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MDL-NBS-HS-000024 REV 01

March 2007

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

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Sandia National Laboratories

Model Signature Page/Change History

Complete only applicable items.

1. Total Pages: 126

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.):

MDL-NBS-HS-000024 REV 01

	Printed Name	Signature	Date
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11. Remarks

Change History

12. Revision No.	13. 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 5.8f)1) per LP-SIII.10Q-BSC.
REV 01	This major change updates the base-case hydrogeologic framework model (HFM) with Nye County Early Warning Drilling Program (EWDP) data through Phase IV and information from the recent USGS update to the Death Valley regional groundwater flow model (Belcher 2004 [DIRS 173179]). The entire model documentation was revised. Changes were too extensive to show changes with change bars.

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FIGURES

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TABLES

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ACRONYMS

AVS	Advanced Visual Systems
CFR	Code of Federal Regulations
DEM	digital elevation model
DTN	data tracking number
DVRGWFS	Death Valley regional groundwater flow system
ERP	Environmental Restoration Program
EWDP	Early Warning Drilling Program
FEPs	features, events, and processes
GFM	geologic framework model
HFM	hydrogeologic framework model
masl	meters above sea level
NAD27	North American Datum of 1927
NTS	Nevada Test Site
NWIS	National Water Information System
SZ	saturated zone
TDMS	Technical Data Management System
TSPA	total system performance assessment
TSPA-LA	total system performance assessment for the license application
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

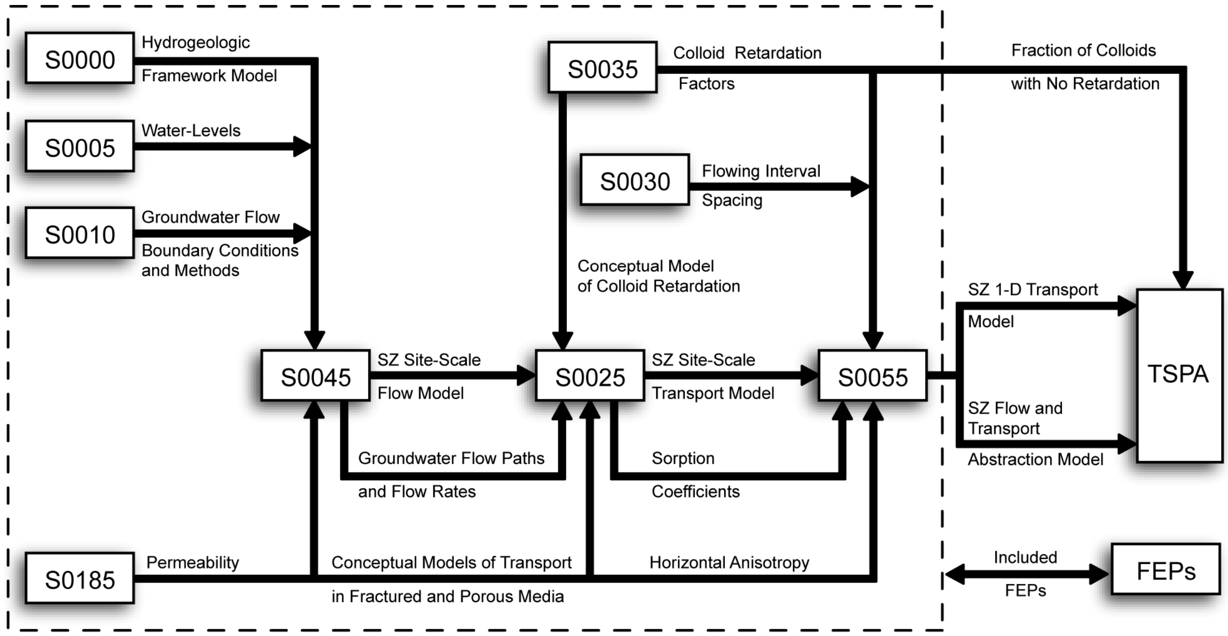
The purpose of this report is to document the hydrogeologic framework model (HFM) developed to support saturated zone flow and transport modeling, in accordance with SCI-PRO-006, *Models*. This revision documents HFM2006 (DTN: MO0610MWDHFM06.002), which updates the base-case HFM by incorporating Nye County Early Warning Drilling Program (EWDP) data through Phase IV. Most of that data has been made available since the completion of the previous version of this report and *Death Valley Regional Ground-Water Flow System, Nevada and California - Hydrogeologic Framework and Transient Ground-Water Flow Model* (Belcher 2004 [DIRS 173179]), hereafter referred to as the DVRGWFS HFM, which was also not available at the time of the completion of Revision 00. The revised report output of HFM2006 will be used in an update to *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]) to update the base-case site-scale saturated zone (SZ) flow model, which simulates groundwater flow directions and fluxes of water from the repository to the regulatory boundary.

This revision of the report includes analysis of new data from Nye County boreholes through Phase IV to determine hydrostratigraphic relationships in the groundwater system, especially the distribution of Tertiary age units south of the Yucca Mountain repository near U.S. Highway 95. The revision includes comparisons of the updated base-case model, HFM2006, with HFM-19, the historical base-case model, and HFM-27, the historical alternative model. This revision will also evaluate the updated HFM2006 to determine if the previous response to the key technical issue (KTI) regarding hydrogeologic cross sections is valid (Williams 2003 [DIRS 170977]).

HFM2006 is developed as a conceptual model of the spatial distribution of the hydrogeologic units at Yucca Mountain and is intended specifically for use in the development of an update to *Saturated Zone Site-Scale Flow Model* (BSC 2004 [DIRS 170037]). HFM2006 is a three-dimensional representation of the hydrogeologic units surrounding the location of the Yucca Mountain geologic repository for spent nuclear fuel and high-level radioactive waste. Figure 1-1 shows the information flow among all of the SZ reports and the relationship of this conceptual model in that flow.

This model report is consistent with the definition of a conceptual model found in SCI-PRO-006, Attachment 1:

> ***Model, Conceptual***—A set of hypotheses consisting of assumptions, simplifications, and idealizations that describes the essential aspects of a system, process, or phenomenon… Such a model may consist of concepts related to geometrical elements of the object (size or shape); dimensionality (one-, two-, or three-dimensional); 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.



Legend

S0000	- Hydrogeologic Framework Model	MDL-NBS-HS-000024
S0005	- Water-Level Data Analysis	ANL-NBS-HS-000034
S0010	- Recharge and Lateral Groundwater Flow Boundary Conditions	ANL-NBS-MD-000010
S0025	- Site-Scale Saturated Zone Transport	MDL-NBS-HS-000010
S0030	- Probability Distribution for Flowing Interval Spacing	ANL-NBS-MD-000003
S0035	- Saturated Zone Colloid Transport	ANL-NBS-HS-000031
S0045	- Site-Scale Saturated Zone Flow Model	MDL-NBS-HS-000011
S0055	- Saturated Zone Flow and Transport Model Abstraction	MDL-NBS-HS-000021
FEPs	- Features, Events, and Processes in SZ Flow and Transport	DTN: MO0508SEPFEPLA.002
S0185	- Saturated Zone In-Situ Testing	ANL-NBS-HS-000039

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NOTES: This figure is a simplified representation of the flow of information among saturated zone reports. Refer to the Document Input Reference System record for each report for a complete listing of data and parameter inputs. This figure does not show inputs external to this suite of saturated zone reports.

1-D = one-dimensional.

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

Parameters used in the other technical products include permeability, porosity, flowing interval spacing, distribution coefficients, and many others. HFM2006 does not generate any of these parameter values. Rather, it provides a static three-dimensional, simplified conceptual model with geometric elements that represent the location of differentiated hydrogeologic units in the site-scale SZ model domain. The hydrogeologic framework model 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 site-scale SZ flow model calibration. 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.

HFM2006 is a conceptual model that provides a static representation of the geometry internal to the volume encompassed by the three-dimensional model domain of the site-scale SZ flow and transport models for the Yucca Mountain site. The HFM2006 represents the hydrogeologic setting for the Yucca Mountain area that covers about 1,350 km^2 with a thickness of about 6 km. The boundaries of the conceptual model (shown in Figure 1-2) were chosen to be coincident with grid cells in the current DVRGWFS HFM (Belcher 2004 [DIRS 173179]) and very nearly identical to historical models, HFM-19 and HFM-27. The base of the site-scale model, HFM2006, is consistent with the base of the regional model, DVRGWFS HFM (Belcher 2004 [DIRS 173179]), at −4,000 m elevation. HFM2006 provides a framework over the area of interest for groundwater flow and radionuclide transport modeling.

The HFM2006 grid consists of a rectangular array of nodes with a horizontal spacing of 125 m discussed in Sections 6.3.2, 6.4.3, and 6.4.4. This selection simplifies the available data near the repository and extrapolates from relatively widely spaced data in other areas of the model domain. HFM2006 is assembled by using geometric gridding techniques and software (described in Sections 3, 6.3.1, and 6.3.2) to fill the domain area with three-dimensional elements corresponding to the hydrogeologic units of interest. HFM2006 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 6.4.3 and confidence building for the model is discussed in Section 7.

Use of the HFM2006 is limited by considerations of spatial resolution, hydrogeologic unit definitions, and data density. The HFM2006 is constructed with a 125 m horizontal spacing and is incapable of resolving geological features at spatial scales smaller than this resolution. The hydrogeologic units used in the model were defined for the specific purpose of simulating groundwater flow and radionuclide transport at the scale of the site-scale SZ flow model. These hydrogeologic unit definitions may not be appropriate for other modeling activities. Finally, the density of data is sparse in some regions of the HFM2006 domain and the resulting large uncertainties in those areas may limit the application of HFM2006 for other applications.

This revision of the report supersedes *Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model* (BSC 2004 [DIRS 170008]), and documents the activities in accordance with *Technical Work Plan for: Saturated Zone Flow and Transport Modeling* (BSC 2006 [DIRS 177375], Section 2.1.1). Revision 00 was developed in accordance with the technical work plan (TWP) in effect at the time (BSC 2004 [DIRS 171421], Section 2.1.1.1). Revision 00 activities included regulatory, technical integration, and data compliance issues in order to address Regulatory Integration Team evaluation comments.

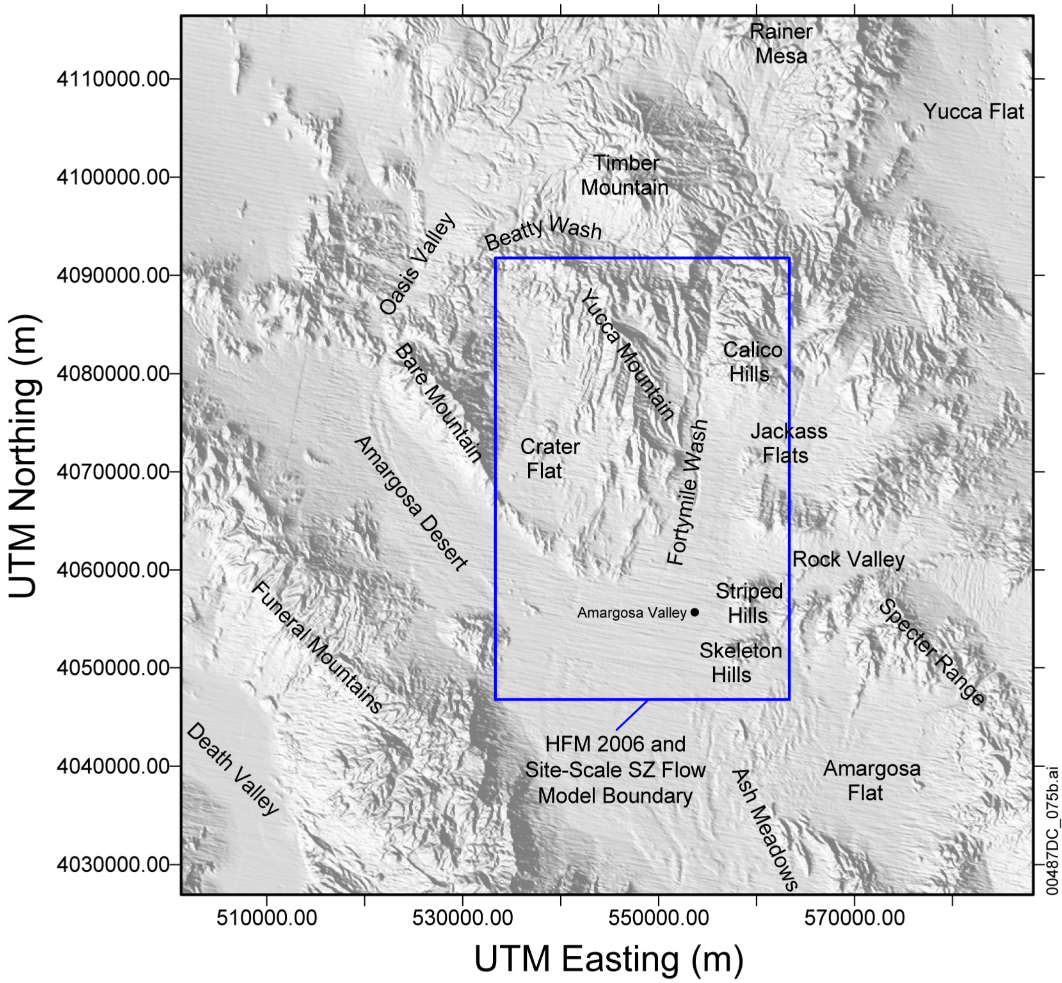
Activities documented in this revision of the report can be summarized as:

- Develop the updated HFM2006 using new information from the Nye County EWDP borehole data through Phase IV and the recent U.S. Geological Survey (USGS) update to the DVRGWFS HFM (Belcher 2004 [DIRS 173179]).

- Qualify all direct input data to HFM2006 for intended use in the model, as needed.

- Revise documentation in this report to present HFM-19 and HFM-27 in summary form as historical models, and to present HFM2006 as the updated base-case model.

- Submit data containing output files of the updated HFM2006 to the Technical Data Management System (TDMS), for utilization by the site-scale SZ flow model.



Source: DTN: GS010908314221.001 [DIRS 162874].

NOTES: The rectangular boundary labeled "Site-Scale SZ Flow Model Boundary" is the domain boundary of HFM2006 and the site-scale SZ flow and transport models.

Coordinates in Universal Transverse Mercator (UTM), Zone 11, North American Datum of 1927 (NAD27), meters.

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

2. QUALITY ASSURANCE

Development of this report and the supporting modeling activities is subject to the Yucca Mountain Project (YMP) Quality Assurance Program, as indicated in *Technical Work Plan for: Saturated Zone Flow and Transport Modeling* (BSC 2006 [DIRS 177375], Section 8.1). Approved quality assurance procedures identified in the TWP (BSC 2006 [DIRS 177375], Section 4) have been used to conduct and document the activities described in this revision. The TWP also identifies the methods used to control the electronic management of data (BSC 2006 [DIRS 177375], Section 8.4).

Planning and preparation of this report was initiated under the BSC QA Program. Therefore, forms and associated documentation prepared prior to October 2, 2006, the date this work transitioned to the Lead Laboratory, were completed in accordance with BSC procedures. Forms and associated documentation completed on or after October 2, 2006 were prepared in accordance with Lead Laboratory procedures.

This 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 [DIRS 176544]. Therefore, it is classified in *Q-List* (BSC 2005 [DIRS 175539]) as “SC” (Safety Category), reflecting its importance to waste isolation. 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.

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3. USE OF SOFTWARE

The development of the HFM from input data to a three-dimensional spatial distribution representing these data uses software designed specifically for use in visualizing data for subsurface geology. Qualified software code (IM-PRO-003, *Software Management*) obtained from Software Configuration Management and used to support model development is shown in Table 3-1. This software code was considered appropriate for the application, and was used only within the range of validation.

3.1 QUALIFIED SOFTWARE

HFM2006 was constructed primarily using EarthVision 5.1 (EARTHVISION V.5.1 [DIRS 167994], STN: 10174-5.1-000) on a Silicon Graphics Octane workstation running IRIX 6.5. EarthVision is a product of Dynamic Graphics, Inc. and is designed for the preparation of three-dimensional geologic models. The use of EarthVision to prepare HFM2006 is described in Sections 6.3.1 and 6.3.2 and is consistent with the intended use of the software. There are no limitations on the use of HFM2006 due to the use of EarthVision.

EarthVision 5.1 can create regularly spaced grids from data representing irregularly spaced data points to create surfaces that represent the top of specific hydrogeological units or the saturated zone. Up to 10,000,000 data points can be gridded to produce a grid with dimensions up to 1,201 by 1,201 (*GS_EV_5_0.pdf*, pp. 22 and 24). Each of the surfaces constructed for HFM2006 were within the range of these limits.

Coordinate conversions for the Nye County boreholes from State Plane coordinates, Central Zone, NAD27, with units of feet to UTM, Zone 11, NAD27, with units of meters were completed using Corpscon 5.11.08 (CORPSCON V.5.11.08 [DIRS 155082], STN: 10547-5.11.08-00). Corpscon is software which allows the user to convert coordinates between Geographic, State Plane and Universal Transverse Mercator systems on the North American Datum of 1927, and 1983 produced by the Geospatial Applications Branch, Topographic Engineering Center, U.S. Army Engineer Research and Development Center. Corpscon is limited to working within the Continental US, Alaska, Hawaii, Virgin Islands, and Puerto Rico. The conversions completed for the construction of the HFM2006 were consistent with the software's intended use and within the limits described.

Table 3-1. Software Used to Support Model Development

Software Name and Version	Software Tracking Number	Computer Platform, Operating System	Description
EarthVision 5.1	STN: 10174-5.1-00 [DIRS 167994]	Silicon Graphics Octane workstation running IRIX 6.5	This software was used for gridding, contouring, plotting, and visualization of the data and for evaluation of results
Corpscon 5.11.08	STN: 10547-5.11.08-00 [DIRS 155082]	PC running Windows NT 4.0	This software was used for coordinate conversions

3.2 EXEMPT SOFTWARE

Several additional, exempt (IM-PRO-003), commercially available software packages were used for data handling, formatting, and data visualization in the preparation of HFM2006. These additional software packages are Microsoft Access (97 and 2000), Microsoft Excel (97 and 2000), AutoCad (2002), EarthVision (7.5.2), and UltraEdit-32 (11.10) by IDM Computer Solutions, Inc. Each of these additional software packages was used on the Windows 2000 platform. No calculations were performed by these commercial software packages and the only output is in the form of visualizations, such as those found in Figures 6-4 through 6-7 and Appendix C. Input files or sources are identified with each figure. AutoCad and EarthVision 7.5.2 were used for data visualization and are therefore exempt under Section 2.0, 5th paragraph, 2nd dash of IM-PRO-003. Access, Excel, and UltraEdit-32 were used for formatting data and were exempt under Section 2.0, 5th paragraph, 1st dash of IM-PRO-003. Each of these exempt software packages is controlled by YMP Software Configuration Management.

4. INPUTS

4.1 DIRECT INPUT

Direct input to HFM2006 consists of regional hydrogeologic framework model surfaces and supporting borehole coordinates and lithostratigraphic interpretations; site-scale geologic framework model (GFM2000) surfaces; and lithostratigraphic interpretations and coordinates for the Nye County EWDP boreholes through Phase IV. The direct inputs used to develop HFM2006 are listed in Table 4-1, and described and/or qualified below. Data are qualified for use within this model in Sections 4.1.1 (DTN: MO0602SPAMODAR.000 [DIRS 177371]), 4.1.2 (DTN: MO0507SPAINHFM.000 [DIRS 174523]), and 4.1.5 (DTN: GS020108314211.001 [DIRS 174112]).

Each of the inputs listed in Table 4-1 is appropriate to be used as direct input to the site-scale SZ hydrogeologic framework model (HFM2006) based on the following discussion. The regional surfaces and two of the lithostratigraphic borehole interpretations are qualified for their intended purpose within HFM2006 in this section. None of the data used to develop the model are used to validate the model. This study does not revise or change any previously developed models. Information from the previously developed and validated GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]) is used as direct input to construct HFM2006.

