS 145591]

Table A-6. Input Data for Upper Volcanic Aquifer (Unit 16 UVA) (Continued)

Data Description	Data Tracking Number
Lithologic data for borehole USW UZ-N17	GS940308314211.019 [DIRS 145591]
Lithologic data for borehole USW UZ-N24 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N25 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N26 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N27	GS940208314211.004 [DIRS 145579]
Lithologic data for borehole USW UZ-N31	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N32	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N33	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N34	GS950108314211.009 [DIRS 152556]
Lithologic data for borehole USW UZ-N35	GS940208314211.007 [DIRS 155533]
Lithologic data for borehole USW UZ-N36	GS940308314211.018 [DIRS 145589]
Lithologic data for borehole USW UZ-N37	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N38	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N40 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N41 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N42 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N43 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N44 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N45 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N46 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N47 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N48 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N49 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N51 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N52 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]

Table A-6. Input Data for Upper Volcanic Aquifer (Unit 16 UVA) (Continued)

Data Description	Data Tracking Number
Lithologic data for borehole USW UZ-N53	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N54	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N55	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-N57	GS940208314211.008 [DIRS 145581]
Lithologic data for borehole USW UZ-N58	GS940208314211.008 [DIRS 145581]
Lithologic data for borehole USW UZ-N59	GS940208314211.008 [DIRS 145581]
Lithologic data for borehole USW UZ-N61	GS940208314211.008 [DIRS 145581]
Lithologic data for borehole USW UZ-N62	GS940208314211.002 [DIRS 145577]
Lithologic data for borehole USW UZ-N65 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N68 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N69 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N70 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N71 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N72 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N73 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N74 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N75 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N76 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N80 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N83 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N84 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N86 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N88 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N89 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N94 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]

Table A-6. Input Data for Upper Volcanic Aquifer (Unit 16 UVA) (Continued)

Data Description	Data Tracking Number
Lithologic data for borehole USW UZ-N95 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW UZ-N96 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW WT-10	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-2	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-7	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 J-11 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 J-12 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-25 JF#3	MO0106STRATHFM.007 [DIRS 155542]
Lithologic data for borehole UE-29 UZN#91 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole UE-29 UZN#92 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]
Lithologic data for borehole USW VH-1	MO0106STRATHFM.008 [DIRS 155543]
Lithologic data for borehole USW VH-2	MO0106STRATHFM.009 [DIRS 155544]

GFM=geologic framework model; MWIS=National Water Information System; RF=repository facilities

Table A-7. Input Data for Upper Volcanic Confining Unit (Unit 15 UVCU)

Data Description	Data Tracking Number
Cross Sections a, b, and c from Lipman and McKay (1965 [DIRS 104158])	MO0106STRATHFM.016 [DIRS 155575]
Cross Sections a, b, and c from Orkild and O'Conner (1970 [DIRS 106459])	MO0106STRATHFM.014 [DIRS 155755]
Cross sections a and c from Christiansen and Lipman (1965 [DIRS 100566])	MO0106STRATHFM.017 [DIRS 155610]
Cross Sections a and b from McKay and Williams (1964 [DIRS 155612])	MO0106STRATHFM.015 [DIRS 155574]
Cross Section a from Sargent et al. (1970 [DIRS 155615])	MO0106STRATHFM.013 [DIRS 155573]
Cross Section d from Frizzell and Shulters (1990 [DIRS 105454])	MO0106STRATHFM.019 [DIRS 155580]
Cross Section a from Byers et al. (1976 [DIRS 103624])	MO0106STRATHFM.018 [DIRS 155579]
Cross sections b and d from Maldonado (1985 [DIRS 104160])	MO0106STRATHFM.011 [DIRS 155546]
Cross Sections a, b, and c from Scott and Bonk (1984 [DIRS 104181])	GS930283117461.001 [DIRS 107027]
Cross Sections a and c from Faulds et al. (1994 [DIRS 105126])	MO0106STRATHFM.022 [DIRS 155583]

Table A-7. Input Data for Upper Volcanic Confining Unit (Unit 15 UVCU) (Continued)

Data Description	Data Tracking Number
Cross Sections a, b, and c from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Geologic map in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
GFM Calico Hills surface	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 a#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 b#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#2	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 J#13	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 p#1	MO0106STRATHFM.029 [DIRS 155590]
Lithologic data for borehole UE-25 UZ#16	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#12	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#14	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#16	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#17	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#18	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW G-1	MO0106STRATHFM.030 [DIRS 155591]
Lithologic data for borehole USW G-2	MO0106STRATHFM.031 [DIRS 155592]
Lithologic data for borehole USW G-3	MO0106STRATHFM.004 [DIRS 155539]
Lithologic data for borehole USW G-4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW GU-3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-1	MO0106STRATHFM.028 [DIRS 155589]

Table A-7. Input Data for Upper Volcanic Confining Unit (Unit 15 UVCU) (Continued)