Table 4-1. Direct Input

Description	Direct Input
27 DVRGWFS Hydrogeologic Framework Model unit grids named unit_modt.asc where 'unit' corresponds to each of the 27 regional hydrogeologic framework model units	DTN: MO0602SPAMODAR.000 [DIRS 177371] (qualified for intended use in Section 4.1.1)
Geologic Framework Model (GFM2000) grids for the CFTA (Tctlv), CFBCU (Tcblv), CFPPA (Tcplv), CHVU (Tac), and PVA (Tpbt2) Hydrogeologic units	DTN: MO0012MWDGFM02.002 [DIRS 153777]
40 borehole contacts outside of the GFM domain	DTN: MO0507SPAINHFM.000 [DIRS 174523] (qualified for intended use in Section 4.1.2)
Lithostratigraphy in NC-EWDP-01DX	DTN: GS000808314211.005 [DIRS 154685]
Lithostratigraphy in NC-EWDP-2DB	DTN: GS011008314211.001 [DIRS 158690]
Lithostratigraphy in NC-EWDP-03D	DTN: GS000808314211.005 [DIRS 154685]
Lithostratigraphy in NC-EWDP-7SC	DTN: GS020108314211.001 [DIRS 174112] (qualified for use in Section 4.1.5)
Lithostratigraphy in NC-EWDP-09SX	DTN: GS000808314211.005 [DIRS 154685]
Lithostratigraphy in NC-EWDP-10SA	DTN: GS030108314211.001 [DIRS 163483]
Lithostratigraphy in NC-EWDP-15D	DTN: GS020108314211.001 [DIRS 174112] (qualified for use in Section 4.1.5)
Lithostratigraphy in NC-EWDP-16P	DTN: GS031108314211.004 [DIRS 174113]
Lithostratigraphy in NC-EWDP-18P	DTN: GS030108314211.001 [DIRS 163483]

Table 4-1. Direct Input (Continued)

Description	Direct Input
Lithostratigraphy in NC-EWDP-19D1	DTN: GS011008314211.001 [DIRS 158690]
Lithostratigraphy in NC-EWDP-22SA	DTN: GS030108314211.001 [DIRS 163483]
Lithostratigraphy in NC-EWDP-23P	DTN: GS030108314211.001 [DIRS 163483]
Lithostratigraphy in NC-EWDP-24P	DTN: GS040908314211.001 [DIRS 174114]
Lithostratigraphy in NC-EWDP-27P	DTN: GS031108314211.004 [DIRS 174113]
Lithostratigraphy in NC-EWDP-28P	DTN: GS031108314211.004 [DIRS 174113]
Lithostratigraphy in NC-EWDP-29P	DTN: GS040908314211.001 [DIRS 174114]
Coordinates for NC-EWDP-01DX	DTN: MO0103GSC01040.000 [DIRS 174110]
Coordinates for NC-EWDP-2DB	DTN: MO0106GSC01043.000 [DIRS 168374]
Coordinates for NC-EWDP-03D	DTN: MO0103GSC01040.000 [DIRS 174110]
Coordinates for NC-EWDP-7SC	DTN: MO0206GSC02074.000 [DIRS 168378]
Coordinates for NC-EWDP-7SC	DTN: MO0106GSC01043.000 [DIRS 168374]
Coordinates for NC-EWDP-09SX	DTN: MO0103GSC01040.000 [DIRS 174110]
Coordinates for NC-EWDP-10SA	DTN: MO0206GSC02074.000 [DIRS 168378]
Coordinates for NC-EWDP-15D	DTN: MO0106GSC01043.000 [DIRS 168374]
Coordinates for NC-EWDP-16P	DTN: MO0307GSC03094.000 [DIRS 170556]
Coordinates for NC-EWDP-18P	DTN: MO0203GSC02034.000 [DIRS 168375]
Coordinates for NC-EWDP-19D	DTN: MO0106GSC01043.000 [DIRS 168374]
Coordinates for NC-EWDP-22SA	DTN: MO0206GSC02074.000 [DIRS 168378]
Coordinates for NC-EWDP-23P	DTN: MO0206GSC02074.000 [DIRS 168378]
Coordinates for NC-EWDP-24P	DTN: MO0312GSC03180.000 [DIRS 174103]
Coordinates for NC-EWDP-27P	DTN: MO0307GSC03094.000 [DIRS 170556]
Coordinates for NC-EWDP-28P	DTN: MO0307GSC03094.000 [DIRS 170556]
Coordinates for NC-EWDP-29P	DTN: MO0312GSC03180.000 [DIRS 174103]

4.1.1 Regional Hydrogeologic Framework Model Unit Surfaces

The most recent regional hydrogeologic framework model to be completed in the Yucca Mountain area is the DVRGWFS HFM (Belcher 2004 [DIRS 173179]). Surfaces representing the tops of the 27 regional hydrogeologic framework model units are included in the unqualified DTN: MO0602SPAMODAR.000 [DIRS 177371], which is made up of the files found in the “model archive” area of the document’s website (http://pubs.usgs.gov/sir/2004/5205/). The surfaces are available as files with the filename *unit_modt.asc*, where “unit” corresponds to each of the 27 regional hydrogeologic framework model units. These surfaces are suitable for direct input into the construction of the corresponding site-scale hydrogeologic framework unit surfaces for HFM2006.

The qualification of these surfaces has been planned in *Technical Work Plan for: Saturated Zone Flow and Transport Modeling* (BSC 2006 [DIRS 177375], Section 1.2.1). These data are considered to be from an outside source because the work was not a deliverable to the YMP and the work was not required to be completed in accordance with YMP procedures. This qualification for use within the product is completed in accordance with SCI-PRO-006, Section 6.2.1.K, and is documented in this section.

The 27 surfaces make up the three-dimensional hydrogeologic framework model constructed to represent the hydrogeologic units and major structures in the DVRGWFS region for the development of the transient numerical groundwater flow model (Belcher 2004 [DIRS 173179], Chapter E). The surfaces were developed from digital elevation models, geologic maps, borehole information, geologic and hydrogeologic cross sections, and other three-dimensional models to represent the geometry of the hydrogeologic units. Structural features such as faults and fractures were also considered. The DVRGWFS HFM represents Precambrian and Paleozoic crystalline and sedimentary rocks, Mesozoic sedimentary rocks, Mesozoic to Cenozoic intrusive rocks, Cenozoic volcanic tuffs and lavas, and late Cenozoic sedimentary deposits (Belcher 2004 [DIRS 173179], p. 1). The construction of the surfaces is documented in Chapter E of the study by Belcher (2004 [DIRS 173179]). Figures E-1 and F-1 of Belcher (2004 [DIRS 173179]) provide the information required to place the surface information from *unit_modt.asc* files in horizontal space. The 27 surfaces cover an area that includes the area of interest for SZ groundwater flow and radionuclide transport modeling for the Yucca Mountain Project. The DVRGWFS surfaces represent the best single source of stratigraphic and structural information for the area surrounding the geologic framework model (GFM2000) area. The DVRGWFS surfaces will be used in combination with GFM2000 surfaces (DTN: MO0012MWDGFM02.002 [DIRS 153777]) and additional borehole data, particularly recent Nye County EWDP data, to produce HFM2006, which represents the stratigraphic and structural relationships of the SZ site-scale flow and transport area. HFM2006 provides the hydrogeologically defined geometry for SZ flow and transport process models, which will be used to assign unit properties to nodes in a mesh for use in SZ site-scale flow and transport models.

The DVRGWFS HFM surfaces in DTN: MO0602SPAMODAR.000 [DIRS 177371] cover the area of interest both vertically and laterally and include all of the hydrogeologic units of interest. The surfaces represent the tops of each of the hydrogeologic units at horizontal grid spacing of 1,500 m. This relatively wide spacing yields surfaces, including the top-most surface, that are relatively smoothed, eliminating the highest points, filling in the lowest points, and softening the "topography" in areas of high relief.

The factors considered in evaluating the suitability of DTN: MO0602SPAMODAR.000 [DIRS 177371] include the reliability of the data source and the qualifications of personnel or organizations generating data. DTN: MO0602SPAMODAR.000 [DIRS 177371] is taken directly from a USGS scientific investigation report (Belcher 2004 [DIRS 173179]). All USGS scientific investigation reports have Bureau Approval (previously referred to as "Director's Approval"), which validates the scientific excellence of the information product. Bureau Approval ensures that all appropriate reviews have been conducted and that the product is consistent with all pertinent USGS and departmental policies. This publication was thoroughly reviewed by experts outside the USGS as well. Claudia Faunt, the first author of Chapter E, earned a Ph.D. in Geological Engineering from the Colorado School of Mines and is currently a hydrologist at the USGS in San Diego, California. She is an expert in the development of hydrogeologic models for groundwater model development using advanced three-dimensional database and visualization methods. Based on the factors considered above, the DVRGWFS regional surfaces, as found in DTN: MO0602SPAMODAR.000 [DIRS 177371], are adequately and appropriately justified for use as direct input to this model report.

4.1.2 Boreholes Supporting DVRGWFS HFM

Files containing the borehole locations of hydrogeologic unit tops used by the USGS to support the construction of the DVRGWFS HFM were submitted to TDMS in the unqualified DTN: MO0507SPAINHFM.000 [DIRS 174523]. Each of the files represents a hydrogeologic unit, but not all units were represented by borehole information. Each of the contacts was examined to assess its contribution to the construction of HFM2006. Those borehole contacts that represent geologic unit tops within the GFM area and correspond to hydrogeologic units of HFM2006 were not specifically included as direct input into HFM2006 because the appropriate borehole contacts are already represented by those GFM surfaces. Nye County EWDP hydrogeologic contacts within the DTN were replaced by (generally) qualified contacts (Sections 4.1.4. and 4.1.5). All other contacts within the files were examined for supporting, corroborating, information. Contacts for which supporting information was available are suitable to be qualified and used as direct input in the construction of HFM2006. All other contacts for which there was no supporting information were not included.

The qualification of these contacts has been planned in *Technical Work Plan for: Saturated Zone Flow and Transport Modeling* (BSC 2006 [DIRS 177375], Section 1.2.1). These data are considered to be from an outside source because the work was not a deliverable to the YMP and the work was not required to be completed in accordance with YMP procedures. This qualification for use within the product is completed in accordance with SCI-PRO-006, Section 6.2.1.K, and is documented in this section. Specifically, corroborating data and qualifications of personnel generating the data, as described in SCI-PRO-001, Attachment 3, Method 2 and part of Method 5(c), are discussed below.

The Death Valley Regional Ground-Water Flow System (DVRGWFS) Hydrogeologic Framework Model (HFM) described in Section 6.3.1.1 included lithologic input from 1,533 boreholes (Belcher 2004 [DIRS 173179], p. 174). The borehole contacts used to make the DVRGWFS HFM grids were submitted to the TDMS and can be found in DTN: MO0507SPAINHFM.000 [DIRS 174523]. The borehole contact data sets used are found in input_data_hfm\wells of DTN: MO0507SPAINHFM.000 [DIRS 174523] where “input_data” represents each of the hydrogeologic units. A total of 2,146 borehole contacts are represented in the wells portion of the DTN. All of the information in these data files is in UTM coordinates, Zone 11, NAD27, with meters as units. All of the borehole contacts were assigned to hydrogeologic framework units and no additional hydrogeologic interpretation was required.

Not all of the borehole contacts in DTN: MO0507SPAINHFM.000 [DIRS 174523] were applicable to the construction of HFM2006. Of the 2,146 borehole contacts, only 371 fell within the HFM2006 domain. These 371 borehole contacts were examined and analyzed for inclusion as hard data in the HFM2006 model. Table B-1 lists these 371 contacts and indicates their role in HFM2006. 272 borehole contacts were within the GFM domain (i.e., already represented in a unit of the GFM2000 that would be included in HFM2006). The construction of GFM2000 assessed all qualified data and produced surfaces representing each geologic unit (Section 4.1.3). No supporting information could be found for 25 borehole contacts; and there is a qualified source of data for the 34 Nye County borehole contacts.

The x, y, and z values of the remaining 40 borehole contacts from the boreholes representing the DVRGWFS HFM (DTN: MO0507SPAINHFM.000 [DIRS 174523]) were compared to x, y, and z values from other sources, mostly qualified. The coordinate values from other sources compare quite closely in most cases to those values from DTN: MO0507SPAINHFM.000 [DIRS 174523]. The coordinate values and sources are provided in Table B-2.

The borehole contacts in DTN: MO0507SPAINHFM.000 [DIRS 174523] and in the cited source in Table 4-1 were either identical or within 1 m horizontally (average 0.06 m) and within 8 m vertically (average 0.12 m). The values shown in Table B-1 are the values used to construct HFM2006. One contact that occurred in two boreholes (out of the 40 contacts described above) was assigned to both the upper and lower Volcanic and Sedimentary unit in DTN: MO0507SPAINHFM.000 [DIRS 174523]. Because there were no hydrogeologic units defined in between these assignments, the values are both included as input to HFM2006 without conflict.

In addition to the very close agreement in corroborating values, the factors considered in evaluating the suitability of DTN: MO0507SPAINHFM.000 [DIRS 174523] include the reliability of the data source and the qualifications of personnel or organizations generating data. DTN: MO0507SPAINHFM.000 [DIRS 174523] is taken directly from the supporting files of a USGS scientific investigation report (Belcher 2004 [DIRS 173179]). All USGS scientific investigation reports have Bureau Approval (previously referred to as "Director's Approval"), which validates the scientific excellence of the information product. Bureau Approval ensures that all appropriate reviews have been conducted and that the product is consistent with all pertinent USGS and Departmental policies. The data supporting this publication was thoroughly reviewed by experts outside the USGS as well. Claudia Faunt, the first author of Chapter E, earned a Ph.D. in Geological Engineering from the Colorado School of Mines and is currently a hydrologist at the USGS in San Diego, California. She is an expert in the development of hydrogeologic models for groundwater model development using advanced three-dimensional database and visualization methods. Based on the factors considered above, the borehole-contact information as found in DTN: MO0507SPAINHFM.000 [DIRS 174523] is adequately and appropriately justified for use as direct input to this model report.

4.1.3 Geologic Framework Model (GFM2000) Unit Surfaces

The geologic framework model (GFM2000) (DTN: MO0012MWDGFM02.002 [DIRS 153777]) represents a three-dimensional interpretation of the geology more immediately surrounding the repository area. The boundaries of the geologic framework model were chosen to encompass the exploratory boreholes and to provide a geologic framework over the area of interest for hydrologic flow and radionuclide transport modeling through the unsaturated zone. The geologic framework model was constructed from geologic map and borehole data, with additional information from measured stratigraphic sections, gravity profiles, and seismic profiles considered. Five geologic units represented by GFM2000 are also represented in the DVRGWFS HFM. For those units common to GFM2000 and the DVRGWFS HFM, the data defining surfaces produced as part of the GFM are used as direct input to HFM2006. The five DVRGWFS HFM units and their equivalent GFM units are: CFTA (Tctlv), CFBCU (Tcblv), CFPPA (Tcplv), CHVU (Tac), and PVA (Tpbt2) (Belcher 2004 [DIRS 173179], Table E-4).

4.1.4 Lithostratigraphic Interpretations for Nye County EWDP Boreholes

The Nye County EWDP through Phase IV has resulted in the drilling of approximately 40 boreholes at 20 locations near and north of highway 95 and south of Yucca Mountain. Interpretations of lithostratigraphy have been completed for at least one borehole, typically the deepest borehole, at 16 of those 20 locations. The lithostratigraphic interpretations for 14 of the borehole locations are qualified and contained in the DTNs shown in Table 4-1. The source of the location information for all 16 boreholes is included in Table 4-1. The lithostratigraphic interpretations and the borehole locations are listed in Table B-3 and are direct input into HFM2006.

4.1.5 Lithostratigraphic Interpretations for NC-EWDP-7SC and NC-EWDP-15D

The qualification of DTN: GS020108314211.001 [DIRS 174112] is documented per SCI-PRO-001, *Qualification of Unqualified Data*, within this section in accordance with the TWP (BSC 2006 [DIRS 177375], Sections 1.2.1 and 2.1.1.2). The data qualification plan for this activity is included as Appendix A. This section qualifies this DTN by providing the desired level of confidence that the data are suited for their intended use of construction HFM2006.

The lithostratigraphic interpretations for boreholes NC-EWDP-7SC and NC-EWDP-15D (DTN: GS020108314211.001 [DIRS 174112]) were completed in the same manner as for the Nye County Boreholes discussed in Section 4.1.4, except that there were no Sample Management Facility (SMF) personnel present when samples were taken during drilling at those two locations. Because no SMF personnel were present when samples were taken, the lithostratigraphic interpretations are not qualified. The samples were collected by persons familiar with SMF and Nye County EWDP sample collection processes. Only a single early step in the custody process is in question. All other examinations and evaluations were completed appropriately and are not suspect.

The data in DTN: GS020108314211.001 [DIRS 174112] consists of 17 lines of information, 10 lines defining lithostratigraphic contacts in borehole NC-EWDP-7SC and seven lines defining lithostratigraphic contacts in borehole NC-EWDP-15D, along with supporting notes and information. This information is summarized within Table B-3.

The method of qualification is Technical Assessment (method 5 defined in SCI-PRO-001, Attachment 3). Technical assessment is appropriate because ‘the procedures used are not adequate’ (i.e. no SMF personnel were on hand when samples were collected). Actions taken include determination of methodology employed and determination that confidence in data is warranted. The qualification process considers attributes 1, 2, 3, 7, and 8, as defined in SCI-PRO-001, Attachment 4.

The criteria to determine the successful completion of this qualification for intended use is the consensus of the qualification team that the results would be the same, within the accuracy stated for the DTN in question, i.e. plus or minus 10 feet if SMF personnel had been present and part of the sample collection team for these two boreholes. This relies largely on understanding how the samples were actually collected and how that differs from what would have happened if SMF personnel had been on site.

For the two boreholes being qualified here, Nye County representatives collected the samples. Samples for NC-EWDP-15D were collected on 4/2/2000 and 4/3/2000. Custody of the samples for NC-EWDP-15D was transmitted to SMF on 4/3/2000 as shown on the Field Container Summary and Transmittal Form (CRWMS M&O 2000 [DIRS 179492]). Samples for NC-EWDP-7SC were collected between 3/12/2000 and 4/15/2000. Custody of the samples for NC-EWDP-7SC was transferred to SMF on 4/17/2000 as shown on the Transfer of Custody Form (Nye County NWRPO 2001 [DIRS 179493]).

Once in the hands of SMF personnel all activities were completed in exactly the same manner as if SMF personnel had been on site while the samples were taken. In other words except that no SMF personnel were on site while samples were taken the methodology employed in the interpretation of lithostratigraphic information in the two NC-EWDP boreholes being qualified was identical to that of other NC-EWDP boreholes listed in Table 4-1. Downhole geophysical methods were employed in addition to a physical examination and description of the cuttings/core. In addition, the data were reviewed by additional USGS team members (USGS 2002 [DIRS 179514], BSC 2001 [DIRS 179517], CRWMS M&O 2001 [DIRS 179510], CRWMS M&O 2001 [DIRS 179522]). All equipment and procedures were adequate to collect and analyze the data. The data are sufficiently of interest for this model.

Confidence in the data of the subject DTN is warranted because with the exception of the presence of the SMF personnel being present during the recovery of samples all activities were completed by the same people, appropriately trained professionals in these fields. In particular the lithostratigraphic interpretations were completed by USGS personnel with more than 10 years familiarity with the YMP.

It is the consensus of the qualification committee that this qualification of DTN: GS020108314211.001 [DIRS 174112] provides confidence that the data are suitable for the intended use of providing a lithostratigraphic interpretation of boreholes NC-EWDP-7SC and NC-EWDP-15D for use as direct input to HFM2006.

4.2 CRITERIA

The work described in this report has been determined to be subject to Requirements for Performance Assessment (10 CFR 63.114 [DIRS 176544]). The applicable federal regulations and technical requirements related to the work activities associated with this report are generally implemented through the appropriate implementing procedures identified in Section 4 or the TWP. In particular, the requirements identified in 10 CFR 63.114 (a), (b), (c), and (g) [DIRS 176544] are implemented through SCI-PRO-006. There are no U.S. Department of Energy orders applicable to the scope of work identified in this report.

This report is subject to regulatory review per the provisions and criteria of *Yucca Mountain Review Plan, Final Report* (YMRP) (NRC 2003 [DIRS 163274]). Listed below are U.S. Nuclear Regulatory Commission acceptance criteria from Section 2.2.1.3.8.3 (Flow Paths in the Saturated Zone) of the YMRP (NRC 2003 [DIRS 163274]), based on the requirements of 10 CFR 63.114 [DIRS 176544]. The following list contains each of the Acceptance Criteria for this report as shown in the TWP ((BSC 2006 [DIRS 177375], Table 5) and all corresponding subcriteria. Acceptance subcriteria, discussed in Section 8.3, are indicated with an asterisk (*).

Acceptance Criteria from YMRP Section 2.2.1.3.8.3 (NRC 2003 [DIRS 163274]), Flow Paths in the Saturated Zone

- **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 saturated zone abstraction process.

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

  (3) The abstraction of flow paths in the saturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, the assumptions used for flow paths in the saturated zone are consistent with the total system performance assessment abstraction of representative volume (Section 2.2.1.3.12 of the Yucca Mountain Review Plan). The descriptions and technical bases provide transparent and traceable support for the abstraction of flow paths in the saturated zone.

  (4*) Boundary and initial conditions used in the total system performance assessment abstraction of flow paths in the saturated zone 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 ground water flow system

  (5) Sufficient data and technical bases to assess the degree to which features, events, and processes have been included in this abstraction are provided.

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

  (7) Long-term climate change, based on known patterns of climatic cycles during the Quaternary period, particularly the last 500,000 years, and other paleoclimate data, are adequately evaluated.

(8) Potential geothermal and seismic effects on the ambient saturated zone flow system are adequately described and accounted for.

(9) The impact of the expected water table rise on potentiometric heads and flow directions, and consequently on repository performance, is adequately considered.

(10*) Guidance in NUREG–1297 and NUREG-1298 (Altman et al. 1988 [DIRS 103597]; 1988 [DIRS 103750]), 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 saturated zone 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 saturated zone.