Data Description	Data Tracking Number
Lithologic data for borehole USW H-3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-5	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW NRG-7/7a	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-9	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-14	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-11	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-2	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-7	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-12	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-7	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW VH-1	MO0106STRATHFM.008 [DIRS 155543]
Lithologic data for borehole USW VH-2	MO0106STRATHFM.009 [DIRS 155544]
Lithologic data for borehole UE-25 JF#3	MO0106STRATHFM.007 [DIRS 155542]

Table A-8. Input Data for Lower Volcanic Aquifer – Prow Pass Tuff (Unit 14 LVA Tcp)

Data Description	Data Tracking Number
Cross Sections a, b, and c from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Sections b and c from Faulds et al. (1994 [DIRS 105126])	MO0106STRATHFM.022 [DIRS 155583]
Geologic map and Cross Sections a, b, and c in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
GFM Prow Pass surface	MO9901MWDGFM31.000 [DIRS 103769]

Table A-8. Input Data for Lower Volcanic Aquifer – Prow Pass Tuff (Unit 14 LVA Tcp) (Continued)

Data Description	Data Description
Cross Section a from Sargent et al. (1970 [DIRS 155615])	MO0106STRATHFM.013 [DIRS 155573]
Cross Section d from Maldonado (1985 [DIRS 104160])	MO0106STRATHFM.011 [DIRS 155546]
Cross Section d from Frizzell and Shulters (1990 [DIRS 105454])	MO0106STRATHFM.019 [DIRS 155580]
Cross Section a from Swadley and Carr (1987 [DIRS 101300])	MO0106STRATHFM.010 [DIRS 155545]
Cross Sections a and b from McKay and Sargent (1970 [DIRS 155611])	MO0106STRATHFM.012 [DIRS 155572]
Lithologic data for borehole UE-25 a#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 b#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#2	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 c#3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 J#13	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 p#1	MO0106STRATHFM.029 [DIRS 155590]
Lithologic data for borehole UE-25 UZ#16	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#17	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 WT#3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW G-1	MO0106STRATHFM.030 [DIRS 155591]
Lithologic data for borehole USW G-2	MO0106STRATHFM.031 [DIRS 155592]
Lithologic data for borehole USW G-3	MO0106STRATHFM.004 [DIRS 155539]
Lithologic data for borehole USW G-4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW GU-3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-1	MO0106STRATHFM.028 [DIRS 155589]
Lithologic data for borehole USW H-3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-5	MO9901MWDGFM31.000 [DIRS 103769]

Table A-8. Input Data for Lower Volcanic Aquifer – Prow Pass Tuff (Unit 14 LVA Tcp) (Continued)

Data Description	Data Description
Lithologic data for borehole USW H-6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW UZ-6	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-1	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-2	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW WT-7	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-12	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-9	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-7	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW VH-1	MO0106STRATHFM.008 [DIRS 155543]
Lithologic data for borehole USW VH-2	MO0106STRATHFM.009 [DIRS 155544]

Table A-9. Input Data for Lower Volcanic Aquifer – Bullfrog Tuff (Unit 13 LVA Tcb)

Data Description	Data Tracking Number
Cross Sections a, b, and c from Faulds et al. (1994 [DIRS 105126])	MO0106STRATHFM.022 [DIRS 155583]
Cross Section a from Swadley and Carr (1987 [DIRS 101300])	MO0106STRATHFM.010 [DIRS 155545]
Cross Section a from Sargent et al. (1970 [DIRS 155615])	MO0106STRATHFM.013 [DIRS 155573]
Geologic map and Cross Sections a, b, c, and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
GFM Bullfrog surface	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-12	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-7	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW VH-1	MO0106STRATHFM.008 [DIRS 155543]
Lithologic data for borehole USW VH-2	MO0106STRATHFM.009 [DIRS 155544]

Table A-10. Input Data for Lower Volcanic Aquifer – Tram Tuff (Unit 12 LVA Tct)

Data Description	Data Tracking Number
Cross Sections b and c from Faulds et al. (1994 [DIRS 105126])	MO0106STRATHFM.022 [DIRS 155583]
Cross Section a from Sargent et al. (1970 [DIRS 155615])	MO0106STRATHFM.013 [DIRS 155573]
Cross Sections a, b, c, and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
GFM Tram surface	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW SD-7	MO9901MWDGFM31.000 [DIRS 103769]

GFM=geologic framework model

Table A-11. Input Data for Lower Volcanic Confining Unit (Unit 11 MVCU)