(3*) Data on the geology, hydrology, and geochemistry of the saturated zone 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.

(2) Uncertainty is appropriately incorporated in model abstractions of hydrologic effects of climate change, based on a reasonably complete search of paleoclimate data.

(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 saturated zone. This may be done either through sensitivity analyses or use of conservative limits. For example, sensitivity analyses and/or similar analyses are sufficient to identify saturated zone flow parameters that are expected to significantly affect the abstraction model outcome.

(4) Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of expert elicitation, conducted in accordance with NUREG–1563 (Kotra et al. 1996 [DIRS 100909]). If other approaches are used, the U.S. Department of Energy adequately justifies their uses.

- **Acceptance Criterion 4**: Model Uncertainty Is Characterized and Propagated Through the Model Abstraction

(1) Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the 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.

4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulation requirements, other than those identified in Section 4.2, are determined to be applicable to this report.

5. ASSUMPTIONS

No assumptions were made with regard to an absence of direct confirming data or evidence for HFM2006.

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6. MODEL DISCUSSION

HFM2006 is a three-dimensional representation of the spatial distribution of hydrogeologic units in the Yucca Mountain area. This static model is developed for use in the site-scale SZ flow and transport models. HFM2006 is also a conceptual model of the Yucca Mountain hydrogeology covering an area of about 1,350 km^2, and a thickness of about 6 km. HFM2006 includes information not previously available and incorporated into previous site-scale SZ models. Specifically HFM2006 includes analysis of new data from Nye County EWDP boreholes through Phase IV and the recent update to the DVRGWFS HFM (Belcher 2004 [DIRS 173179]). Historic HFMs, particularly HFM-19 (the previous base-case model) and HFM-27 (the previous alternative model) are described in Section 6.1. Section 6.2 describes the features, events, and processes (FEPs) considered in the HFM, and Section 6.3 describes the construction of HFM2006, including input data.

HFM2006 is a conceptual model as defined by SCI-PRO-006, Attachment 1. The model does not provide any hydraulic parameters and cannot approximate a system behavior, process, or phenomenon. HFM2006 is static and fixed and cannot perform any of these functions. As a conceptual model, HFM2006 does not consider alternative conceptual models. This report does not discuss results of model testing, sensitivities, or calibration activities, as these attributes do not apply to HFM2006. Conceptual models do not require validation. Consequently, the requirements regarding model validation in SCI-PRO-002, *Planning for Science Activities* (Attachment 1 and Section 2.2 of Attachment 3), do not apply to HFM2006. Section 6.4 documents confidence-building activities, including three-dimensional visualization of HFM2006, comparisons between input data and hydrogeologic unit surfaces, and comparisons with previous models.

Although validation of HFM2006 is not required due to its nature as a conceptual model, further confidence in HFM2006 is established through the validation of the site-scale SZ flow model (SNL 2007 [DIRS 177391], Section 7). HFM2006 is used in *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391]) to update the base-case site-scale SZ flow model, which simulates groundwater flow directions and fluxes of water from the repository to the regulatory boundary. The validation of the site-scale flow model indirectly provides post-development confidence building in the embedded HFM2006.

6.1 PREVIOUS HYDROGEOLOGIC MODELS

The geologic setting, history, stratigraphy, and structure of Yucca Mountain as represented in HFM2006 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 composed of volcanic rocks of Tertiary age possibly 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. West of Crater Flat is Bare Mountain (Figure 1-2), which is composed of Paleozoic and Precambrian sedimentary and crystalline rocks. Fortymile Wash (Figure 1-2), is a prominent topographic feature east 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 first truly three-dimensional groundwater modeling of the Death Valley regional groundwater flow system supported by the Office of Civilian Radioactive Waste Management was published in 1997 and was designated the YMP/HRMP model (D'Agnese et al. 1997 [DIRS 100131]). The hydrogeologic framework model used in that 1997 USGS regional modeling contained 10 hydrogeologic units (D'Agnese et al. 1997 [DIRS 100131], Table 1). The first hydrogeologic framework model for the saturated zone site-scale flow and transport model was completed in 2000 (USGS 2000 [DIRS 146835]). This first site-scale model cited the previous regional model (D'Agnese et al. 1997 [DIRS 100131]) and contained 19 hydrogeologic units (excluding the base) (USGS 2000 [DIRS 146835], Table 6-2), hence the name HFM-19. HFM-19 utilized data from the Geologic Framework Model 3.1 (GFM 3.1) (DTN: MO9901MWDGFM31.000 [DIRS 103769]) and contained no Nye County EWDP data. HFM-19 had been the site-scale base-case hydrogeologic framework model until HFM2006 was completed and will be referred to in this report as the historic base case. HFM2006 will update the base case.

Another regional three-dimensional HFM was developed for groundwater modeling (Belcher et al. 2002 [DIRS 158875]) that contained 28 units. Another site-scale model was also developed as an alternative model (HFM-27) and documented in the previous version of this report (BSC 2004 [DIRS 170008], Section 6.4.2). The alternative model, HFM-27, was made up of 27 layers (excluding the base) (BSC 2004 [DIRS 170008], Table 6-5). Although 27 layers, excluding the base, are present in the regional model, only 23 units are present within the area of the site-scale HFM. This site-scale model included data from GFM 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]) and contained the Nye County EWDP data available at the time of development. A more recent alternative model has not been constructed, but new data are now available and the HFM-27 will be referred to in this report as the historic alternative model (to the historic base case, HFM-19).

Death Valley Regional Ground-Water Flow System, Nevada and California - Hydrogeologic Framework and Transient Ground-Water Flow Model (Belcher 2004 [DIRS 173179]), which represents the most recent interpretation of ground water flow in the Death Valley region, was published in late 2004. This regional model includes 27 layers, excluding the base, but only 23 are present within the site-scale HFM area. The units have been assigned identification numbers following the order of presentation found in Table E-2 of the scientific investigations report by Belcher (2004 [DIRS 173179]), which is slightly different than the stacking order of the units found in Table E-1 of the same document. In addition, several new boreholes completed as part of the Nye County EWDP provide new stratigraphic information south of Yucca Mountain and mostly north of Highway 95. HFM2006 is based primarily on the new regional model, with the addition of new Nye County borehole data through Phase IV and GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]). Using the DVRGWFS HFM surfaces as the initial basis for HFM2006 allows a near seamless interface to the regional model DVRGWFS HFM and aids flow and transport modelers with consistency across models.

Comparisons of HFM-19 (the historic base case), HFM-27 (the historic alternate model), and HFM2006 are presented in Section 6.4 as a portion of the confidence-building activities.

6.2 FEATURES, EVENTS, AND PROCESSES CONSIDERED IN MODEL

As anticipated in *Technical Work Plan for: Saturated Zone Flow and Transport Modeling* (BSC 2006 [DIRS 177375], Section 2.1.1.4), the FEPs documented in *Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model* (BSC 2004 [DIRS 170008], Section 6.2) are not affected with the completion of HFM2006. That report addressed the SZ FEPs pertaining to HFM-19 for the site-scale SZ flow and transport models that are included FEPs for the total system performance assessment for the license application (TSPA-LA) (Table 6-1). Table 6-1 provides a list of FEPs relevant to HFM2006 (and the HFM-19 model), in accordance with their assignment in the LA FEP List and Screening (DTN: MO0508SEPFEPLA.002 [DIRS 175064]). Specific reference to the various sections within this document where issues related to each FEP are addressed is provided in Table 6-1.

Table 6-1. Features, Events, and Processes Included in TSPA-LA and Relevant to This Report

FEP No.	FEP Name	Sections Where Disposition Is Supported	FEP Topic Addressed in Other SZ Reports
1.2.02.01.0A	Fractures	4.1.1, 6.4.3	Upstream Feeds : N/A Corroborating : BSC 2004 [DIRS 170010] ; SNL 2007 [DIRS 177391] Expanded Discussion : BSC 2004 [DIRS 170014]
1.2.02.02.0A	Faults	4.1.1, 6.1, 6.3.1.1, 6.3.1.2, 6.4.2, 6.4.4, 7.1	Upstream Feeds : N/A Corroborating : BSC 2004 [DIRS 170010] Expanded Discussion : SNL 2007 [DIRS 177391]
2.2.03.01.0A	Stratigraphy	4.1.1, 4.1.4, 6.1, 6.3	Upstream Feeds : N/A Corroborating : BSC 2004 [DIRS 170010] ; BSC 2004 [DIRS 170014] Expanded Discussion : SNL 2007 [DIRS 177391]
2.2.03.02.0A	Rock properties of host rock and other units	6.3.2, 6.4.3, 8.1	Upstream Feeds : N/A Corroborating : BSC 2004 [DIRS 170010]
2.2.07.13.0A	Water conducting features in the SZ	6.3.2, 6.4.3, 8.1	Upstream Feeds: N/A Corroborating: BSC 2004 [DIRS 170010] Expanded Discussion: SNL 2007 [DIRS 177391]
2.2.12.00.0B	Undetected features in the SZ	6.4.3, 8	Upstream Feeds: N/A Corroborating: BSC 2004 [DIRS 170010]; BSC 2004 [DIRS 170014]

Source: BSC 2004 [DIRS 170010].

NOTES: 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 analysis. N/A indicates no upstream feeds. Figure 1-1 does not indicate any upstream feeds to this report.

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

Expanded Discussion: The primary discussion of the FEP topic is discussed in the referenced SZ report.

6.3 CONSTRUCTION OF HFM2006

The HFM2006 conceptual model was constructed to provide a simplified characterization of the complex lithostratigraphic conditions beneath the Yucca Mountain site-scale area suitable for the site-scale SZ flow and transport models. HFM2006 represents the hydrogeologic setting for the Yucca Mountain area that covers about 1,350 km^2 and a thickness of about 6 km. The boundaries of the conceptual model (shown in Figures 1-2 and 6-1) were chosen to be coincident with grid cells in the current DVRGWFS (Death Valley Regional Ground-Water Flow System) HFM (Belcher 2004 [DIRS 173179]) and very nearly identical to the historical models, HFM-19 and HFM-27. The base of the site-scale model, HFM2006, is consistent with the base of the regional model, DVRGWFS HFM (Belcher 2004 [DIRS 173179]), at −4,000 m elevation. HFM2006 provides a framework over the area of interest for groundwater flow and radionuclide transport modeling.

The HFM2006 grid consists of a rectangular array of nodes with a horizontal spacing of 125 m. This horizontal spacing simplifies the available data near the repository where data are plentiful and extrapolates from more widely spaced data in other areas of the model domain. HFM2006 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 confidence building for the model is discussed in Section 7.

Use of HFM2006 is limited by considerations of spatial resolution, hydrogeologic unit definitions, and data density. HFM2006 is constructed with a 125-m horizontal spacing and is incapable of resolving geological features at smaller spatial scales. The hydrogeologic units used in the model were defined for the specific purpose of simulating groundwater flow and radionuclide transport at the scale of the site-scale SZ flow model. These hydrogeologic unit definitions may not be appropriate for other modeling activities. Finally, the density of primary measured data is relatively sparse in some regions of the HFM2006 domain and the resulting large uncertainties in those areas may limit the application of the HFM2006 for other uses.

To accommodate computer mapping, framework modeling, and groundwater flow modeling limitations, the geologic stratigraphy and structure have been simplified into hydrogeologic framework models. In simplifying geologic units, emphasis was placed on maintaining a highly generalized structural and stratigraphic framework that incorporated previously described hydrogeologic units. Geologic units were grouped into the hydrogeologic units. These groupings have changed over time and become more exact as computing capabilities and geologic understanding have increased. A comparison of the hydrogeologic unit groupings is included in Table 6-3 and Section 6.4 where various historic models are compared with HFM2006.

HFM2006 is based primarily on the regional hydrogeologic framework model as developed in the recent USGS update to the Death Valley Regional Ground-Water Flow System (DVRGWFS) (Belcher 2004 [DIRS 173179]). HFM2006 also includes data from the geologic framework model (GFM) designated GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]), existing boreholes in the general area, and recent lithostratigraphic information from the Nye County EWDP through Phase IV. Several regional and site-scale hydrogeologic framework models preceded the current HFM2006.

An important goal of HFM2006 was to seamlessly fit within the regional DVRGWFS HFM. This seamless fit allows more direct comparisons with the regional conditions and parameters without a transition at the site-scale model boundary. The previous historical models (HFM-19 and HFM-27) are compared to the updated HFM2006 in Section 6.4.2.

6.3.1 Direct Input

Four categories of direct input were used in the construction of HFM2006. More details of data reduction and incorporation are described in the following sections. All of the direct input is included in Table 4-1. These four categories are:

(1) Grid nodes at regular x and y (easting and northing) intervals, which represent the surfaces of the hydrogeologic units from the DVRGWFS HFM (Belcher 2004 [DIRS 173179]; DTN: MO0602SPAMODAR.000 [DIRS 177371]).

(2) Grid nodes at regular x and y (easting and northing) intervals that represent the surfaces of five geologic units from GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]). These surfaces also correspond to the surfaces of five equivalent horizons or hydrogeologic units in the DVRGWFS HFM.

(3) Location and lithostratigraphic contact information or logs from boreholes within the site-scale HFM area.

(4) Location and lithostratigraphic contact information or logs from boreholes of the Nye County EWDP.

For each of the surfaces present in the HFM2006 area, all of the data points from each of the four data categories were combined and gridded using the minimum tension gridding method (using EarthVision 5.1; see Section 3.1).

6.3.1.1 Death Valley Regional Ground-Water Flow System Hydrogeologic Framework

The most recent regional hydrogeologic framework model to be completed in the Yucca Mountain area was a component of *Death Valley Regional Ground-Water Flow System, Nevada and California—Hydrogeologic Framework and Transient Ground-Water Flow Model* (Belcher 2004 [DIRS 173179]). The DVRGWFS HFM represents Precambrian and Paleozoic crystalline and sedimentary rocks, Mesozoic sedimentary rocks, Mesozoic to Cenozoic intrusive rocks, Cenozoic volcanic tuffs and lavas, and late-Cenozoic sedimentary deposits of the DVRGWFS region (Belcher 2004 [DIRS 173179], p. 1). The unconsolidated sediments and consolidated rocks were subdivided into 27 hydrogeologic framework units based on lateral extent, physical characteristics, and structural features (Belcher 2004 [DIRS 173179], Chapters B and E). The 27 surfaces representing the hydrogeologic units cover an area that includes the area of interest for groundwater flow and radionuclide transport modeling for the Yucca Mountain Project. The DVRGWFS surfaces represent the best single source of geohydrologic unit and structural information for the area surrounding the geologic framework model (GFM2000) area. Figure 6-1 illustrates the area of the DVRGWFS relative to the site-scale SZ model area and other features.

The DVRGWFS HFM (Belcher 2004 [DIRS 173179]) was constructed to represent the hydrogeologic units and major structures in the Death Valley region. The DVRGWFS HFM (Belcher 2004 [DIRS 173179]) has a horizontal resolution of 1,500 m and includes 27 hydrogeologic units (excluding the base), and it extends from the ground surface to a depth of 4,000 m below sea level. Data sets such as elevation models, geologic maps, borehole lithologic logs, cross sections, and digital geologic models were combined and utilized to create the DVRGWFS HFM. The 27 hydrogeologic unit surfaces produced for the DVRGWFS HFM (Belcher 2004 [DIRS 173179], files: *unit_modt.asc*) were included as part of the model archive for the web-published version of the DVRGWFS report. With a resolution of 1,500 m, the DVRGWFS HFM (Belcher 2004 [DIRS 173179]) necessarily contains less detail and, thus, smoothes each of the surfaces, moderating the extreme highs and lows of each surface, including the upper-most surface representing topography.

The construction of the HFM used as the basis for the DVRGWFS, including the conceptual model, modeling approach, data inputs, gridding, and model building is more completely described by Belcher (2004 [DIRS 173179], Chapter E, "Three-Dimensional Hydrogeologic Framework Model"). Several aspects of the construction of the DVRGWFS HFM will be described here.

The hydrogeologic framework model was constructed to represent the complex hydrogeology of the area. The unconsolidated sediments and consolidated rocks were subdivided into 27 hydrogeologic units based on lateral extent, physical characteristics, and structural features. The hydrogeologic units are described in Table 6-2 (Belcher 2004 [DIRS 173179], Table E-1). Background information describing the selection of these hydrogeologic units may be found in the report by Belcher (2004 [DIRS 173179], Chapter B). The hydrogeologic units selected and described by Belcher (2004 [DIRS 173179], Tables E-1 and B-2) are the units used in the construction of HFM2006.

Information describing the three-dimensional distribution of the hydrogeologic units within the larger Death Valley area included: (1) geologic maps ranging in scale from 1:250,000 to 1:50,000 (Belcher 2004 [DIRS 173179], p. 173); (2) borehole lithologic data from 1,533 boreholes (Belcher 2004 [DIRS 173179], p. 174); (3) geologic and hydrogeologic cross sections from five sources (Belcher 2004 [DIRS 173179], p. 176); and (4) three existing geologic framework models (Belcher 2004 [DIRS 173179], p. 179). The Nye County cross sections (Belcher 2004 [DIRS 173179], p. 176), provide the same interpretation of the NC-EWDP area as found in crosssections Nye-1, Nye-2, and Nye-3 of DTN: GS031108314211.005 [DIRS 168526]. The inclusion of these cross-sections as described here satisfies the agreement to provide the hydrostratigraphic crosssections in an update to the site-scale HFM. The previous response to the KTI issues remains valid because the same interpretation of the Nye crosssections was provided in the responses (Williams 2003 [DIRS 170977], Appendix B.) In addition, regionally important faults that influence groundwater flow were used in the construction the DVRGWFS HFM (Belcher 2004 [DIRS 173179], p. 181). Most structures are high-angle faults (greater than 60 degrees) and are treated in the DVRGWFS HFM as vertical features. Figure 6-2 illustrates the traces of structures represented in the HFM (Belcher 2004 [DIRS 173179], Figure E-6).

The grids describing the surfaces of the hydrogeologic units resulting from the regional model are described in Section 4.1.1 and determined to be qualified for intended use in this report and model. Those surfaces may be found in DTN: MO0602SPAMODAR.000 [DIRS 177371].

The DVRGWFS HFM was constructed with a horizontal resolution of 1,500 m. Resolution in the vertical dimension ranges from 0 to the maximum thickness of each hydrogeologic unit. The vertical range of the DVRGWFS HFM extends from 4,000 m below sea level to the ground surface. More particulars of the DVRGWFS HFM are described in the report by Belcher (2004 [DIRS 173179], Chapter E).

The resulting surfaces were included with the web-published version of the report (Belcher 2004 [DIRS 173179]) at http://pubs.usgs.gov/sir/2004/5205. The surfaces were in the input directory of the model archive link found on that web page. Specifically, the surfaces are available as files (*unit_modt.asc*), where "unit" corresponds to each of the 27 regional hydrogeologic framework model units. These files are included in unqualified DTN: MO0602SPAMODAR.000 [DIRS 177371]. The grids resulting from the regional model are described in Section 4.1.1 and determined to be qualified for intended use in this report and model.

Because HFM2006 is based primarily on the regional hydrogeologic framework model as developed in the recent USGS update to the DVRGWFS (Belcher 2004 [DIRS 173179]) the DVRGWFS surface information is in the appropriate hydrogeologic units, and no geologic or hydrogeologic interpretation was required. The data from this source is in the UTM projection Zone 11, NAD27, with meters as units. This is the coordinate system used for the development of HFM2006, so no conversions were required.

The consistent 1,500-m spacing of the DVRGWFS HFM provides a good foundation on which to add more-detailed measured information for the construction of HFM2006. The grid nodes spacing results in a somewhat subdued topography for each of the units, which at times contrasts with the more detailed information available in some areas.

These regional grid nodes are the product of combining many types of information measured directly and inferred without a direct measurement. Direct measurements are those observations that can be seen on the surface. Some contacts can be measured nearly directly using downhole geophysics combined with direct observations of cuttings or core. Inferred information includes geophysical data or cross-section information, which provides some consensus of the nature of the stratigraphy but does not involve a direct measurement.

Uncertainty with regard to the spatial position of contact information in the DVRGWFS HFM is not quantified but is discussed generally within the report by Belcher (2004 [DIRS 173179], p. 184). Information nearest the surface and in the immediate proximity of boreholes is relatively less uncertain than areas away from direct measurements. The 1,500 m resolution of the DVRGWFS HFM is too coarse to represent accurately some features such as faults, but provides enough detail to capture fault-induced truncation of hydrogeologic units. The DVRGWFS HFM was evaluated for accuracy by visual inspection and by mathematical manipulations of the gridded surfaces for extent and thickness of the hydrogeologic units. The DVRGWFS HFM was compared to the known extent of hydrogeologic units, input cross sections, and other 3-D framework models (Belcher 2004 [DIRS 173179], p. 184).