Data Description	Data Tracking Number
Cross Sections a, b, and c from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Section d from Frizzell and Shulters (1990 [DIRS 105454])	MO0106STRATHFM.019 [DIRS 155580]
Cross Section b from Maldonado (1985 [DIRS 104160])	MO0106STRATHFM.011 [DIRS 155546]
Geologic map in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
Lithologic data for borehole UE-25 J#13	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole UE-25 p#1	MO0106STRATHFM.029 [DIRS 155590]
Lithologic data for borehole USW G-1	MO0106STRATHFM.030 [DIRS 155591]
Lithologic data for borehole USW G-2	MO0106STRATHFM.031 [DIRS 155592]
Lithologic data for borehole USW G-3	MO0106STRATHFM.004 [DIRS 155539]
Lithologic data for borehole USW H-1	MO0106STRATHFM.028 [DIRS 155589]
Lithologic data for borehole USW H-3	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-4	MO9901MWDGFM31.000 [DIRS 103769]
Lithologic data for borehole USW H-6	MO9901MWDGFM31.000 [DIRS 103769]

Table A-12. Input Data for Older Volcanic Aquifer (Unit 10 LVA)

Data Description	Data Tracking Number
Lithologic data for borehole UE-25 p#1	MO0106STRATHFM.029 [DIRS 155590]
Lithologic data for borehole USW G-1	MO0106STRATHFM.030 [DIRS 155591]
Lithologic data for borehole USW G-2	MO0106STRATHFM.031 [DIRS 155592]
Lithologic data for borehole USW G-3	MO0106STRATHFM.004 [DIRS 155539]
Lithologic data for borehole USW H-1	MO0106STRATHFM.028 [DIRS 155589]

Table A-13. Input Data for Older Volcanic Confining Unit (Unit 9 LVCU)

Data Description	Data Tracking Number
Cross Section c from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Section d from Frizzell and Shulters (1990 [DIRS 105454])	MO0106STRATHFM.019 [DIRS 155580]
Cross Section b from Maldonado (1985 [DIRS 104160])	MO0106STRATHFM.011 [DIRS 155546]
Cross Section c from Scott and Bonk (1984 [DIRS 104181])	GS930283117461.001 [DIRS 107027]
Lithologic data for borehole UE-25 p#1	MO0106STRATHFM.029 [DIRS 155590]

Table A-14. Input Data for Undifferentiated Valley Fill (Unit 8 Leaky)

Data Description	Data Tracking Number
Cross Section a from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Section a from Sargent et al. (1970 [DIRS 155615])	MO0106STRATHFM.013 [DIRS 155573]
Geologic map and Cross Sections a, b, c, and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
Lithologic data for the Collins well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]
Lithologic data for the Heindel well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]
Lithologic data for the Bettles well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]
Lithologic data for Felderhoff 5-1 borehole	MO0007LLGLOG51.000 [DIRS 152894]
Lithologic data for Felderhoff 25-1 borehole	MO0007LGLOG251.000 [DIRS 152893]

Table A-15. Input Data for Upper Carbonate Aquifer (Unit 7 UCA)

Data Description	Data Tracking Number
Locations for the Felderhoff boreholes	MO0007BLFHF525.000 [DIRS 152892]
Cross Section CR4 from NTS ERP DTN: GS000400002332.002 [DIRS 149021]	MO0106STRATHFM.024 [DIRS 155585]

Table A-16. Input Data for Upper Clastic Confining Unit (Unit 5 UCCU)

Data Description	Data Tracking Number
Cross Section b from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Section CR4 from NTS ERP DTN: GS000400002332.002 [DIRS 149021]	MO0106STRATHFM.024 [DIRS 155585]
Cross Sections a and b from McKay and Williams (1964 [DIRS 155612])	MO0106STRATHFM.015 [DIRS 155574]
Cross Section b from Maldonado (1985 [DIRS 104160])	MO0106STRATHFM.011 [DIRS 155546]
Geologic map and Cross Sections c and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
Lithologic data for UE-25a#3 (NWIS)	MO0109STRATHFM.001 [DIRS 156252]

Table A-17. Input Data for Lower Carbonate Aquifer (Unit 4 LCA)

Data Description	Data Tracking Number
Cross Section b from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Sections BS1, BS2, BS9, CR4 and CR5 from NTS ERP DTN: GS000400002332.002 [DIRS 149021]	MO0106STRATHFM.024 [DIRS 155585]
Cross Sections a, b, i, and j from Moench (1965 [DIRS 155613])	MO0106STRATHFM.023 [DIRS 155584]
Beatty, Fortymile Wash, and Amargosa seismic refraction profiles from Oliver et al. (1995 [DIRS 106447])	MO0106STRATHFM.025 [DIRS 155586]
Regional Geophysical lines 2 and 3 from Brocher et al. (1996 [DIRS 101495], Figures 16 and 17)	(see Appendix B, Section B.2 for the justification for use of data)
Cross Section a from Sargent et al. (1970 [DIRS 155615])	MO0106STRATHFM.013 [DIRS 155573]
Geologic map and Cross Sections a, b, c, and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]
Resistivity soundings from Greenhaus and Zablocki (1982 [DIRS 105144])	MO0106STRATHFM.026 [DIRS 155587]
Lithologic data for borehole UE-25 p#1	MO0106STRATHFM.029 [DIRS 155590]
Lithologic data for Felderhoff 5-1 borehole	MO0007LLGLOG51.000 [DIRS 152894]
Lithologic data for Felderhoff 25-1 borehole	MO0007LGLOG251.000 [DIRS 152893]

Table A-17. Input Data for Lower Carbonate Aquifer (Unit 4 LCA) (Continued)

Data Description	Data Tracking Number
Locations for the Felderhoff boreholes	MO0007BLFHF525.000 [DIRS 152892]
Lithologic data for the Spring Meadows, Inc. well (water resource wells)	MO0106STRATHFM.003 [DIRS 155538]

Table A-18. Input Data for Lower Carbonate Aquifer Thrust Plate (Unit 6 LCA-t2)

Data Description	Data Tracking Number
Cross Section b from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Section b from McKay and Williams (1964 [DIRS 155612])	MO0106STRATHFM.015 [DIRS 155574]
Geologic map and Cross Sections a and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]

Table A-19. Input Data for Lower Clastic Confining Unit (Unit 3 LCCU)

Data Description	Data Tracking Number
Cross Section b from USGS (1984 [DIRS 101305])	MO0106STRATHFM.021 [DIRS 155582]
Cross Sections BS1, BS2, BS9, CR4 and CR5 from NTS ERP DTN: GS000400002332.002 [DIRS 149021]	MO0106STRATHFM.024 [DIRS 155585]
Cross Sections a, b, i, and j from Moench (1965 [DIRS 155613])	MO0106STRATHFM.023 [DIRS 155584]
Geologic map and Cross Sections a, b, c, and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]

Table A-20. Input Data for Granitic Confining Unit (Unit 2 Granites)

Data Description	Data Tracking Number
Cross Sections a, c, and d in Potter et al. (2002 [DIRS 160060])	GS010908314221.001 [DIRS 162874]

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APPENDIX B

QUALIFICATION OF EXTERNAL SOURCES

The justification and qualification of two data sets for intended use in this document is presented in this appendix. The first data set (DTN MO09901MWDGFM31.000) is the GFM that was superceded by the next generation of the GFM. The superceded DTN is justified for intended use in this document by following guidance in Section 5.2.1 l) of AP-SIII.10Q, Models. The justification is presented in Section B.1.

The second data source provided unqualified data that have been used as direct input to this document. The inputs from this source are qualified in this appendix for intended use within the document using the criteria found in AP-SIII.10Q, Models, and AP-SIII.2Q, *Qualification of Unqualified Data*. The following information is provided for the source data: the full reference citation, a description of the data that were used from the source, and the extent to which the data demonstrate the properties of interest. An independent evaluation was undertaken that documented that an acceptable methodology was used, that confidence in the results is warranted, and that the data have been used in similar applications. The qualification of these data is presented in Section B.2.

B1. GEOLOGIC FRAMEWORK MODEL 3.1

Reference– DTN: MO9901MWDGFM31.000 [DIRS 103769]

If the document and the product output have been superseded, procedure AP-SIII.10Q Section 5.2.1 l) provides the requirements necessary to justify the use of the data in this document. The justification requires that the reason for specific supersession must be considered. In addition, one or more of the following criteria must be addressed:

- Reliability of data source
- Qualifications of personnel or organizations generating the data
- Prior uses of the data
- Availability of corroborating data.

The criteria described above meet the requirements of AP-SIII.10Q and are provided as justification that the data that have been used from these sources are considered to be qualified for intended use.

Reason for Supersession–This product (GFM 3.1 DTN: MO9901MWDGFM31.000 [DIRS 103769]) was superceded by GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]) due to response to review comments. Revisions to the model are minor and are primarily in outlying areas. Changes between GFM 3.1 and GFM2000 include; changes in isochore grids for some units concerning the Crater Flat Group, Topopah Spring tuff, thickness of model unit "RHHHtop" and grid flexure at extreme north edge, Ghost Dance fault was modified at depth, improvements in fault displacements, an added fault between Fortymile and Paintbrush Canyon Faults, and the incorporation of additional borehole data. See report for full details, GFM2000 (BSC 2004 [DIRS 170029], Section 6.3.4).

Description of Use–Within the immediate repository area (Figure 4-1), the site GFM 3.1 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 (Table 6-3). For these units, the GFM is effectively embedded within the HFM in a relatively small area located immediately around the repository. Faults are defined separately in the HFM and are represented over the full site-scale domain.

Justification of Use–The changes to GFM2000 improve the accuracy and location of units, especially in the area of the Crater Flat group, but do not change their definition in any significant way. The model report for GFM2000 (BSC 2000 [DIRS 170029], Section 6.3.4) describes the impact of these changes on SZ models, stating that "For SZ models that use the entire GFM area, the changes would have minor impact because of the lower spatial resolution of those models and the lack of subsurface data in the affected areas."