Table 6-2. Hydrogeologic Units for the Death Valley Regional Ground-Water Flow System Hydrogeologic Framework Model

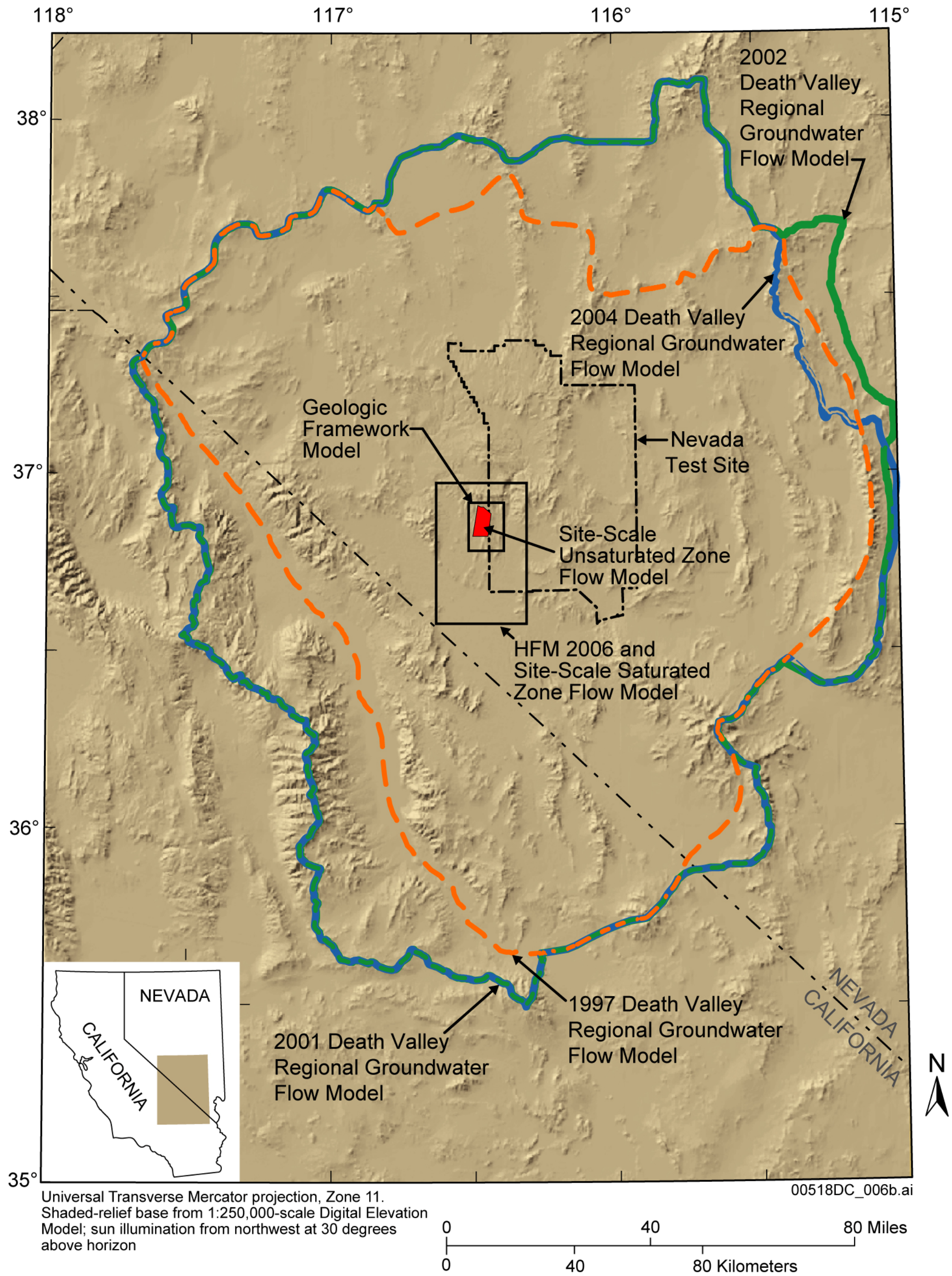
HFM2006 Unit ID	Hydrogeologic Unit Abbreviation	Hydrogeologic Unit Name	Description	Stacking Order
28	YAA	Younger alluvial aquifer	Pliocene to Holocene coarse-grained basin-fill deposits	27
27	YACU	Younger alluvial confining unit	Pliocene to Holocene playa and fine-grained basin-fill deposits	26
26	OAA	Older alluvial aquifer	Pliocene to Holocene coarse-grained basin-fill deposits	25
25	OACU	Older alluvial confining unit	Pliocene to Holocene playa and fine-grained basin-fill deposits (not in HFM2006 domain)	24
24	LA	Limestone aquifer	Cenozoic limestone, undivided	23
23	LFU	Lava-flow unit	Cenozoic basalt cones and flows and surface outcrops of rhyolite-lava flows	22
22	YVU	Younger volcanic-rock unit	Cenozoic volcanic rocks that overlie the Thirsty Canyon Group (not in HFM2006 domain)	21
21	Upper VSU	Volcanic- and sedimentary-rock unit	Cenozoic volcanic and sedimentary rocks, undivided, that overlie volcanic rocks of SWNVF	20
20	TMVA	Thirsty Canyon-Timber Mountain volcanic-rock aquifer	Miocene Thirsty Canyon and Timber Mountain Groups, plus Stonewall Mountain tuff, undivided	19
19	PVA	Paintbrush volcanic-rock aquifer	Miocene Paintbrush Group	18
18	CHVU	Calico Hills volcanic-rock unit	Miocene Calico Hills Formation	17
17	WVU	Wahmonie volcanic-rock unit	Miocene Wahmonie and Salyer Formations	16
16	CFPPA	Crater Flat-Prow Pass aquifer	Miocene Crater Flat Group, Prow Pass Tuff	15
15	CFBCU	Crater Flat-Bullfrog confining unit	Miocene Crater Flat Group, Bullfrog Tuff	14
14	CFTA	Crater Flat-Tram aquifer	Miocene Crater Flat Group, Tram Tuff	13
13	BRU	Belted Range unit	Miocene Belted Range Group (not in HFM2006 domain)	12
12	OVU	Older volcanic-rock unit	Oligocene to Miocene; near the NTS consists of all volcanic rocks older than the Belted Range Group. Elsewhere, consists of all tuffs that originated outside of the SWNVF	11
11	Lower VSU	Volcanic- and sedimentary-rock unit	Cenozoic volcanic and sedimentary rocks, undivided; where named Cenozoic volcanic rocks exist, lower VSU underlies them	10

Table 6-2. Hydrogeologic Units for the Death Valley Regional Ground-Water Flow System Hydrogeologic Framework Model (Continued)

HFM2006 Unit ID	Hydrogeologic Unit Abbreviation	Hydrogeologic Unit Name	Description	Stacking Order
10	SCU	Sedimentary-rock confining unit	Paleozoic and Mesozoic sedimentary and volcanic rocks (not in HFM2006 domain)	9
7	UCA	Upper carbonate-rock aquifer	Paleozoic carbonate rocks (UCA only used where UCCU exists, otherwise UCA is lumped with LCA)	8
6	UCCU	Upper clastic-rock confining unit	Upper Devonian to Mississippian Eleana Formation and Chainman Shale	7
9	LCA_T1	Lower carbonate-rock aquifer (thrusted)	Cambrian through Devonian predominantly carbonate rocks - thrusted	6
8	LCCU_T1	Lower clastic-rock confining unit (thrusted)	Late Proterozoic through Lower Cambrian primarily siliciclastic rocks (including the Pahrump Group and Noonday dolomite) - thrusted	5
5	LCA	Lower carbonate-rock aquifer	Cambrian through Devonian predominantly carbonate rocks	4
4	LCCU	Lower clastic-rock confining unit	Late Proterozoic through Lower Cambrian primarily siliciclastic rocks (including the Pahrump Group and Noonday dolomite)	3
3	XCU	Crystalline-rock confining unit	Middle Proterozoic metamorphic and igneous rocks	2
2	ICU	Intrusive-rock confining unit	All intrusive rocks, regardless of age	1

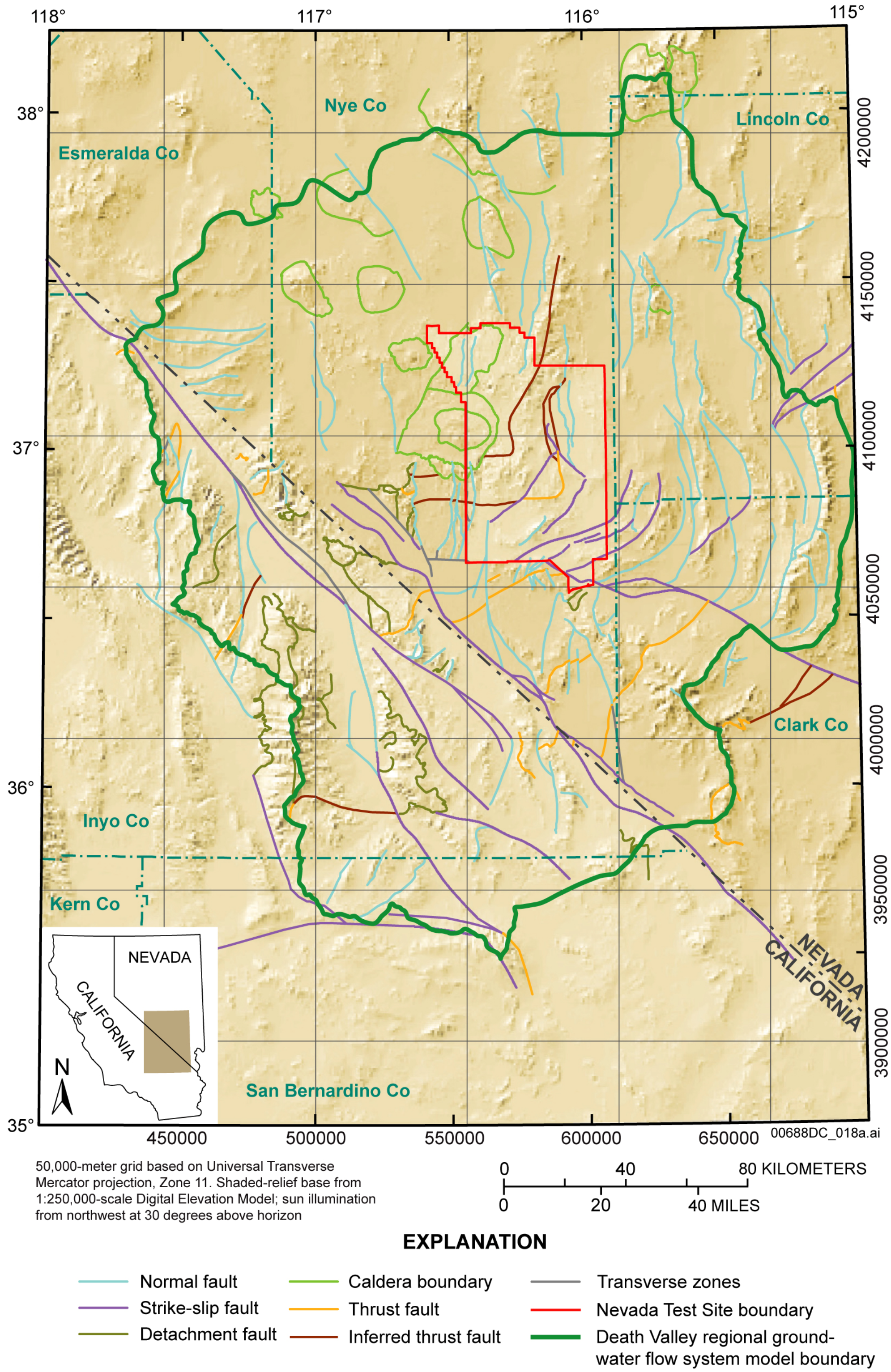
Source: Adapted from Belcher 2004 [DIRS 173179], Table E-1.

NOTE: HFM2006 unit ID numbers found in the left-most column reflects intermediate model development and do not correspond to the stacking order in the right-most column. There is no unit ID 1 in the intermediate model development from which the HFM2006 unit IDs were derived. The difference in numbering or stacking order does not impact the HFM2006 model because of the spatial distribution of the units.



Source: Belcher 2004 [DIRS 173179], Figure A-1 (Modified); DTN: MO0012MWDGFM02.002 [DIRS 153777]; BSC 2004 [DIRS 169855], Table 6-3.

Figure 6-1. Location of Several Hydrogeologic Framework Model Domains



Source: Belcher 2004 [DIRS 173179], Figure E-6.

Figure 6-2. Traces of Structures Represented in the DVRGWFS HFM

6.3.1.2 Geologic Framework Model (GFM2000)

The geologic framework model represents a three-dimensional interpretation of the geology surrounding the location of the planned repository. This model includes an area of about 65 square miles (168 square kilometers) and a volume of about 185 cubic miles (771 cubic kilometers) (BSC 2004 [DIRS 170029], p. 1-1). The boundaries of the geologic framework model (Figure 6-1) were chosen to cover the area of interest for the hydrologic flow and radionuclide transport modeling through the unsaturated zone (UZ). The geologic framework model was constructed from geologic map and borehole data with consideration given to measured stratigraphic sections, gravity profiles, and seismic profiles (BSC 2004 [DIRS 170029], p. 1-1). As can be seen in Figure 6-1, the geologic framework model occupies the north central part of the HFM2006 domain. The current version of the geologic framework model is GFM2000 (BSC 2004 [DIRS 170029]).

GFM2000 was constructed using the Nevada State Plane (Central Zone) coordinate system, NAD27, with feet as units. The horizontal limits of the GFM2000 are from 738,000 ft to 787,000 ft north and from 547,000 ft to 584,000 ft east. The output grids were constructed using a 200-ft horizontal spacing (BSC 2004 [DIRS 170029]).

The relationship between the geologic units of GFM2000 and the hydrogeologic units of HFM2006 are shown in *Death Valley Regional Ground-Water Flow System, Nevada and California - Hydrogeologic Framework and Transient Ground-Water Flow Model* (Belcher 2004 [DIRS 173179], Table E-4). Five grids representing geologic or hydrostratigraphic unit surfaces occur in both GFM2000 and the DVRGWFS HFM. The area of GFM2000 is completely encompassed by the area of HFM2006. Data from GFM2000 for those five surfaces were included in the construction of the DVRGWFS HFM. DTN: MO0507SPAINHFM.000 [DIRS 174523] includes the GFM2000 data as it was included in the DVRGWFS HFM as the files *unit_gfm.txt*, where "unit" corresponds to the tram, bullfrog, prow, calico, and paintbrush units in the UTM coordinate system, NAD27, with units of meters.

The GFM data used to construct the DVRGWFS HFM are included in DTN: MO0507SPAINHFM.000 [DIRS 174523]. The GFM data used in the construction of the DRGWFS HFM were compared with data from GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]). The comparisons show that some differences exist between the GFM2000 output and the data used as input to the DVRGWFS HFM. Belcher (2004 [DIRS 173179], p. 186) indicates that some editing of the data was done to produce a more accurate match to known geologic conditions. Within the DVRGWFS HFM the majority of the change consists of maintaining the tops of the Tram, Bullfrog, Prow, and Calico units from GFM2000 at elevations no lower than 300, 400, 450, and 450 m. Because of the relatively wider grid node spacing (1,500 m) in the regional model, many of the details in the GFM2000 data were necessarily smoothed and diminished. Adding GFM2000 data (originally at finer resolution, 200 feet) to the process of creating the HFM2006 horizon grids allows most of the GFM2000 detail to be retained in HFM2006. The extra resolution provided by the GFM data are appropriate because there is more geologic information available close to the repository area. The incorporation of high-resolution data and low-resolution data may create potential problems in adjacent horizons.

Uncertainty in GFM2000 as with other models is greatest in areas where data are most sparse and less in areas of abundant data. In relatively less complex areas (less faulting), where there is sufficient borehole data to somewhat constrain geologic behavior, the uncertainty has been quantified using a cross-correlation bootstrap method to show that at a distance of about 1,000 m from a known data point, an uncertainty of plus or minus 78 feet (23.8 m) may exist in the vertical location of a contact (BSC 2004 [DIRS 170029], Section 6.6.3).

6.3.1.3 Boreholes Supporting the DVRGWFS HFM

The Death Valley Regional Ground-Water Flow System (DVRGWFS) Hydrogeologic Framework Model (HFM) described in Section 6.3.1.1 included lithologic input from 1,533 boreholes (Belcher 2004 [DIRS 173179], p. 174). As with the GFM2000 data, the resulting borehole data set was used in the preparation of the HFM2006 surfaces.

Borehole contacts represent real measurements and those borehole contacts that were found to be appropriate were included specifically in the construction of HFM2006. The included boreholes were 1) within the HFM2006 model domain and not within GFM units and area. The 40 appropriate borehole contacts from the boreholes representing the DVRGWFS HFM were qualified in Section 4.1.2 and used as input to HFM2006.

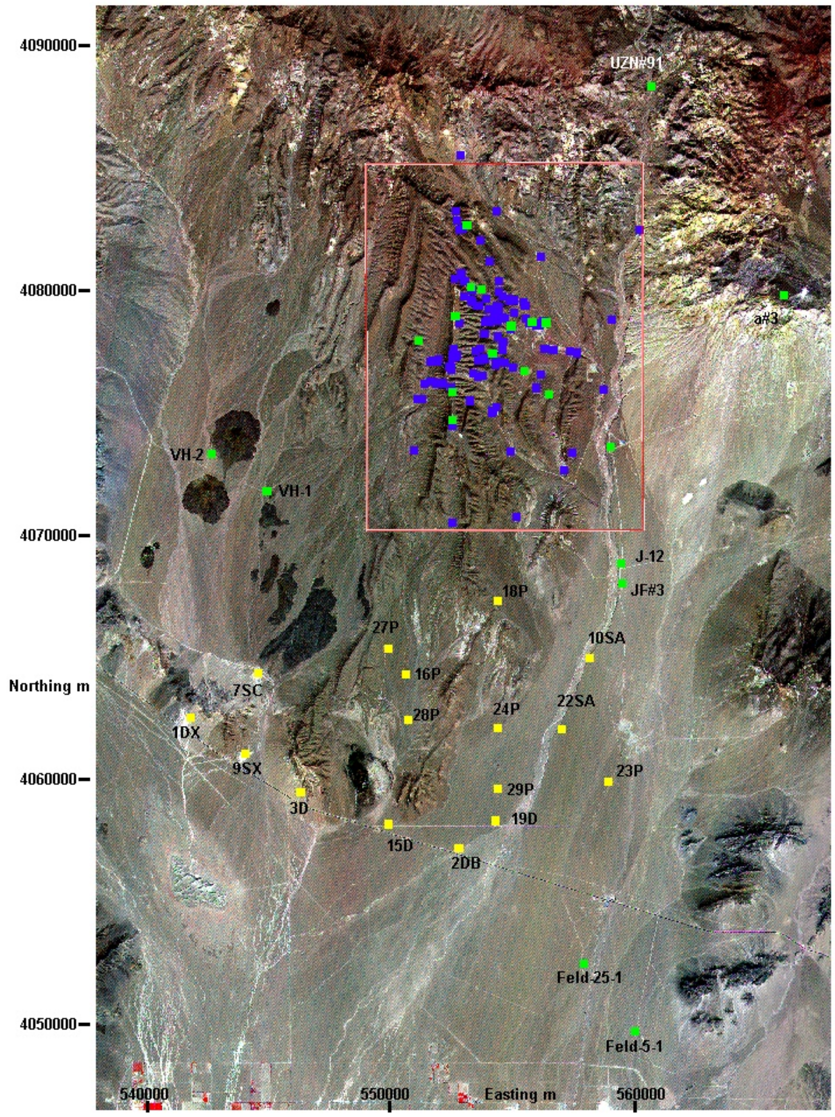
Uncertainty associated with the borehole contacts supporting DVRGWFS HFM is probably comparable to the uncertainty attributed to the Nye County EWDP borehole contacts due to the similarity in methodologies, personnel, and review of information. The uncertainty for the Nye County EWDP boreholes has been stated as plus or minus 10 ft (3 m) (DTNs: GS020108314211.001 [DIRS 174112], GS000808314211.005 [DIRS 154685], GS030108314211.001 [DIRS 163483], GS011008314211.001 [DIRS 158690], GS031108314211.004 [DIRS 174113], GS040908314211.001 [DIRS 174114]).

6.3.1.4 Nye County EWDP Boreholes

The Nye County EWDP through Phase IV has resulted in the drilling of approximately 40 boreholes at 20 locations near and north of Highway 95 and south of Yucca Mountain. Interpretations of lithostratigraphy have been completed for at least one borehole, typically the deepest borehole, at 16 of those 20 locations. The lithostratigraphic interpretations for 14 of the borehole locations are qualified and contained in the DTNs shown in Table 4-1. The lithostratigraphic interpretations of the other two interpreted boreholes have been qualified for use in this model in Section 4.1.5. The source of the location information for all 16 boreholes is included in Table 4-1. The lithostratigraphic interpretations and the borehole locations are direct input to HFM2006. These new boreholes, located south of Yucca Mountain and mostly north of Highway 95, provide new stratigraphic information in that area.

The lithostratigraphic interpretations were transformed into hydrogeologic units using DVRGWFS HFM (Belcher 2004 [DIRS 173179], Table E-3). The lithostratigraphic interpretations were completed using feet as the unit of elevation. These elevations were converted to meters. The Nye County EWDP borehole locations are given in the several DTNs listed in Table 4-1 and are in the Nevada State Plane coordinate system, Central Zone, NAD27 with feet as the unit. Conversions to UTM, Zone 11, NAD27, with meters as units was completed using Corpscon 5.11.08 (Section 3.1).