Updates to HFM-27, using newly developed hydrogeologic data and GFM2000, significantly reduce the grid effects seen in the HFM-19, specifically in the Crater Flat Group. The report summarizes that current revisions of the GFM and HFM resolve major differences in the thickness of the hydrogeologic units in the northwest corner of the GFM model domain. The report further notes that the HFM and GFM are different model interpretations of the Yucca Mountain area and have different intended applications within performance assessment. Therefore, these discontinuities do not affect the applicability of the HFM-19 in providing an appropriate hydrogeologic framework for the site-scale SZ flow model, and indicate that as data availability increases and input models evolve, any benefits will propagate through the HFM-19 and thus the flow and transport models. Additional discussion of the grid discontinuity is given in Appendix C

Changes to units used in the HFM-19 and the effect of the resulting representation in the flow model are discussed in Section 6.4. Alternate representations of units and their displacements due to faults, may be hydrologically significant in controlling groundwater flow and recharge in the flow model domain. However, the changes in the GFM 3.1 are too minor in respect to the full HFM-19 to show any obvious impact on the flow model. Additionally, allowance for the potential effects of features and faults are incorporated into the flow model with explicitly defined zones. These zone definitions are discussed in detail in *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037], Section 6.5.3).

Reliability of Data Source–As stated in the Technical Information form in this DTN, the GFM 3.1 is still valid, 12/18/2002, and requires no verification. Qualification work is a result of work reported in Wilson (2001[DIRS 155614]). The supersession does not reduce the adequacy of GFM 3.1 and its use in HFM-19.

B2. REGIONAL GEOPHYSICAL LINES 2 AND 3

Reference: *Hybrid-Source Seismic Reflection Profiling Across Yucca Mountain, Nevada: Regional Lines 2 and 3* (Brocher et al. 1996 [DIRS 101495], Figures 16 and 17).

Description of Use–The Brocher et al. interpretations of seismic line migration depth sections provide the stratigraphy to depths of 1000s of meters below sea level. The two cross sections (Brocher et al. 1996 [DIRS 101495], Figures 16 and 17) and the single available borehole, UE-25 #p1, provide depth information for the Paleozoic carbonate surface (top of Lower Carbonate Aquifer) in an east-west section across the southern end of the Yucca Mountain

Repository. Note that Figure 6-6o shows how little data were available near the repository, the primary source for information here are the geophysical data. Little data are available to check that this representation is correct, but one borehole used in the GFM corroborated the location of this unit in the HFM (Wilson 2001 [DIRS 155614], p 66).

The two cross sections were digitized to provide control on the top of the Paleozoic carbonate aquifer. These two digitized cross sections were processed as were the other cross sections used in the analysis (Faunt 2002 [DIRS 171453], p 129).

Extent to which the Data Demonstrate the Properties of Interest–At the time of building this model, data to define units in the deep units such as the Paleozoic rocks were sparse and little was approved for use. Cross sections were used as data sources, but are interpretive for the carbonate aquifer and other units at depth. These deep seismic cross-sections provide the data needed to construct the top of the Paleozoic units across the Yucca Mountain site.

Data Collection and Interpretation Methodology–Brocher et al (1998 [DIRS 100022], p 952) provide the following summary of the data acquisition and processing:

> Brocher et al. (1996) described the acquisition and processing of the seismic reflection lines. Sources used to image the crust to a depth of about 24 km (two-way travel time of 8 s) included vibrator, Poulter (air blast) sources, and small shothole (minihole) pattern. Environmental, operational, and topographic limitations required using different sources; nonetheless, vibrator sources were used for nearly 80% of the survey. In addition, large (45 kg) shotholes every 2 km were used to attempt to image the crust down to the Moho. All sources were recorded using a 480-channel receiver array. Spectra of the data indicate that the vibrator sources primarily produced useful data between 11 and 35 Hz. Poulter sources produced slightly lower frequency data, on average between 3 and 30 Hz.
>
> A standard processing sequence for the seismic lines ended with poststack migration. Prior to merging the data derived from different seismic sources, a compensation filter was applied to the vibrator source data to transform its source signature from its initial zero phase wavelet into a minimum phase wavelet. Following this phase compensation, both the vibrator and explosion source data were deconvoluted using the same deconvolution operator. Stacking velocities picked continuously along the profile varied smoothly in time and distance along the profile. Velocities needed to convert the section to depth and for poststack migration were calculated from the stacking velocities. Reflector depths obtained using these velocity functions are comparable to those obtained using refraction velocities from a coincident seismic refraction line.

The methodology for data collection and processing was subjected to external peer review as part of the journal publication process and found to be acceptable.

Reliability of Data Source–The geophysical data were collected by the USGS geologic division and were among the few accepted data available at depth (Figure 6-6o). The work of Brocher et al (1996 [DIRS 101495]) was later published in the Bulletin of the Geological Society of America (Brocher et al 1998 [DIRS 100022]). This later publication is cited in *Geologic Framework Model (GFM2000)* (BSC 2004 [DIRS 170029]) as a source for assessing the style of faults in the Yucca Mountain region. It is also cited in report *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Section 6.4.1 and Figure 6-6). In both cases, the work of Brocher at al (1998 [DIRS 100022]) is used as corroborating data supporting conclusions regarding the nature and depth of faulting. The work documented in Brocher et al (1996 [DIRS 101495] and 1998 [DIRS 100022]) has been cited in other project documents and is generally considered to be reliable. Since measured geophysical data are generally accepted, and the location of the Lower Carbonate is uncertain because of the scarcity of drill hole data, using these data for this purpose is appropriate and generally effective.

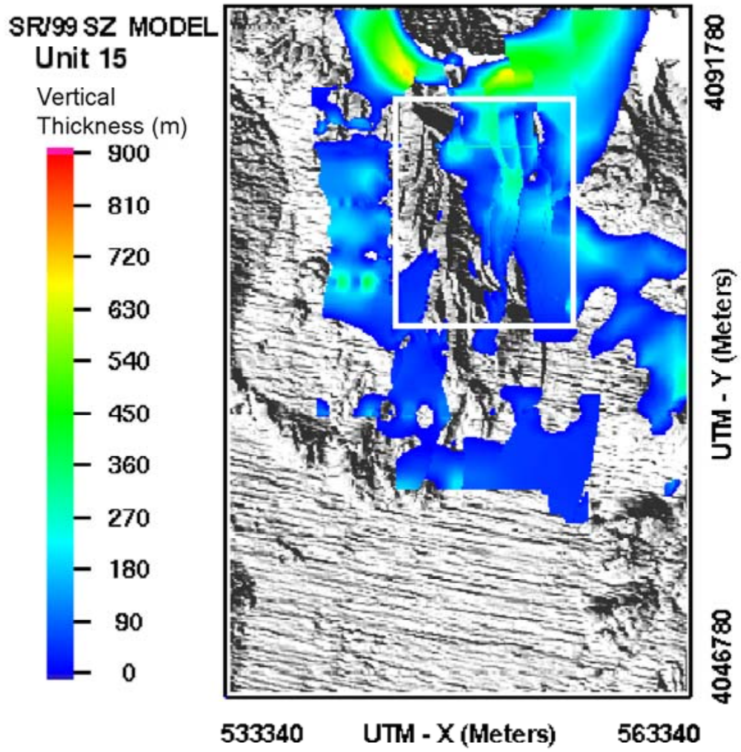
Summary–The seismic cross sections in Brocher et al. (1996 [DIRS 101495], Figures 16 and 17) are shown to have been collected and analyzed by accepted methods. The interpretation of the data were later published in the peer-reviewed literature (Brocher et al., 1998 [DIRS 100022]) and cited by several other project reports. The seismic cross sections are considered qualified for intended use within this document.

APPENDIX C

DISCUSSION OF DISCONTINUITIES BETWEEN THE HYDROGEOLOGIC FRAMEWORK MODEL AND GEOLOGIC FRAMEWORK MODEL

This appendix section presents maps showing vertical thicknesses (Figures C-1 through C-5) used to identify apparent discontinuities in unit thickness that occur as a result of differences between the GFM and HFM. The differences in the GFM and HFM are the result of the gridding techniques used to create the units in each of the models. The gridding of the GFM did not use data outside the GFM boundary; hence, extrapolation to the boundary differed from the HFM, which used data on both sides of the GFM boundary. Discontinuities occur near the northwestern boundary of the GFM and are nearly parallel to the boundary of the GFM. In Figures C-1 through C-3, 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 C-4).

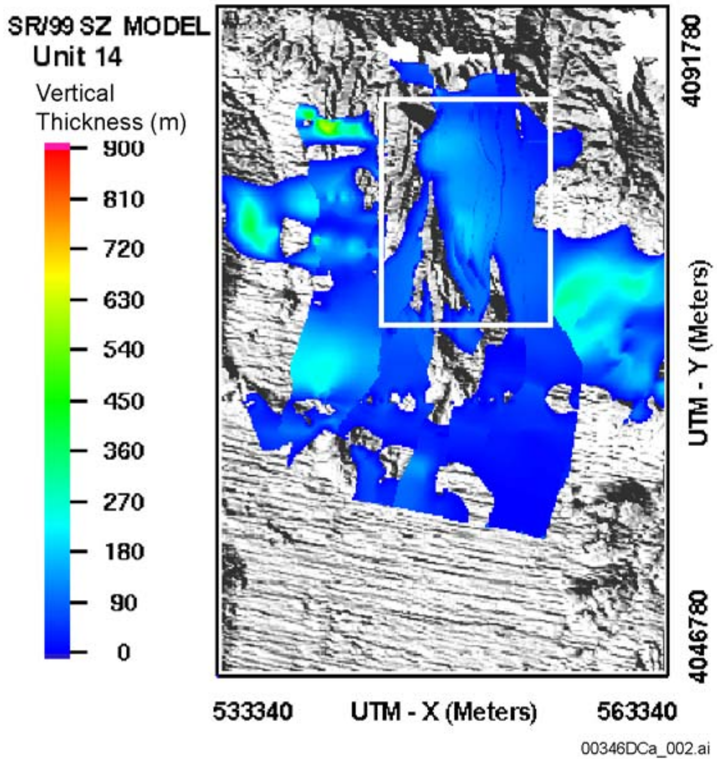
In the Tram Tuff, a large discontinuity was identified in the northwest corner of the GFM area. In this area, the Tram Tuff pinches out to zero thickness in the GFM, but it becomes thicker in the HFM. This can be seen in Figure C-4 as an abrupt change in color (straight, north-south line in northwest 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 meters and the GFM shows a thickness of about 350 meters. The impact of the discontinuity on the groundwater flow away from the repository occurs west of the Solitario Canyon Fault in the region of the Large Hydraulic Gradient. Both features limit the impact on flow in the vicinity of the repository. This apparent discontinuity was identified (Wilson 2001 [DIRS 155614]), 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-27 (DTN: GS021008312332.002 [DIRS 164363]), is consistent with data from boreholes and is consistent with the current version of the GFM, GFM 2000 (BSC 2004 [DIRS 170029]). The smooth transition enhances the applicability of the HFM-27 in providing a hydrogeologic framework for the site-scale flow model. Figures C-4 and C-5 show the thickness of the Tram Tuff unit. HFM-27 (Figure C-5) shows a smooth transition from the GFM-defined thickness to the area outside of the GFM. In general, HFM-27 shows fewer anomalies (e.g., trenches and peaks). These features normally do not show up in 500-meter computational grids, but they are addressed and resolved in HFM-27 to create a smoother surface.