The hydrogeologic contact values with easting and northing coordinates and elevations in the units of HFM2006 are given in Table B-2. Figure 6-3 shows the location of the Nye County EWDP boreholes, boreholes included with GFM2000 and other boreholes in relationship to the HFM2006 model area and the GFM area.



Source: DTNs: MO0103GSC01040.000 [DIRS 174110], MO0106GSC01043.000 [DIRS 168374], MO0203GSC02034.000 [DIRS 168375], MO0206GSC02074.000 [DIRS 168378], MO0307GSC03094.000 [DIRS 170556], MO0312GSC03180.000 [DIRS 174103], and MO0507SPAINHFM.000 [DIRS 174523].

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. The edge of the figure is the boundary of the HFM2006 model area.

Figure 6-3. Site-Scale Map Showing Nye County EWDP Boreholes used in HFM2006 (yellow) Boreholes Included with GFM2000 (blue), other Included Borehole Contacts (green), and GFM Area (red box)

The uncertainty for the Nye County EWDP boreholes has been stated as plus or minus 10 feet (3 m) (DTNs: GS020108314211.001 [DIRS 174112], GS000808314211.005 [DIRS 154685], GS030108314211.001 [DIRS 163483], GS011008314211.001 [DIRS 158690], GS031108314211.004 [DIRS 174113], and GS040908314211.001 [DIRS 174114]).

6.3.2 Methodology

HFM2006 output DTN: MO0610MWDHFM06.002 consists of surfaces representing the top of the hydrogeologic units. Table 6-2 lists the units included. These surfaces define the spatial distribution of the hydrogeologic units within the HFM2006 model area.

HFM2006 was constructed with a horizontal resolution of 125 m (same as the previous historic base-case model, HFM-19, and the previous alternative model, HFM-27). In UTM coordinates, HFM2006 ranges from 533,000 to 563,000 m (easting) and 4,046,500 to 4,091,500 m (northing). Vertically, the top of HFM2006 is not clipped at the water table; rather, it represents the span from the land surface to 4,000 m below sea level. This depth is identical to the DVRGWFS HFM and is interpreted to encompass nearly all of the aquifer units in the regional groundwater flow system (Sweetkind et al. 2001 [DIRS 159092]). 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 (Faunt 2002 [DIRS 170974]). All corners and edges of HFM2006 are coincident with grid nodes in the DVRGWFS HFM. Twenty-three of the 27 hydrogeologic units modeled in the DVRGWFS HFM are present in the area of the site-scale hydrogeologic model, HFM2006.

The DVRGWFS HFM (Belcher 2004 [DIRS 173179]) was constructed to represent the hydrogeologic units and major structures in the Death Valley region. Data sets such as elevation models, geologic maps, borehole lithologic logs, cross sections, and digital geologic models were combined and utilized to create the DVRGWFS HFM. With a resolution of 1,500 m, the DVRGWFS HFM necessarily contains less detail and thus smoothes each of the surfaces, moderating the extreme highs and lows of each surface, including the upper-most surface representing topography.

In addition to the DVRGWFS HFM, data from the geologic framework model and borehole data were combined to construct HFM2006. The borehole data represents specific measured contact values to be used as direct input. The geologic framework model information represents closely spaced (200-ft) data constructed in an area of relatively high amounts of data. For that reason, in areas where the various types of input do not agree well, the directly measured values and the values from GFM2000 are used preferentially over the regional, widely spaced values of the DVRGWFS HFM. This is most apparent in the areas of the new drilling, the Nye County EWDP boreholes, which are providing solid information in an area where there was very limited information.

The use of the regional DVRGWFS HFM values in the construction of HFM2006 helps to provide a seamless interface between the site-scale HFM2006 and the regional model DVRGWFS HFM. In addition modeling was completed for an area 1,500 meters larger on each side of the final model area to assure a good fit with the regional model. Structural features were specifically modeled within the DVRGWFS HFM and GFM2000, and the resulting grids produced by those two models reflect the modeled structures. Structural features are represented within HFM2006 by incorporation of these two models.

The minimum tension method (sometimes referred to as minimum curvature) is generally recognized as providing geologically reasonable surfaces except where very steep surfaces are encountered (vertical distances many times greater than the data spacing). Very steep surfaces were encountered only in a few of the deeper units. Control points were added to five horizons to limit the tendency to overshoot very steep gradients where the overshooting propagated into superjacent horizons.

In those areas where a unit is indicated to have zero thickness, the newly created grids were assigned the same elevation as the underlying horizon.

The methodology used to construct HFM2006 is listed below:

- The data for each hydrogeologic unit is gathered from the applicable sources. If different data sources indicate local differences or discrepancies, "hard," measured data (boreholes) and the GFM data are preferentially retained over the regional data. Particularly, regional grid nodes were discarded if they fell in close proximity to or between closely spaced EWDP boreholes.

- Special attention is given to areas of extreme elevation differences and extra control is considered if necessary.

- Special attention is given to areas near the top and at the bottom of the boreholes. The effects of partially penetrated hydrogeologic units are considered and extra control is considered if necessary. Areas of zero thickness for units must be considered throughout.

- The data for each layer are compared with data for the subjacent layer to define areas of zero thickness.

- In areas of thickness (i.e. not zero thickness), a surface is created using EarthVision 5.1 and the minimum tension gridding. If needed, assignment is made to the subjacent horizon. A checking process during model construction looks for geologically unreasonable constructions (e.g., does not allow inversion to occur).

- In-process checking includes comparison of new surfaces with input data boreholes, regional, GFM, etc. It also includes a comparison of isopachs with regional data isopachs.

- The uppermost surface is defined by drillhole collars as well as regional grid points.

6.4 RESULTS AND DISCUSSION

HFM2006 is a conceptual model that provides a static representation of the geometry internal to the volume encompassed by the three-dimensional model domain of the site-scale SZ flow and transport models for the Yucca Mountain site. All appropriate data that were available to define the geometric relationships within the HFM2006 model domain are used in constructing HFM2006. Belcher (2004 [DIRS 173179], Chapters B and E) defined the hydrogeologic units as shown in Table 6-2. HFM2006 is assembled from the hydrogeologic units by using standard and acceptable techniques to interpolate and extrapolate the locations and extent of the hydrogeologic units based on data from boreholes and other models that incorporate surface geologic maps, geologic cross sections, and geophysical surveys.

Figures C-1 through C-23 illustrate the distribution and vertical thickness of each of the hydrogeologic units in HFM2006.

Evaluation of HFM2006 consists of comparing the surfaces of HFM2006 (output DTN: MO0610MWDHFM06.002) to data and model sources, and checking that the representation is adequate for its intended use in flow and transport modeling. The accuracy of HFM2006 is checked by comparing the model against the input data used to build it (Section 6.4.1). New data were added and the resulting HFM2006 can be used to evaluate the impact of this new data (Section 6.4.2). Section 6.4.3 discusses uncertainties in HFM2006 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 historical HFM-19 and HFM2006 (Section 6.4.4).

6.4.1 Evaluation of HFM2006 Construction and Data

The model construction process was checked by comparing input data (regional data, geologic framework data, and borehole contacts) with interpolations to grids representing the tops of hydrogeologic units in HFM2006. Specifically, the value of each input data point may be compared with an interpolated value on the grid representing the top of the hydrogeologic unit from the HFM2006.

By design, the resulting horizon grids for HFM2006 exactly reproduce the DVRGWFS grid nodes, except where more-detailed data were available, in the GFM and the Nye County EWDP areas and in areas of other boreholes. This means that HFM2006 will closely match the DVRGWFS HFM at the model boundaries. Querying the HFM2006 horizon grids at the borehole locations indicates that the average difference between the borehole horizon contacts and the HFM2006 grids is 0.9 m. The greatest differences occur (1) in an area where four boreholes (UE-25 NRG #2, UE-25 NRG #2b, UE-25 NRG #2c, and UE-25 NRG #2d) are located within very close proximity to each other but show greater than 10 m difference in contact elevation, and (2) in areas of high contrast with regional values. The median value of the differences between HFM2006 grid values and the borehole contacts is 0.17 m.

6.4.2 Impact of New Data and Comparisons of Hydrogeologic Framework Models

HFM2006 represents some new data since the development of the historic base case hydrogeologic framework model (HFM-19) for the site-scale SZ flow and transport models. Revision 00 of this report (BSC 2004 [DIRS 170008]) documents HFM-19, the historic base-case site-scale SZ flow model. In that same report, an historic alternative model (HFM-27) to the hydrogeologic framework model that incorporated some Nye County EWDP data and the regional model HFM (Faunt 2002 [DIRS 171453]) was documented. This report, Revision 01, documents an updated base-case model, HFM2006 (output DTN: MO0610MWDHFM06.002), which includes Nye County data made available since the completion of the earlier HFMs. HFM2006 was independently developed from the updated sources previously used to develop HFM-27.

- The historical base-case hydrogeologic framework model HFM-19 is based on 1997 USGS regional model work, GFM 3.1, and includes no Nye County EWDP data.
- The historic alternative model HFM-27 is based on 2002 USGS regional model work, GFM 3.1, and includes the early part of the Nye County EWDP data.
- The new base-case hydrogeologic framework model HFM2006 is based on published 2004 USGS regional model work (Belcher 2004 [DIRS 173179]), GFM2000, and Nye County EWDP data through Phase IV.

HFM2006 is based primarily on this new interpretation of the regional model, the DVRGWFS HFM, with the addition of new Nye County borehole data available since the preparation of the regional model.

The comparisons of the new base case, HFM2006, the historic base case, HFM-19, and the historic alternative, HFM-27, are made within the context of the historical HFM-19 units as shown in Table 6-3. Table 6-3 provides a correlation of units found in HFM2006 and the previous historic alternative model, HFM-27, with the previous historic base-case model, HFM-19.

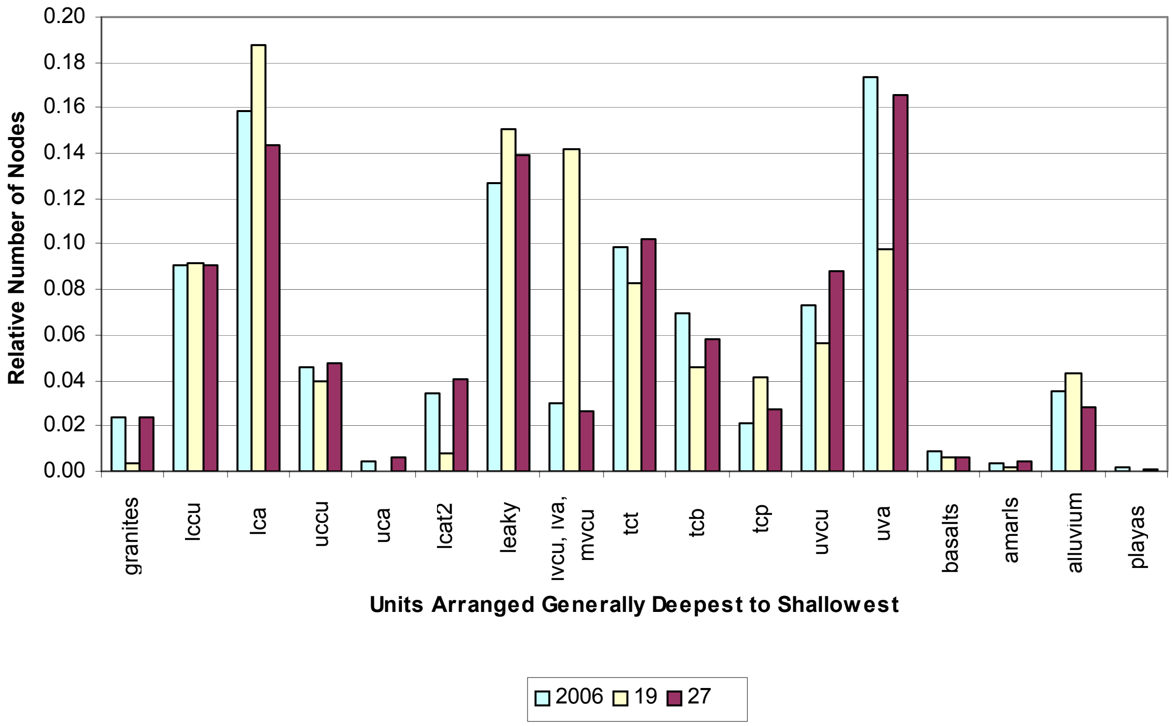
Figure 6-4 shows the relative amounts of each of the hydrogeologic units represented by the models determined at a consistent but irregularly-spaced grid pattern used for the HFM-19 modeling. The largest difference apparent in Figure 6-4 is the apparent reassignment of some areas from lower volcanic units into upper volcanic units that occurred between models HFM-19 and HFM-27.

Table 6-3. Correlation of HFM2006 and HFM-19 Units

	HFM2006		HFM-19	
Abbreviation	**Hydrogeologic Name**	**Unit**	**Unit**	**Hydrogeologic Name**
YAA	Young Alluvial Aquifer	28	20	Valley-Fill Aquifer (alluvium)
YACU	Young Alluvial Confining Unit	27	19	Valley-Fill Confining Unit (playas)
OAA	Older Alluvial Aquifer	26	20	Valley-Fill Aquifer (alluvium), Undifferentiated Valley-Fill (leaky)
OACU	Older Alluvial Confining Unit (none in site area)	—	—	—
LA	Limestone Aquifer	24	18	Limestone Aquifer (amarls)
LFU	Lava flow Unit	23	17	Lava-Flow Aquifer (basalts)
YVU	Young Volcanic Units (none in site area)	—	—	—
VSU	Volcanic and Sedimentary Units	21	8	Undifferentiated Valley-Fill (leaky)
TMVA	Timber Mountain Volcanic Aquifer	20	16	Upper Volcanic Aquifer (uva)
PVA	Paintbrush Volcanic Aquifer	19	16	Upper Volcanic Aquifer (uva)
CHVU	Calico Hills Volcanic Unit	18	15	Upper Volcanic Confining Unit (uvcu)
WVU	Wahmonie Volcanic Unit	17	15	Upper Volcanic Confining Unit (uvcu)
CFPPA	Crater Flat – Prow Pass Aquifer	16	14	Lower Volcanic Aquifer – Prow Pass Tuff (tcp)
CFBCU	Crater Flat – Bullfrog Confining Unit	15	13	Lower Volcanic Aquifer – Bullfrog Tuff (tcb)
CFTA	Crater Flat – Tram Aquifer	14	12	Lower Volcanic Aquifer – Tram Tuff (tct)
BRU	Belted Range Unit (none in site area)	—	—	—
OVU	Older Volcanic Units	12	9,10, 11	Older Volcanic Confining Unit, Older Volcanic Aquifer, Lower Volcanic Confining Unit (lvcu, lva, mvcu)
VSU Lower	Lower Volcanic and Sedimentary Units	11	8	Undifferentiated Valley-Fill (leaky)
SCU	Sedimentary Confining Unit (none in site area)	—	—	—
LCA_T1	Lower Carbonate Aquifer – Thrust	9	6	Lower Carbonate Aquifer Thrusts 1 and 2 (lcat1, lcat2)
LCCU_T1	Lower Clastic Confining Unit – Thrust	8		Lower Clastic Confining Unit – Thrust 1 (lccut1)
UCA	Upper Carbonate Aquifer	7	7	—
UCCU	Upper Clastic Confining Unit	6	5	Upper Clastic Confining Unit, Upper Clastic Confining Unit – Thrust 2 (uccu, uccut2)
LCA	Lower Carbonate Aquifer	5	4	Lower Carbonate Aquifer (lca)
LCCU	Lower Clastic Confining Unit	4	3	Lower Clastic Confining Unit (lccu)
XCU	Crystalline Confining Unit	3	3	Lower Clastic Confining Unit (lccu)
ICU	Intrusive Confining Unit	2	2	Granitic Confining Unit (granites)
Base	Base (–4,000 m)	1	1	Base (bottom of regional flow model)

Source: Adapted from BSC 2004 [DIRS 170008], Table 6-5, and from Belcher 2004 [DIRS 173179], Table E-1.

NOTE: These units do not have a one-to-one correlation. This table approximately relates HFM2006 hydrogeologic units to the historical HFM-19 hydrogeologic units.



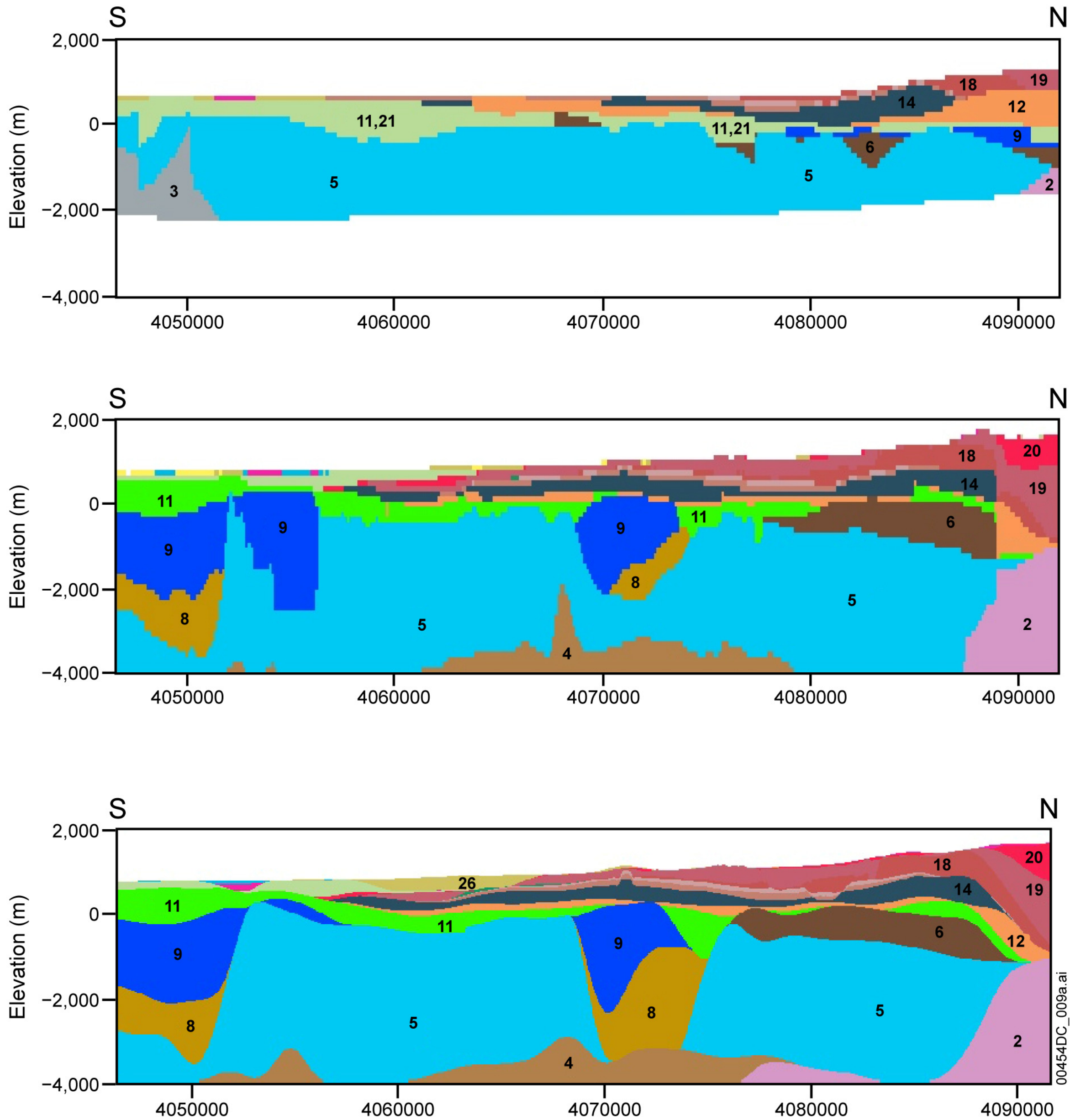
Source: DTNs: MO0610MWDHFM06.002, LA0304TM831231.001 [DIRS 164797], LA0510TM831233.001 [DIRS 175623].

Figure 6-4. Relative Amounts of Each Hydrogeologic Unit Represented in HFM-19, HFM-27, and HFM2006 Using Nomenclature of Historical HFM-19

Figures 6-5 through 6-7 represent sections cut through HFM-19, HFM-27, and HFM2006 to illustrate the similarities and differences between the resulting models. Figure 6-5 is a north-to-south vertical section cut at an easting of 552500 m. This north-to-south section is located approximately along the flowpath from Yucca Mountain to the south. Figure 6-6 is a west-to-east vertical section cut at a northing of 4064000 m. This west-to-east section is located within the area of the newest Nye County EWDP boreholes. This section cuts across most of the faulting in the area and demonstrates the difference in models where faults were explicitly included in the HFM-27 model and where the faulting is represented in the more widely spaced data of the regional model, which served as the basis for HFM2006. Figures 6-5 and 6-6 show that HFM-19 is truncated at the top at the water table and extends to a depth of about –2000 m elevation. Figure 6-5 shows a large block of the lower carbonate thrust (unit 9) sitting within the lower carbonate unit (unit 5) south of the Nye County EWDP area.