Output DTN: GS030208312332.001.

NOTES: 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 TSPA Site Recommendation HFM model (HFM-19). UTM-X =UTM-Easting and UTM-Y =UTM-Northing.

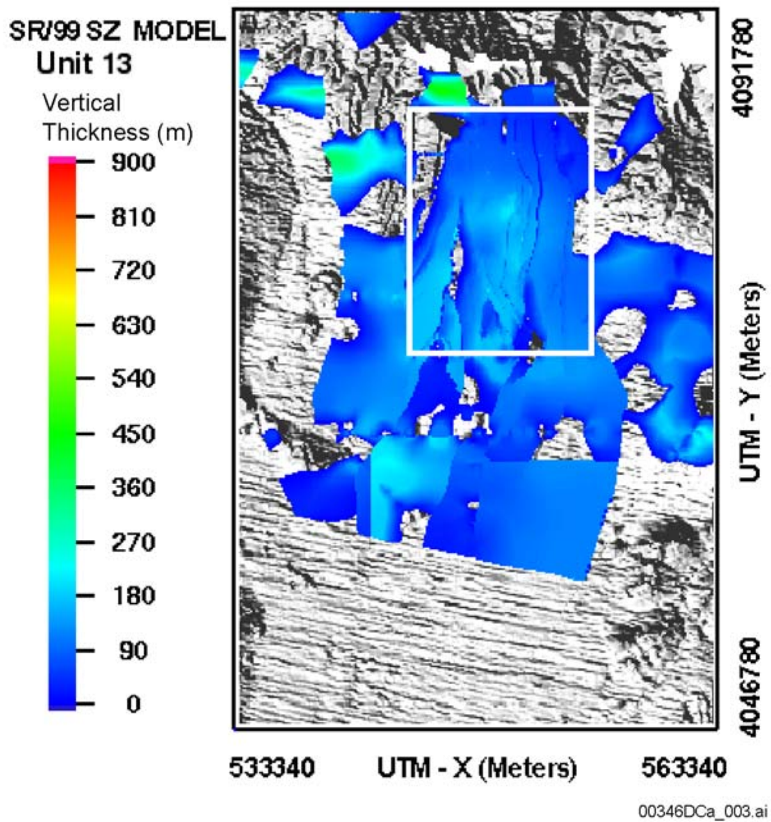
Figure C-1. Vertical Thickness of the Upper Volcanic Unit in the HFM-19



Output DTN: GS030208312332.001.

NOTES: 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 TSPA Site Recommendation HFM model (HFM-19). UTM-X =UTM-Easting and UTM-Y =UTM-Northing.