Figure 6-7 shows near-horizontal sections cut at the water table (DTN: LA0304TM831231.001 [DIRS 164797] for 6-7a and 6-7b; DTN: MO0611SCALEFLW.000 [DIRS 178483] for 6-7c) showing the distribution of hydrogeologic units. There are some differences between the two water tables used for slicing the models but the differences occur primarily in the northwest portion of the models and not in the likely flow-path of concern. The correlation between the units used in HFM-19 and the two newer models is not a simple relationship (see Table 6-3), the colors and numbers used reflect the HFM-27 and HFM2006 units with appropriate assignments made for the HFM-19 illustration.

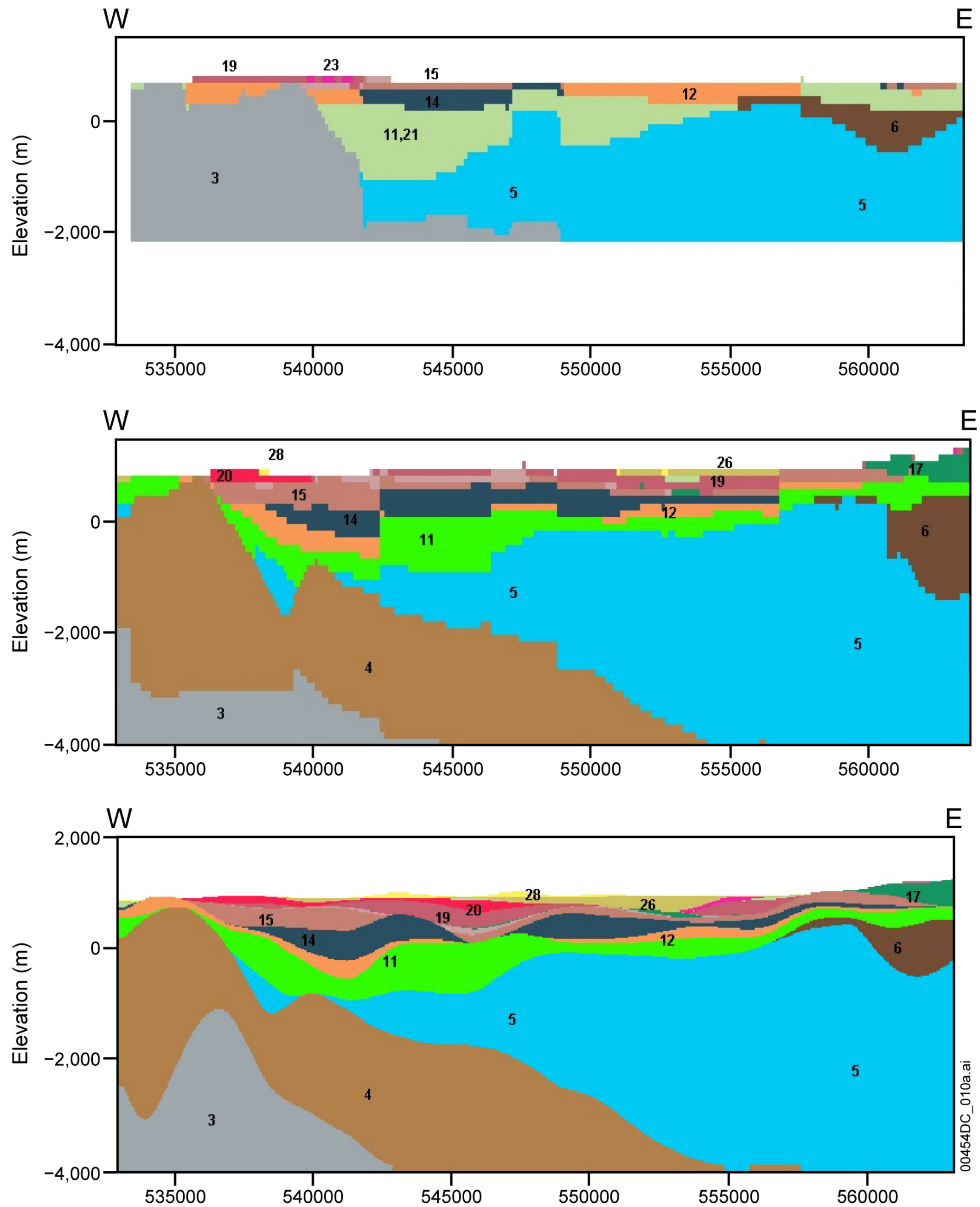
All three models show similarities in general distribution of units, with the GFM area in particular showing the most consistency. The most visible difference between the alternative model HFM-27 and HFM2006, as seen in Figures 6-7b and 6-7c, is the large addition of alluvial material (unit 26) in HFM2006 replacing volcanic and sedimentary units (unit 21) in HFM-27. This alluvial material was revealed by the recent Nye County EWDP results. The Nye County EWDP drilling also revealed more of unit 20 (Timber Mountain Volcanics) to the south of the GFM area than was previously indicated. Comparisons with HFM-19 are not as easily discernible because of the difference in the number and classification of the hydrogeologic units. Reassignment of the definition of some of the volcanic and sedimentary units (from unit 8 to units 11 and 21) is most noticeable as shown in Figure 6-4. The lack of explicit faults and relatively widely spaced regional grid information in HFM2006 gives the model results a in a more curvilinear appearance without the fault offsets of some units. The impact of new data and updated models will also be evaluated by SZ flow modeling using HFM2006, which incorporates the newer DVRGWFS HFM (Belcher 2004 [DIRS 173179]), GFM2000 (DTN: MO0012MWDGFM02.002 [DIRS 153777]), and all of the Nye County EWDP data to date.



Source: DTNs: MO0610MWDHFM06.002, LA0304TM831231.001 [DIRS 164797], and LA0510TM831233.001 [DIRS 175623].

NOTES: Coordinates in UTM, Zone 11, NAD27, meters. 2 times vertical exaggeration. Unit numbers correlate to the HFM2006 unit numbers shown in Table 6-3. See also legend for Figure 6-7a.

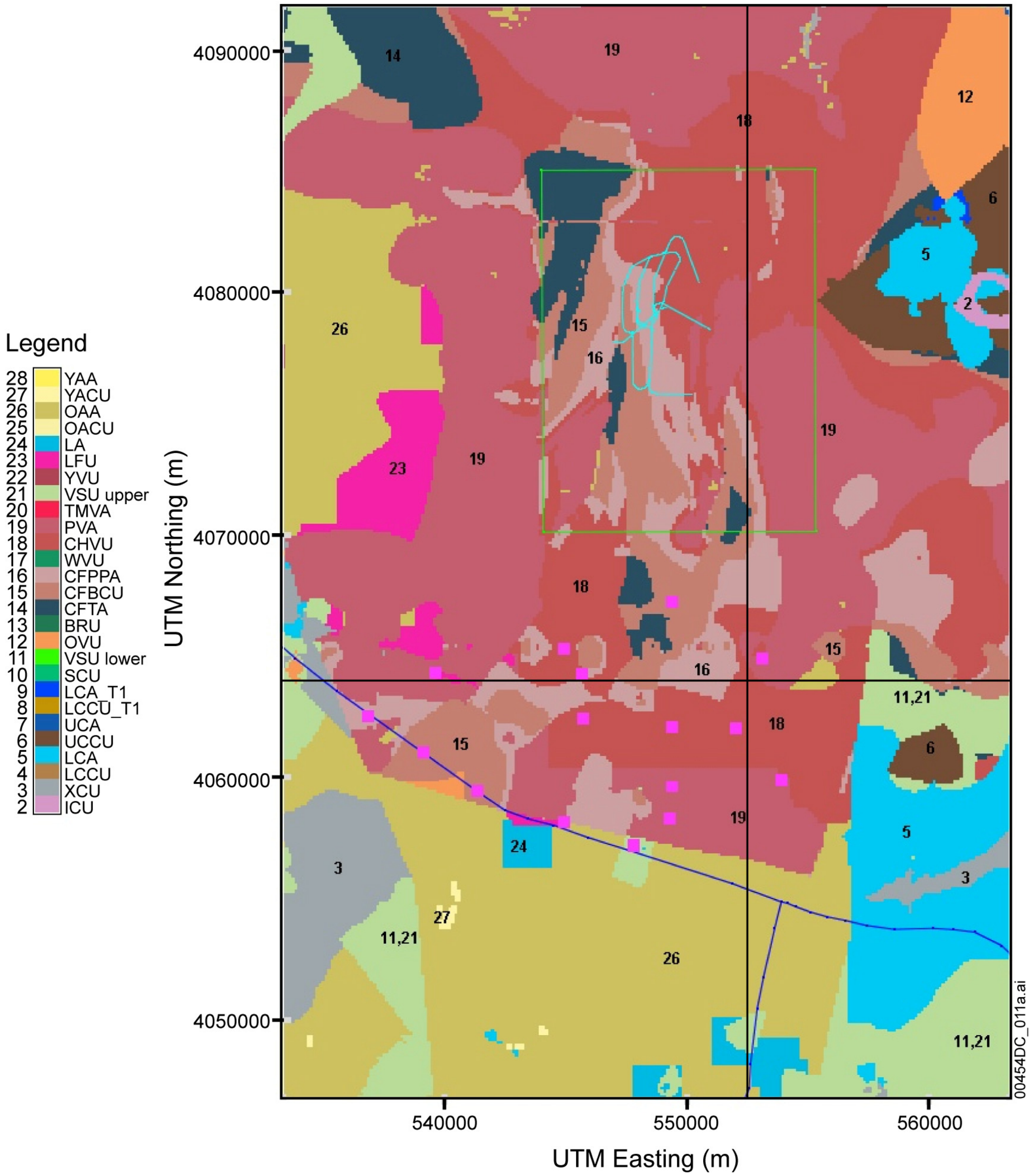
Figure 6-5. North–South Cross Section through HFM-19 (top), HFM-27 (middle), and HFM2006 (bottom) at Easting = 552,500 m



Source: DTNs: MO0610MWDHFM06.002, LA0304TM831231.001 [DIRS 164797], and LA0510TM831233.001 [DIRS 175623].

NOTES: Coordinates in UTM, Zone 11, NAD27, meters. 2 times vertical exaggeration. Unit numbers correlate to the HFM2006 unit numbers shown in Table 6-3. See also legend for Figure 6-7a.

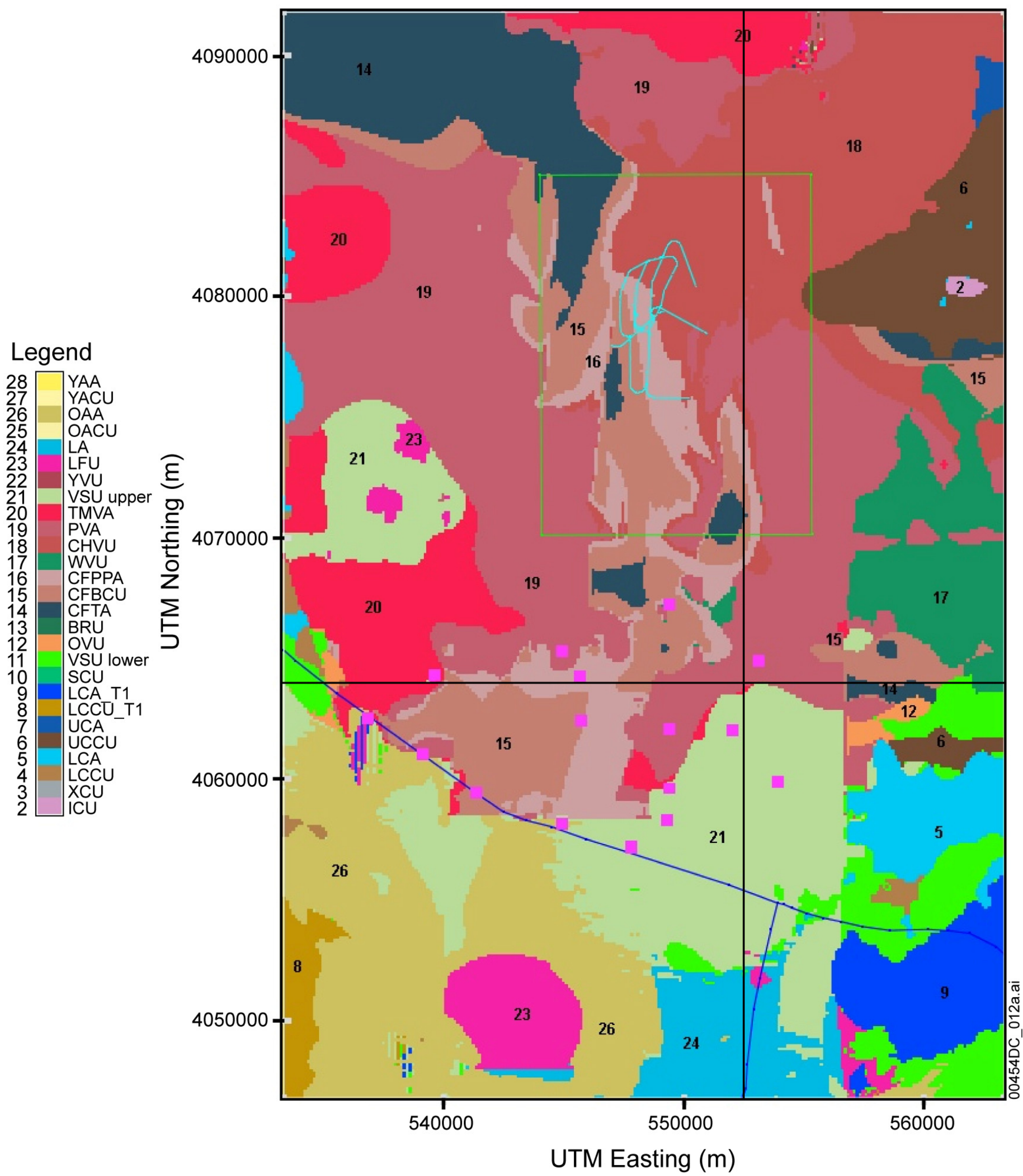
Figure 6-6. West–East Cross Section through HFM-19 (top), HFM-27 (middle), and HFM2006 (bottom) at Northing = 4,064,000 m



Source: DTN: LA0304TM831231.001 [DIRS 164797].

NOTES: Coordinates in UTM, Zone 11, NAD27, meters. Figure also shows the GFM area, Nye County EWDP borehole locations, the repository area (BSC 2003 [DIRS 165572]), and Highways 95 and 373. Cross section locations are in black. Unit numbers correlate to the HFM2006 unit numbers shown in Table 6-3.

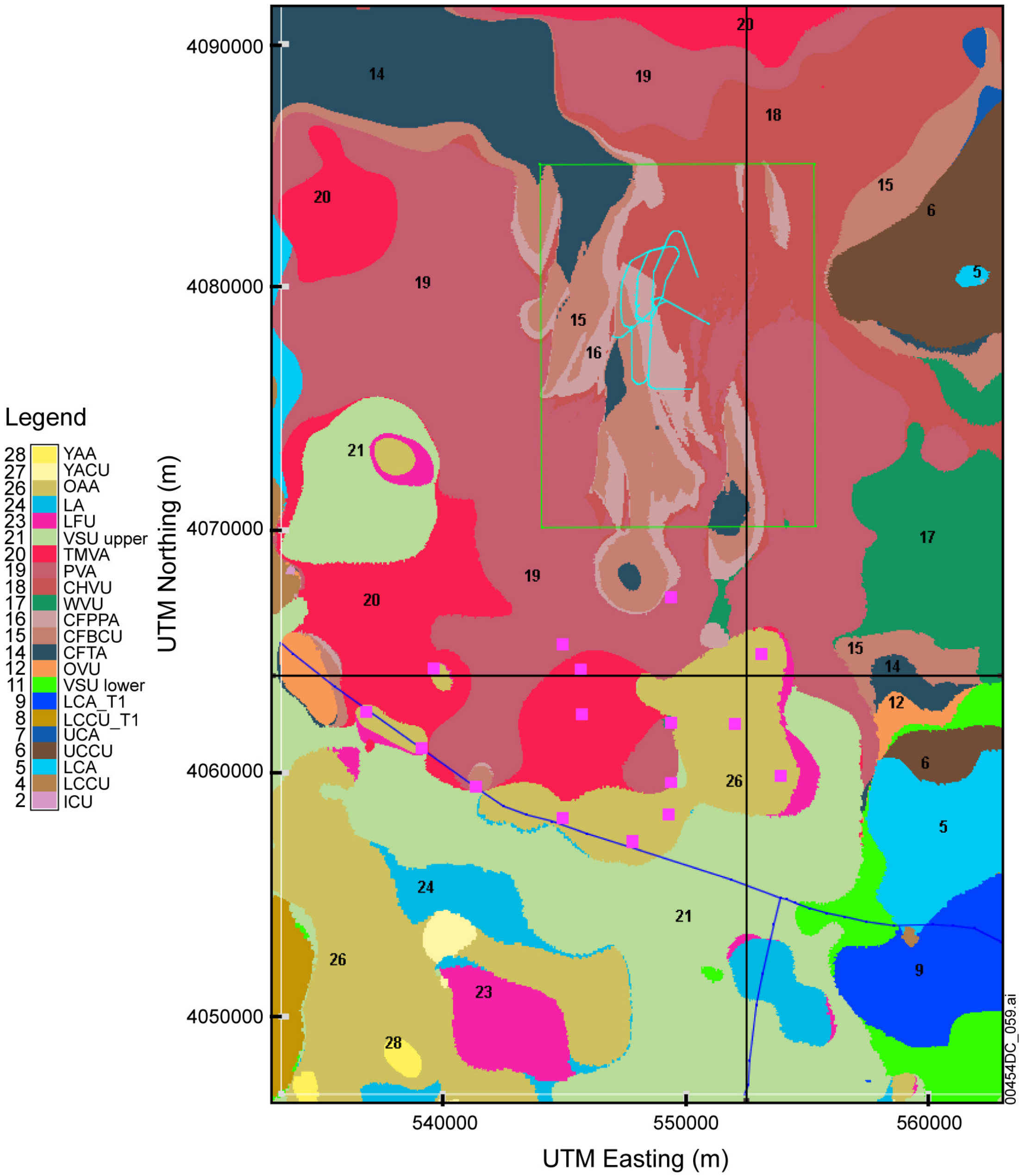
Figure 6-7a. Map of Geology at the Water Table for HFM-19



Source: DTN: LA0510TM831233.001 [DIRS 175623].

NOTES: Coordinates in UTM, Zone 11, NAD27, meters. Figure also shows the GFM area, Nye County EWDP borehole locations, the repository area (BSC 2003 [DIRS 165572]), and Highways 95 and 373. Cross section locations are in black. Unit numbers correlate to the HFM2006 unit numbers shown in Table 6-3.

Figure 6-7b. Map of Geology at the Water Table for HFM-27



Source: DTN: MO0610MWDHFM06.002.

NOTES: Coordinates in UTM, Zone 11, NAD27, meters. Figure also shows the GFM area, Nye County EWDP borehole locations, the repository area (BSC 2003 [DIRS 165572]), and Highways 95 and 373. Cross section locations are in black. Unit numbers correlate to the HFM2006 unit numbers shown in Table 6-3.

Figure 6-7c. Map of Geology at the Water Table for HFM2006

6.4.3 Uncertainties

For HFM2006, 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 on which it is built. The primary factor affecting uncertainty in HFM2006 is the distance from the final grid points to the nearest input data, and the overall distribution of the input data over the site scale domain. These input data include the surfaces that were defined in the DVRGWFS, which included geophysical methods and knowledge of the thicknesses and thickness trends of units from both outcrops and boreholes. Most of the borehole data are limited to very shallow depths (corresponding with high unit identification numbers) and near the repository and EWDP areas; therefore, uncertainty increases with depth (low unit identification numbers) and with distance from the repository and EWDP areas. Hence, interpretations regarding deeper hydrogeologic units have more uncertainty associated with them than that associated with shallower hydrogeologic units.

HFM2006 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. Confidence building for the model is discussed in Section 7.

Use of HFM2006 is limited by considerations of spatial resolution, hydrogeologic unit definitions and data density. HFM2006 is constructed with a 125-m horizontal spacing and is incapable of resolving geological features at spatial scales smaller than this. The hydrogeologic units used in the model were defined for the specific purpose of simulating groundwater flow and radionuclide transport at the scale of the site-scale SZ flow model. These hydrogeologic unit definitions may not be appropriate for other modeling activities. Finally, the density of data is sparse in some regions of the HFM2006 domain and the resulting large uncertainties in those areas limit the application of HFM2006 for other applications.

HFM2006 is constructed with a horizontal grid spacing of 125 m. Most of the volume of the model does not contain sufficient geologic detail to support the 125 m resolution. This results in smoothly interpreted or interpolated surfaces at a resolution finer than supported by the geologic data. This finer resolution does not add any additional error. Specific borehole data and other measured data were incorporated where available.