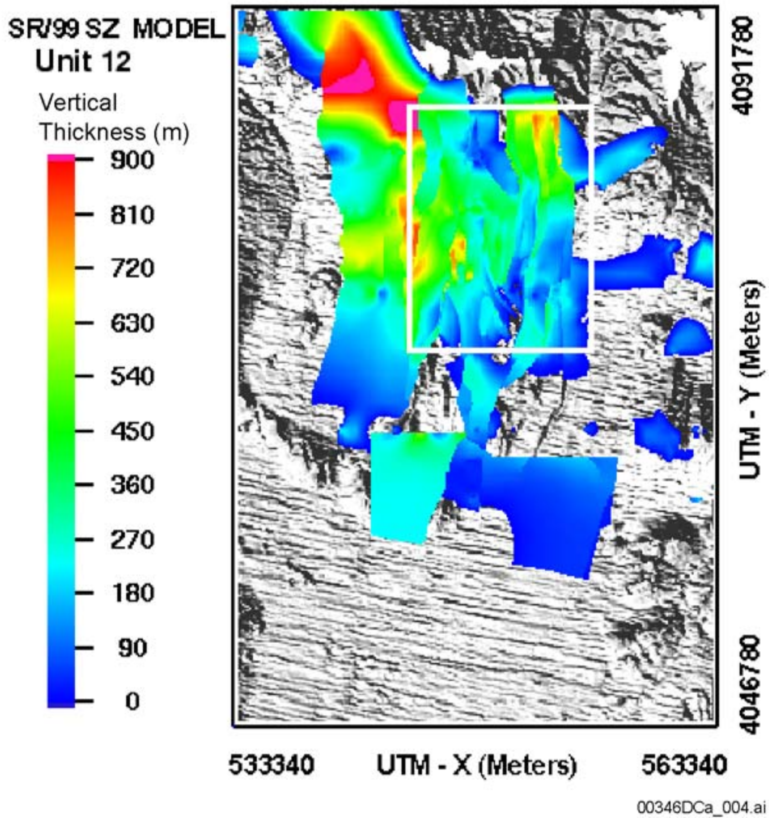
Figure C-2. Vertical Thickness of the Prow Pass Unit in the HFM-19



Output DTN: GS030208312332.001.

NOTES: 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 TSPA Site Recommendation HFM model (HFM-19). UTM-X =UTM-Easting and UTM-Y =UTM-Northing.

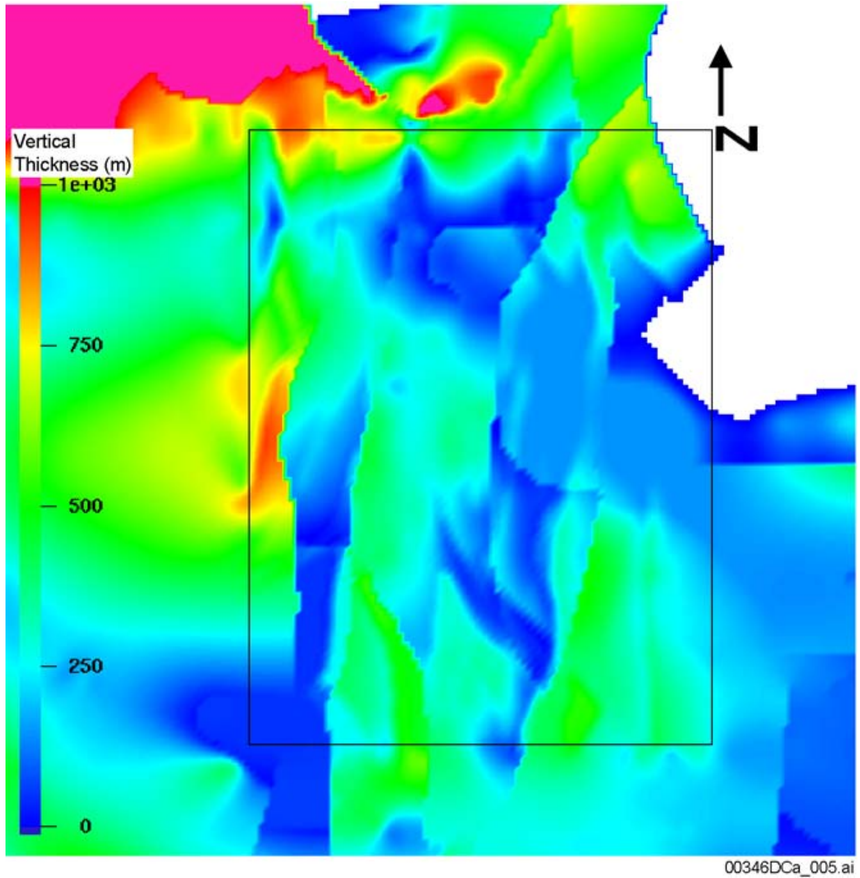
Figure C-3. Vertical Thickness of the Bullfrog Unit in the HFM-19



Output DTN: GS030208312332.001.

NOTES: 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 TSPA Site Recommendation HFM model (HFM-19). UTM-X =UTM-Easting and UTM-Y =UTM-Northing.

Figure C-4. Vertical Thickness of the Tram Unit in the HFM-19



Source: DTN: GS021008312332.002 [DIRS 164363].

NOTES: The black rectangular box shows the GFM area with lower left coordinates of 544067 meters UTM Easting, 4070099 meters UTM Northing and upper right coordinates of 555341 meters UTM Easting, 4085070 meters UTM Northing. White gaps appear where the hydrogeologic unit is pinched out to zero thickness by other units or is truncated by the water table surface.

UTM = Universal Transverse Mercator

Figure C-5. Vertical Thickness of the Bullfrog Unit in HFM-27