The sparseness of hard data contributes to uncertainty in the configuration of the unconformity between Tertiary and Paleozoic rocks. One borehole (UE 25 p#1) in the vicinity of Yucca Mountain and a second borehole (NC-EWDP-2DB) in the NCEWDP area penetrate the contact between the Tertiary volcanic and underlying Paleozoic rocks. Paleozoic rocks also crop out in several areas surrounding Yucca Mountain.

Vertical uncertainty of the input data is variable with borehole contacts at approximately plus or minus 10 ft (3 m). Uncertainty in relatively less complex areas of the GFM with some geologic constraints has been described as plus or minus 78 ft (23.8 m) at a distance of about 1,000 m from a known data point (BSC 2004 [DIRS 170029], Section 6.6.3). The depth from the top of the upper layer of the HFM2006 model to the water table (DTN: MO0611SCALEFLW.000 [DIRS 178483]) is less than 1,000 m and averages 255 m over the model area. This distance constraint provides confidence that the uncertainty is less than that described for some of the GFM. The upper portion of the model, less than 1,000-m deep and close to the surface provides less uncertainty than the deeper portions of the model.

Uncertainty within the HFM is propagated to the SZ site-scale flow model (SNL 2007 [DIRS 177391]) where the HFM surfaces are represented by a finite element mesh. The flow model indicates that as long as the horizontal spatial ambiguity in the location of hydrogeologic contacts is less than 125 meters (one half the horizontal grid cell size), there is essentially no impact on model specific discharge or flux calculations (SNL 2007 [DIRS 177391], Section 6.7.3). Because the majority of flow leaving the repository area is confined to a few of the more-permeable units, the vertical dimension of the computational flow grid deserves special consideration and is quantified in the flow model (SNL 2007 [DIRS 177391], Section 6.7.3). Uncertainty in hydrogeologic contacts was determined within the SZ site-scale flow model to not warrant propogation to the TSPA-LA (SNL 2007 [DIRS 177391], Section 8.4).

An important consideration in understanding the SZ flow system is the relationship between flow in the fractured tuff aquifers immediately beneath and downgradient from Yucca Mountain, and the alluvial aquifer from which groundwater discharges in the Amargosa Valley. 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 (SNL 2007 [DIRS 177390]). More discussion of the impacts on groundwater flow paths due to uncertainty in the hydrogeologic conceptual model are presented in *Saturated Zone Site Scale Flow Model* (SNL 2007 [DIRS 177391], Section 6.7.10).

Uncertainty is an inherent part of the HFM2006 and its input data. Users of the HFM2006 should consider uncertainty when using the model and determine whether the uncertainty described is appropriate to specific uses.

6.4.4 Adequacy and Intended Use

The site-scale HFM2006 is developed specifically as a hydrogeologic framework for the site-scale SZ groundwater flow and transport models. HFM2006 will be 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-Transfer (FEHM) model (Zyvoloski et al. 1997 [DIRS 110491]; 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, HFM2006 provides an internally consistent, geometric representation of the spatial distribution of hydrogeologic units within the three-dimensional SZ flow and transport model domain. The hydrogeologic properties within the three-dimensional flow and transport model domain are partially thought to be controlled by the hydrogeologic units. This representation is founded on the underlying geologically defined stratigraphic and structural framework. Spatial resolution obtainable within HFM2006 is limited by the lack of well-distributed subsurface data over most of the model domain, and consequently HFM2006 must be considered a coarse-scale approximation rather than an accurate depiction of reality.

Structural features were included in the preparation of the horizon grids of the final DVRGWFS HFM by incorporating geophysical information, as well as direct measurements. Even though there is no faulting explicitly represented by the final DVRGWFS HFM hydrogeologic unit surfaces, offsets on the faults are preserved through changes in depths 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. Grid effects seen in the historical HFM-19 are resolved with improved data and techniques in the revised HFM2006 and enhance the applicability of the HFM.

The significance of HFM2006 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 are based.

The conceptual framework model was constructed to provide a characterization of the complex three-dimensional media beneath Yucca Mountain for the site-scale SZ flow and transport models. HFM2006 was developed to locate hydrogeologic units on a 125-m computation grid used in site-scale SZ flow modeling. As a result, HFM2006 has simplifications that may restrict its use for other applications.

The HFM2006 model domain is encompassed within the Death Valley regional flow model (Belcher 2004 [DIRS 173179]). The site-scale model covers a larger area than that of the three-dimensional GFM2000 (BSC 2004 [DIRS 170029]). The HFM2006 was developed to support the Yucca Mountain saturated zone flow and transport models, and extends deeper into the SZ than the GFM2000. An important goal of the hydrogeologic framework model HFM2006 was to seamlessly fit within the regional DVRGWFS HFM. This seamless fit allows more direct comparisons with the regional conditions and parameters, without a transition at the site-scale model boundary. The previous historical HFM-19 and HFM-27 models are compared to the updated HFM2006 in Section 6.4.2.

7. VALIDATION

HFM2006 is a conceptual model that provides a static three-dimensional 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 and site-scale SZ transport model and is not a numerical predictive model (Section 6). Confidence building and postdevelopment model validation activities of the numerical models that implemented the conceptual model (i.e., the site-scale SZ flow model and site-scale SZ transport model) are described in *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391]) and the successor to *Site-Scale Saturated Zone Transport* (BSC 2004 [DIRS 170036]). The SZ flow and transport models have been previously validated under Level II model validation activities as described in Section 2.2.1.1 of the SZ TWP (BSC 2004 [DIRS 171421]), and these models are being updated (BSC 2006 [DIRS 177375]). Sections 2.1.1.1 and 2.2.1.1 of the current SZ TWP (BSC 2006 [DIRS 177375]) require the documentation of the development of HFM2006 and are described in Section 7.1.

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 Attachment 2 of SCI-PRO-006. The development of HFM2006 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. (SCI-PRO-006, Section 6 of Attachment 2, and SCI-PRO-002, Attachment 3, Level I)

Data were selected for input into the model upon completion of an extensive literature search. As discussed in detail in Section 4, inputs to HFM2006 include hydrogeologic surfaces from the Death Valley regional groundwater flow model, borehole lithologic logs, and the GFM2000 (BSC 2004 [DIRS 170029]). The lower boundary of HFM-2006 is selected to be consistent with the lower boundary of the Death Valley regional groundwater flow model (Belcher 2004 [DIRS 173179]). These data constitute a necessary and sufficient data set with which to represent the three-dimensional conceptual model at the designated scale of resolution required for the SZ flow and transport models. The selection of these data and groupings of the hydrogeologic units are addressed in Section 6.3.1.

The primary input data for HFM2006 are hydrogeologic surfaces from the Death Valley regional groundwater flow model, stratigraphic contact data from boreholes, and GFM2000, as listed in Table 4-1. Direct input data sets and associated DTNs are listed in Table 4-1. The selection and use of site-specific information adds confidence in the model. Thus, this requirement is 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.

(SCI-PRO-006, Section 6 of Attachment 2, and SCI-PRO-002, Attachment 3, Level I(5))

Sections 1 and 6.3.2 explain how the boundaries of the HFM were established. HFM2006 represents the hydrogeologic setting for the Yucca Mountain area, which covers about 1,350 km^2 and includes a saturated thickness of about 4.75 km. HFM2006 extends from 533,000 m to 563,000 m (west to east) and 4,046,500 m to 4,091,500 m (south to north), UTM Zone 11 (Figure 1-2). The base of the model is selected to be consistent with the base of the Death Valley regional groundwater flow model (Belcher 2004 [DIRS 173179]) and will propagate through the SZ site-scale flow and transport models using HFM2006. The top of the model is ground surface.

This model is static and provides a hydrogeologic definition that propagates through the abstraction process as part of the flow modeling process. Discussion of HFM2006 impact in process models is discussed in *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391]). 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. (SCI-PRO-006, Section 6 of Attachment 2, and SCI-PRO-002, Attachment 3, Level (6))

For HFM2006, 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 on which it is built. The primary factor affecting uncertainty in HFM2006 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. Most of the borehole data are limited to very shallow depths (corresponding with high unit identification numbers), and 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 is 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. (SCI-PRO-002, Attachment 3, Level I (2))

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:

- Within the supporting DVRGWFS HFM 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 6-2).

Discussion of simplifications is provided in Section 6.3 in discussions of data selection and model methods.

5. Consistency with physical principles, such as conservation of mass, energy, and momentum. (SCI-PRO-006, Attachment 3, Level I (3))

Model grids were constructed using standard methods to generate structure contour maps, which were converted into a three-dimensional representation of the hydrogeologic units of the site-scale SZ (HFM2006) 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 models. Therefore, a discussion of confidence building of the model after development is not included in this section. The site-scale SZ flow (SNL 2007 [DIRS 177391]) discuss confidence building after model development.

7.3 VALIDATION SUMMARY

The HFM is a conceptual model that is considered part of the site-scale SZ flow and transport models. Requirements for confidence building during model development have been satisfied. The accuracy of HFM2006 is checked by comparing the model against the input data used to build it (Section 6.4.1). Section 6.4.3 discusses uncertainties in HFM2006 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 in Section 7 of *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391]).

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8. CONCLUSIONS

8.1 SUMMARY OF MODELING ACTIVITY

HFM2006 is an interpretation of surface and subsurface geologic and geophysical data that is based on fundamental geologic principles and the established geologic history of Yucca Mountain 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.

HFM2006 is a conceptual model that provides a static three-dimensional geometric idealization of the hydrogeologic units in the site-scale SZ domain and is intended specifically for use in the site-scale SZ flow (SNL 2007 [DIRS 177391]) and the successor to site-scale SZ transport (BSC 2004 [DIRS 170036]) models. The HFM is not a numerical predictive model (Section 6). Mathematical implementation of HFM2006 occurs when it is used as a basis for assigning hydrologic properties within the SZ site-scale flow model domain. Therefore, this product provides no hydraulic parameters. It 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* (SNL 2007 [DIRS 177391]).

HFM2006 is appropriate for use in the site-scale SZ flow and site-scale SZ transport models because its development was achieved utilizing standard geologic methods and software based on all appropriate data from the Yucca Mountain area. The top of HFM2006 is coincident with the topographic surface. The gridding process is a simplification and idealization relating geometrical elements to the controlling data within the domain.

The hydrogeologic layers of HFM2006 form a series of alternating 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, Section 6.3.1.1). HFM2006 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

The HFM2006 input and output files are contained in DTN: MO0610MWDHFM06.002. The output of HFM2006 consists of the values of elevation of the upper surface of each hydrogeologic unit on a regular grid. These output files are ASCII files in several different formats, including ASCII triplets, EarthVision v.5.1, and AVS visualization software formats.

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 6-2), and high-angle faults represented as individual vertical fault planes. As a result, many fault offsets are smoothed in HFM2006. In the area of the GFM, the appropriate offsets on units, based on dipping faults, are retained. 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 HFM2006 can be attributed to interpretations and simplifications driven largely 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 HFM2006 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 and borehole lithologic logs). 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, only one borehole 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.

Additional boreholes have been drilled by Nye County since the development of HFM-19, primarily to characterize the contact between the valley-fill and the volcanic rocks in the southern portion of the model area. These new data were incorporated in the development of HFM2006; however, these new data did not eliminate all uncertainty in the location and character of this contact.

Uncertainties due to the definition of the hydrogeologic units propagate through the flow and transport model abstraction (BSC 2005 [DIRS 174012]). Uncertainties in HFM2006 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. Considering these constraints, HFM2006 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, are 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 YMRP Section 2.2.1.3.8.3, Flow Paths in the Saturated Zone (NRC 2003 [DIRS 163274]), 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. 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 6-2 shows the geologic groupings chosen for representing the geologic heterogeneity, which is introduced by stratigraphy, and influences the modeling of groundwater flow. Section 3 identifies the software and methods used to construct these groupings into the HFM. These descriptions are adequate because they are based on a substantial amount of data.

Subcriterion (4)—Sections 1 and 6.3 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. Section 6.3 describes the steps taken to build the model beginning with the base, using a grid coincident to the regional model, and building to the ground surface. These features propagate through the abstraction process as part of the flow modeling process.

Subcriterion (6)—Section 6.4.4 describes how HFM2006 was developed specifically to support the modeling of flow and transport in the site-scale SZ. Because HFM2006 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 *Quality Assurance Requirements and Description* (DOE 2006 [DIRS 177092]), 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 hydrogeologic surface values that were used as direct input, and shows why they are adequately justified. The lower boundary of HFM2006 is consistent with the lower boundary of the Death Valley regional groundwater flow model.

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 that were used to develop the data on the hydrogeologic surfaces of the SZ, which were used in the TSPA abstraction.

Subcriterion (4)—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 methods and the interpolation and extrapolation of stratigraphy. Standard methods were used to generate structure contour maps that were converted into a three-dimensional representation of the hydrogeology of the site-scale SZ and HFM2006, 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 125 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 specific discharge that results from uncertainty in the vertical location of certain strata.

Subcriterion (3)—Section 6.4.1 evaluates the agreement between HFM2006 and input data, concluding that HFM2006 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 is propagated through the flow model.

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 HFM2006. The increase in uncertainty about deeper hydrogeologic units and the existence of alternative interpretations of the location of the carbonate aquifers and clastic confining units are acknowledged. Section 6.4.3 also describes the propagation of uncertainty within the HFM as discussed in the flow model. Uncertainty in the alluvial volcanic contact is included in *Saturated Zone Site-Scale Flow and Transport Model Abstraction* (SNL 2007 [DIRS 177390]).

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)— The results and limitations of this model are appropriately considered in the flow and transport abstraction.

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APPENDIX A
QUALIFICATION PLAN FOR DTN: GS020108314211.001

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Sandia National Laboratories

Data Qualification Plan

Complete only applicable items.

QA: QA

Page 1 of 1

Section I. Organizational Information

Qualification Title

Qualification of Interpretation of the lithostratigraphy in deep boreholes, NC-EWDP-7SC AND NC-EWDP-15D. GS020108314211.001

Requesting Organization

PA / Natural Systems

Section II. Process Planning Requirements

1. List of Unqualified Data to be Evaluated

DTN: GS020108314211.001

2. Type of Data Qualification Method(s) [Including rationale for selection of method(s) (Attachment 3) and qualification attributes (Attachment 4)]

The TDIF for DTN: GS020108314211.001 says: "UN-Q STATUS DUE TO CORE FOR BOTH BOREHOLES (NC-EWDP-7SC AND NC-EWDP-15D), WHICH ARE CONSIDERED UN-Q BECAUSE NO SMF PERSONNEL PRESENT ON-SITE WHEN CORE WAS DRILLED."

Method 5, Technical Assessment will be used. Technical Assessment is appropriate because 'the procedures used are not adequate' i.e. no SMF personnel were on hand when core was drilled.

Actions to be taken include determination of methodology employed and determination that confidence in data is warranted.

Qualification attributes considered will include: 1, 2, 3, 7, 8,

3. Data Qualification Team and Additional Support Staff Required

Tim Vogt (chair) Originator of MDL-NBS-HS-000024 REV. 01
Peter Persoff

No additional support staff required.

4. Data Evaluation Criteria

The criterion to determine that the data are qualified for intended use is the consensus of the qualification team that the results would be the same, i.e. within the accuracy stated for the DTN in question, plus or minus 10 feet if SMF personnel had been present and part of the sample collection team for these two boreholes. This determination will rely largely on understanding how the samples were actually collected and how that differs from what would have happened if SMF personnel had been on site. This criterion is appropriate because the TDIF for the DTN states that the data are "CONSIDERED UN-Q BECAUSE NO SMF PERSONNEL PRESENT ON-SITE WHEN CORE WAS DRILLED."

5. Identification of Procedures Used

SCI-PRO-006 and SCI-PRO-001.

Section III. Approval

Qualification Chairperson Printed Name	Qualification Chairperson Signature	Date
Tim Vogt	Tim Vogt	3-6-07
Responsible Manager Printed Name	**Responsible Manager Signature**	**Date**
Stephanie Kuzio for	Ken Rehfeldt	3/6/2007

SCI-PRO-001.1-R0

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APPENDIX B
BOREHOLE LITHOSTRATIGRAPHIC DATA

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Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
547721	4057190	−12.2	LCA	NC-EWDP[a]
551501	4075659	−129.4	LCA	Included
552908	4052495	113.0	LCA	Included
555012	4049735	513.7	LCA	Included
562604	4054686	882.7	LCA	Unsupported[b]
561084	4079697	1,385.6	UCCU	Included
536768	4062487	245.9	Lower VSU	NC-EWDP[a]
536768	4062487	245.9	Lower VSU	NC-EWDP[a]
541274	4059457	224.0	Lower VSU	NC-EWDP[a]
541274	4059457	224.0	Lower VSU	NC-EWDP[a]
544000	4049966	713.6	Lower VSU	Unsupported[b]
544027	4059809	830.8	Lower VSU	Unsupported[b]
547721	4057190	387.1	Lower VSU	NC-EWDP[a]
547721	4057190	387.1	Lower VSU	NC-EWDP[a]
548840	4047109	734.5	Lower VSU	Unsupported[b]
549238	4058265	402.9	Lower VSU	NC-EWDP[a]
549238	4058265	402.9	Lower VSU	NC-EWDP[a]
549553	4052721	719.5	Lower VSU	Unsupported[b]
551992	4049197	749.4	Lower VSU	Unsupported[b]
552908	4052495	402.5	Lower VSU	Included
553283	4055241	749.5	Lower VSU	Unsupported[b]
555012	4049735	606.7	Lower VSU	Included
555677	4058244	747.9	Lower VSU	NC-EWDP[a]
555677	4058244	747.9	Lower VSU	NC-EWDP[a]
536768	4062487	404.4	OVU	NC-EWDP[a]
541274	4059457	402.3	OVU	NC-EWDP[a]
546188	4077816	424.5	OVU	Included
547543	4074619	299.1	OVU	Included
547562	4075759	374.6	OVU	Included
547668	4078841	435.9	OVU	Included
548143	4082542	340.2	OVU	Included
548306	4080016	241.4	OVU	Included
548727	4079926	187.1	OVU	Included
549188	4077309	84.5	OVU	Included
549949	4078423	−6.3	OVU	Included
551501	4075659	241.6	OVU	Included
554017	4073517	29.8	OVU	Included
536768	4062487	440.9	CFTA	NC-EWDP[a]
537738	4073214	−339.0	CFTA	Unsupported[b]
539976	4071714	243.0	CFTA	Unsupported[b]
541274	4059457	685.8	CFTA	NC-EWDP[a]
546188	4077816	613.5	CFTA	Within GFM[c]

Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
547543	4074619	676.7	CFTA	Within GFM[c]
547562	4075759	728.2	CFTA	Within GFM[c]
547668	4078841	643.1	CFTA	Within GFM[c]
547721	4057190	449.6	CFTA	NC-EWDP[a]
547740	4057179	437.3	CFTA	NC-EWDP[a]
548143	4082542	464.5	CFTA	Within GFM[c]
548306	4080016	521.5	CFTA	Within GFM[c]
548384	4076499	575.6	CFTA	Within GFM[c]
548727	4079926	470.9	CFTA	Within GFM[c]
548933	4078602	429.5	CFTA	Within GFM[c]
549188	4077309	436.5	CFTA	Within GFM[c]
549949	4078423	322.0	CFTA	Within GFM[c]
550955	4075871	301.6	CFTA	Within GFM[c]
550955	4075871	303.5	CFTA	Within GFM[c]
550955	4075933	291.2	CFTA	Within GFM[c]
550955	4075933	308.1	CFTA	Within GFM[c]
551501	4075659	424.7	CFTA	Within GFM[c]
554017	4073517	292.6	CFTA	Within GFM[c]
536768	4062487	690.9	CFBCU	NC-EWDP[a]
537738	4073214	−239.3	CFBCU	Included
539558	4064318	657.9	CFBCU	NC-EWDP[a]
539976	4071714	342.6	CFBCU	Included
541274	4059457	745.5	CFBCU	NC-EWDP[a]
544876	4058146	697.1	CFBCU	NC-EWDP[a]
546188	4077816	754.6	CFBCU	Within GFM[c]
547543	4074619	871.2	CFBCU	Within GFM[c]
547562	4075759	901.9	CFBCU	Within GFM[c]
547592	4077514	841.1	CFBCU	Within GFM[c]
547668	4078841	789.1	CFBCU	Within GFM[c]
547721	4057190	475.2	CFBCU	NC-EWDP[a]
548036	4080264	776.2	CFBCU	Within GFM[c]
548143	4082542	553.5	CFBCU	Within GFM[c]
548306	4080016	663.6	CFBCU	Within GFM[c]
548384	4076499	701.8	CFBCU	Within GFM[c]
548492	4077415	707.9	CFBCU	Within GFM[c]
548727	4079926	595.9	CFBCU	Within GFM[c]
548933	4078602	584.9	CFBCU	Within GFM[c]
549188	4077309	555.1	CFBCU	Within GFM[c]
549925	4078330	488.1	CFBCU	Within GFM[c]
549949	4078423	481.1	CFBCU	Within GFM[c]
550955	4075871	480.5	CFBCU	Within GFM[c]
550955	4075871	480.5	CFBCU	Within GFM[c]

Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
550955	4075933	474.4	CFBCU	Within GFM[c]
550955	4075933	483.1	CFBCU	Within GFM[c]
551501	4075659	557.6	CFBCU	Within GFM[c]
552090	4072550	772.1	CFBCU	Within GFM[c]
554017	4073517	396.5	CFBCU	Within GFM[c]
537738	4073214	−163.4	CFPPA	Included
539558	4064318	674.7	CFPPA	NC-EWDP[a]
539976	4071714	396.3	CFPPA	Included
546151	4075474	718.0	CFPPA	Within GFM[c]
546188	4077816	842.1	CFPPA	Within GFM[c]
547507	4076745	1,015.9	CFPPA	Within GFM[c]
547543	4074619	1,006.8	CFPPA	Within GFM[c]
547562	4075759	1,027.5	CFPPA	Within GFM[c]
547592	4077514	959.4	CFPPA	Within GFM[c]
547668	4078841	886.1	CFPPA	Within GFM[c]
548036	4080264	874.3	CFPPA	Within GFM[c]
548143	4082542	729.4	CFPPA	Within GFM[c]
548306	4080016	777.6	CFPPA	Within GFM[c]
548384	4076499	873.1	CFPPA	Within GFM[c]
548492	4077415	857.2	CFPPA	Within GFM[c]
548550	4079254	786.3	CFPPA	Within GFM[c]
548595	4077028	815.5	CFPPA	Within GFM[c]
548727	4079926	735.8	CFPPA	Within GFM[c]
548933	4078602	732.1	CFPPA	Within GFM[c]
549188	4077309	752.6	CFPPA	Within GFM[c]
549485	4076986	784.9	CFPPA	Within GFM[c]
549905	4073307	736.6	CFPPA	Within GFM[c]
549925	4078330	640.8	CFPPA	Within GFM[c]
549949	4078423	627.1	CFPPA	Within GFM[c]
550955	4075871	622.6	CFPPA	Within GFM[c]
550955	4075871	626.9	CFPPA	Within GFM[c]
550955	4075933	614.9	CFPPA	Within GFM[c]
550955	4075933	634.0	CFPPA	Within GFM[c]
551501	4075659	675.0	CFPPA	Within GFM[c]
552090	4072550	874.0	CFPPA	Within GFM[c]
554017	4073517	489.8	CFPPA	Within GFM[c]
554498	4067974	590.0	WVU	Included
546151	4075474	758.6	CHVU	Within GFM[c]
546188	4077816	888.4	CHVU	Within GFM[c]
547507	4076745	1,056.1	CHVU	Within GFM[c]
547542	4070428	725.9	CHVU	Within GFM[c]
547543	4074619	1,049.8	CHVU	Within GFM[c]

Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
547562	4075759	1,056.5	CHVU	Within GFM[c]
547592	4077514	1,006.3	CHVU	Within GFM[c]
547668	4078841	959.2	CHVU	Within GFM[c]
548036	4080264	974.9	CHVU	Within GFM[c]
548143	4082542	1,018.4	CHVU	Within GFM[c]
548306	4080016	891.3	CHVU	Within GFM[c]
548384	4076499	938.9	CHVU	Within GFM[c]
548492	4077415	929.2	CHVU	Within GFM[c]
548550	4079254	890.2	CHVU	Within GFM[c]
548595	4077028	899.3	CHVU	Within GFM[c]
548697	4081910	938.6	CHVU	Within GFM[c]
548727	4079926	844.3	CHVU	Within GFM[c]
548905	4079526	851.2	CHVU	Within GFM[c]
548933	4078602	840.0	CHVU	Within GFM[c]
549152	4074967	779.6	CHVU	Within GFM[c]
549188	4077309	847.1	CHVU	Within GFM[c]
549352	4083103	1,198.0	CHVU	Within GFM[c]
549468	4080238	842.6	CHVU	Within GFM[c]
549485	4076986	872.6	CHVU	Within GFM[c]
549905	4073307	819.8	CHVU	Within GFM[c]
549925	4078330	781.9	CHVU	Within GFM[c]
549949	4078423	778.6	CHVU	Within GFM[c]
550168	4070659	685.8	CHVU	Within GFM[c]
550439	4079412	816.9	CHVU	Within GFM[c]
550472	4076600	775.3	CHVU	Within GFM[c]
550955	4075871	725.3	CHVU	Within GFM[c]
550955	4075871	731.1	CHVU	Within GFM[c]
550955	4075933	724.0	CHVU	Within GFM[c]
550955	4075933	730.0	CHVU	Within GFM[c]
551146	4081234	885.4	CHVU	Within GFM[c]
551501	4075659	727.1	CHVU	Within GFM[c]
552090	4072550	920.9	CHVU	Within GFM[c]
552630	4077330	707.6	CHVU	Within GFM[c]
554017	4073517	559.6	CHVU	Within GFM[c]
555753	4088351	1,157.2	CHVU	Unsupported[b]
536768	4062487	712.2	PVA	NC-EWDP[a]
537738	4073214	379.7	PVA	Included
539033	4061018	749.6	PVA	NC-EWDP[a]
539976	4071714	808.1	PVA	Included
545964	4073378	1,105.1	PVA	Within GFM[c]
546151	4075474	1,184.7	PVA	Within GFM[c]
546188	4077816	1,292.6	PVA	Within GFM[c]

Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
546300	4075444	1,177.4	PVA	Within GFM[c]
546396	4076061	1,204.6	PVA	Within GFM[c]
546663	4076987	1,236.6	PVA	Within GFM[c]
546668	4076155	1,236.9	PVA	Within GFM[c]
546762	4077018	1,246.6	PVA	Within GFM[c]
546866	4076063	1,274.7	PVA	Within GFM[c]
546886	4077019	1,267.1	PVA	Within GFM[c]
546891	4076125	1,266.4	PVA	Within GFM[c]
546936	4076988	1,271.6	PVA	Within GFM[c]
546960	4077050	1,279.9	PVA	Within GFM[c]
547164	4076096	1,368.4	PVA	Within GFM[c]
547407	4076775	1,508.5	PVA	Within GFM[c]
547457	4076745	1,501.4	PVA	Within GFM[c]
547457	4076775	1,502.4	PVA	Within GFM[c]
547491	4075939	1,449.6	PVA	Within GFM[c]
547507	4076652	1,491.4	PVA	Within GFM[c]
547507	4076683	1,500.8	PVA	Within GFM[c]
547507	4076745	1,501.1	PVA	Within GFM[c]
547529	4077115	1,501.1	PVA	Within GFM[c]
547542	4070428	1,081.9	PVA	Within GFM[c]
547543	4074619	1,480.5	PVA	Within GFM[c]
547545	4074372	1,467.9	PVA	Within GFM[c]
547553	4077238	1,494.7	PVA	Within GFM[c]
547562	4075759	1,483.2	PVA	Within GFM[c]
547579	4077146	1,490.2	PVA	Within GFM[c]
547592	4077514	1,482.1	PVA	Within GFM[c]
547649	4080342	1,452.6	PVA	Within GFM[c]
547668	4078841	1,478.9	PVA	Within GFM[c]
547678	4077146	1,476.4	PVA	Within GFM[c]
547685	4083086	1,609.9	PVA	Within GFM[c]
547702	4077239	1,469.7	PVA	Within GFM[c]
547721	4057190	520.9	PVA	NC-EWDP[a]
547727	4077270	1,462.7	PVA	Within GFM[c]
547755	4082717	1,594.2	PVA	Within GFM[c]
547827	4078562	1,459.8	PVA	Within GFM[c]
547849	4082329	1,567.5	PVA	Within GFM[c]
547861	4085395	1,440.8	PVA	Within GFM[c]
547906	4080568	1,371.9	PVA	Within GFM[c]
547932	4080476	1,355.4	PVA	Within GFM[c]
547984	4082370	1,564.1	PVA	Within GFM[c]
548035	4079644	1,384.4	PVA	Within GFM[c]
548036	4080264	1,395.5	PVA	Within GFM[c]

Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
548057	4080261	1,336.9	PVA	Within GFM[c]
548143	4082542	1,553.9	PVA	Within GFM[c]
548263	4075345	1,315.5	PVA	Within GFM[c]
548273	4075368	1,308.5	PVA	Within GFM[c]
548281	4075393	1,311.9	PVA	Within GFM[c]
548282	4075409	1,313.8	PVA	Within GFM[c]
548306	4080016	1,307.6	PVA	Within GFM[c]
548308	4079492	1,400.0	PVA	Within GFM[c]
548358	4079887	1,347.6	PVA	Within GFM[c]
548359	4079400	1,321.3	PVA	Within GFM[c]
548376	4079914	1,332.3	PVA	Within GFM[c]
548384	4076499	1,352.2	PVA	Within GFM[c]
548492	4077415	1,358.0	PVA	Within GFM[c]
548550	4079254	1,324.9	PVA	Within GFM[c]
548574	4076350	1,333.5	PVA	Within GFM[c]
548595	4077028	1,283.0	PVA	Within GFM[c]
548632	4079247	1,331.7	PVA	Within GFM[c]
548696	4077031	1,318.0	PVA	Within GFM[c]
548697	4081910	1,477.8	PVA	Within GFM[c]
548706	4077510	1,329.3	PVA	Within GFM[c]
548718	4077091	1,288.4	PVA	Within GFM[c]
548727	4079926	1,303.0	PVA	Within GFM[c]
548743	4077060	1,283.5	PVA	Within GFM[c]
548772	4076413	1,315.0	PVA	Within GFM[c]
548839	4078114	1,312.2	PVA	Within GFM[c]
548854	4078132	1,314.2	PVA	Within GFM[c]
548859	4078571	1,273.8	PVA	Within GFM[c]
548892	4077061	1,264.1	PVA	Within GFM[c]
548892	4077092	1,266.4	PVA	Within GFM[c]
548892	4077092	1,269.5	PVA	Within GFM[c]
548905	4079526	1,302.6	PVA	Within GFM[c]
548933	4078602	1,260.3	PVA	Within GFM[c]
548957	4078694	1,290.7	PVA	Within GFM[c]
548982	4078633	1,256.4	PVA	Within GFM[c]
549016	4079096	1,278.0	PVA	Within GFM[c]
549032	4078633	1,248.2	PVA	Within GFM[c]
549081	4078603	1,250.3	PVA	Within GFM[c]
549082	4081057	1,392.5	PVA	Within GFM[c]
549129	4079106	1,259.6	PVA	Within GFM[c]
549152	4074967	1,192.3	PVA	Within GFM[c]
549177	4074875	1,189.0	PVA	Within GFM[c]
549188	4077309	1,248.5	PVA	Within GFM[c]

Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
549226	4074967	1,181.1	PVA	Within GFM[c]
549238	4058265	565.9	PVA	NC-EWDP[a]
549274	4078871	1,253.2	PVA	Within GFM[c]
549279	4078696	1,242.7	PVA	Within GFM[c]
549296	4076851	1,270.5	PVA	Within GFM[c]
549299	4076975	1,260.0	PVA	Within GFM[c]
549303	4076905	1,259.9	PVA	Within GFM[c]
549349	4075122	1,186.0	PVA	Within GFM[c]
549350	4079251	1,240.8	PVA	Within GFM[c]
549352	4083103	1,263.0	PVA	Within GFM[c]
549378	4078635	1,229.3	PVA	Within GFM[c]
549382	4077957	1,219.8	PVA	Within GFM[c]
549382	4078019	1,232.3	PVA	Within GFM[c]
549407	4077957	1,215.5	PVA	Within GFM[c]
549407	4077988	1,219.2	PVA	Within GFM[c]
549407	4078019	1,221.9	PVA	Within GFM[c]
549446	4079837	1,230.8	PVA	Within GFM[c]
549450	4079227	1,241.9	PVA	Within GFM[c]
549451	4078944	1,209.1	PVA	Within GFM[c]
549468	4080238	1,336.4	PVA	Within GFM[c]
549485	4076986	1,225.3	PVA	Within GFM[c]
549582	4077619	1,210.7	PVA	Within GFM[c]
549595	4079653	1,209.4	PVA	Within GFM[c]
549600	4078791	1,207.9	PVA	Within GFM[c]
549608	4077435	1,206.4	PVA	Within GFM[c]
549631	4077774	1,190.5	PVA	Within GFM[c]
549675	4078729	1,174.1	PVA	Within GFM[c]
549685	4076942	1,189.9	PVA	Within GFM[c]
549865	4079442	1,252.3	PVA	Within GFM[c]
549866	4079480	1,235.8	PVA	Within GFM[c]
549868	4079501	1,188.4	PVA	Within GFM[c]
549868	4079501	1,190.5	PVA	Within GFM[c]
549869	4079439	1,198.5	PVA	Within GFM[c]
549869	4079439	1,203.0	PVA	Within GFM[c]
549869	4079470	1,187.5	PVA	Within GFM[c]
549869	4079470	1,188.1	PVA	Within GFM[c]
549869	4079470	1,188.1	PVA	Within GFM[c]
549869	4079470	1,193.9	PVA	Within GFM[c]
549875	4079517	1,240.7	PVA	Within GFM[c]
549905	4073307	1,114.9	PVA	Within GFM[c]
549925	4078330	1,190.1	PVA	Within GFM[c]
549949	4078423	1,153.1	PVA	Within GFM[c]

Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
550008	4076759	1,178.4	PVA	Within GFM[c]
550042	4079471	1,177.1	PVA	Within GFM[c]
550076	4078982	1,148.8	PVA	Within GFM[c]
550168	4070659	1,056.4	PVA	Within GFM[c]
550439	4079412	1,153.7	PVA	Within GFM[c]
550472	4076600	1,104.8	PVA	Within GFM[c]
550473	4076582	1,132.7	PVA	Within GFM[c]
550514	4079258	1,150.6	PVA	Within GFM[c]
550514	4079258	1,152.1	PVA	Within GFM[c]
550514	4079258	1,152.1	PVA	Within GFM[c]
550532	4078731	1,178.1	PVA	Within GFM[c]
550677	4078543	1,147.1	PVA	Within GFM[c]
550742	4078564	1,139.5	PVA	Within GFM[c]
550781	4078602	1,127.4	PVA	Within GFM[c]
550791	4078583	1,122.4	PVA	Within GFM[c]
550799	4078586	1,120.6	PVA	Within GFM[c]
550807	4078584	1,118.7	PVA	Within GFM[c]
550955	4075871	1,110.9	PVA	Within GFM[c]
550955	4075871	1,110.9	PVA	Within GFM[c]
550955	4075933	1,107.9	PVA	Within GFM[c]
550955	4075933	1,112.3	PVA	Within GFM[c]
550987	4078461	1,151.9	PVA	Within GFM[c]
551117	4078446	1,122.3	PVA	Within GFM[c]
551146	4081234	1,169.2	PVA	Within GFM[c]
551156	4076463	1,111.0	PVA	Within GFM[c]
551179	4078542	1,112.2	PVA	Within GFM[c]
551242	4078640	1,101.8	PVA	Within GFM[c]
551321	4077496	1,082.3	PVA	Within GFM[c]
551381	4078528	1,052.1	PVA	Within GFM[c]
551501	4075659	1,075.5	PVA	Within GFM[c]
551679	4077467	1,063.2	PVA	Within GFM[c]
552090	4072550	1,026.7	PVA	Within GFM[c]
552333	4077389	1,047.8	PVA	Within GFM[c]
552424	4073284	1,072.2	PVA	Within GFM[c]
552630	4077330	1,043.8	PVA	Within GFM[c]
553730	4075827	965.5	PVA	Within GFM[c]
554017	4073517	878.7	PVA	Within GFM[c]
554034	4078694	1,019.2	PVA	Within GFM[c]
554444	4068774	796.6	PVA	Included
554498	4067974	791.1	PVA	Included
555174	4082338	1,100.6	PVA	Within GFM[c]
555680	4088196	1,182.7	PVA	Included

Table B-1. Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Use in HFM2006
536768	4062487	757.9	TMVA	NC-EWDP[a]
537738	4073214	585.5	TMVA	Included
539558	4064318	775.3	TMVA	NC-EWDP[a]
550472	4076600	1,133.7	TMVA	Included
550781	4078602	1,154.2	TMVA	Included
550791	4078583	1,166.0	TMVA	Included
550799	4078586	1,151.0	TMVA	Included
550807	4078584	1,165.9	TMVA	Included
551371	4078565	1,083.4	TMVA	Included
551381	4078528	1,086.8	TMVA	Unsupported[b]
555753	4088351	1,202.6	TMVA	Unsupported[b]
536768	4062487	245.9	Upper VSU	NC-EWDP[a]
541274	4059457	224.0	Upper VSU	NC-EWDP[a]
544000	4049966	713.6	Upper VSU	Unsupported[b]
544027	4059809	830.8	Upper VSU	Unsupported[b]
547721	4057190	387.1	Upper VSU	NC-EWDP[a]
548840	4047109	734.5	Upper VSU	Unsupported[b]
549238	4058265	402.9	Upper VSU	NC-EWDP[a]
549553	4052721	719.5	Upper VSU	Unsupported[b]
551992	4049197	749.4	Upper VSU	Unsupported[b]
552908	4052495	402.5	Upper VSU	Included
553283	4055241	749.5	Upper VSU	Unsupported[b]
555012	4049735	606.7	Upper VSU	Included
555677	4058244	747.9	Upper VSU	NC-EWDP[a]
537738	4073214	615.6	LFU	Included
539976	4071714	934.9	LFU	Included
544000	4049966	742.5	LFU	Unsupported[b]
544027	4059809	827.7	LFU	Unsupported[b]
552908	4052495	679.9	LFU	Included
555012	4049735	690.5	LFU	Included
543494	4057280	735.0	LA	Unsupported[b]
551992	4049197	761.0	LA	Unsupported[b]
552059	4049100	766.5	LA	Unsupported[b]
553283	4055241	770.9	LA	Unsupported[b]
554107	4047449	749.3	LA	Unsupported[b]

Source: DTN: MO0507SPAINHFM.000 [DIRS 174523].

[a] Replaced with NC-EWDP data from Q source.
[b] No available supporting information.
[c] Included within GFM2000.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. See Table 6-2 for explanation of Hydrogeologic Unit abbreviations.

Table B-2. Comparative Coordinates of Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006

Borehole	UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Comparative Source
UE-25 p #1	551501	4075659	−129.4	LCA	GS010908312332.002 [DIRS 163555]
Felderhoff-25-1	552908	4052495	113.0	LCA	MO0007BLFHF525.000 [DIRS 152892]
Felderhoff-5-1	555012	4049735	513.7	LCA	MO0007BLFHF525.000 [DIRS 152892]
UE-25 a #3	561084	4079697	1,385.6	UCCU	GS010908312332.002 [DIRS 163555]
Felderhoff-25-1	552908	4052495	402.5	Lower VSU	MO0007BLFHF525.000 [DIRS 152892]
Felderhoff-5-1	555012	4049735	606.7	Lower VSU	MO0007BLFHF525.000 [DIRS 152892]
USW H-6 upper	546188	4077816	424.5	OVU	GS010908312332.002 [DIRS 163555]
USW G-3	547543	4074619	299.1	OVU	GS010908312332.002 [DIRS 163555]
USW H-3 upper	547562	4075759	374.6	OVU	GS010908312332.002 [DIRS 163555]
USW H-5 upper	547668	4078841	435.9	OVU	GS010908312332.002 [DIRS 163555]
USW G-2	548143	4082542	340.2	OVU	GS010908312332.002 [DIRS 163555]
USW G-1	548306	4080016	241.4	OVU	GS010908312332.002 [DIRS 163555]
USW H-1 tube 1	548727	4079926	187.1	OVU	GS010908312332.002 [DIRS 163555]
USW H-4 upper	549188	4077309	84.5	OVU	GS010908312332.002 [DIRS 163555]
UE-25 b#1upper	549949	4078423	−6.3	OVU	GS010908312332.002 [DIRS 163555]
UE-25 p #1	551501	4075659	241.6	OVU	GS010908312332.002 [DIRS 163555]
UE-25 J-13	554017	4073517	29.8	OVU	GS010908312332.002 [DIRS 163555]
USW VH-2	537738	4073214	−239.3	CFBCU	GS010908312332.002 [DIRS 163555]
USW VH-1	539976	4071714	342.6	CFBCU	GS010908312332.002 [DIRS 163555]
USW VH-2	537738	4073214	−163.4	CFPPA	GS010908312332.002 [DIRS 163555]
USW VH-1	539976	4071714	396.3	CFPPA	GS010908312332.002 [DIRS 163555]
UE-25 JF #3	554498	4067974	590.0	WVU	GS010908312332.002 [DIRS 163555]
USW VH-2	537738	4073214	379.7	PVA	GS010908312332.002 [DIRS 163555]

Table B-2. Comparative Coordinates of Borehole Lithostratigraphic Data from the Death Valley Regional Groundwater Flow Model HFM within the Area of the HFM2006 (Continued)

Borehole	UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation	Comparative Source
USW VH-1	539976	4071714	808.1	PVA	GS010908312332.002 [DIRS 163555]
UE-25 J-12	554444	4068774	796.6	PVA	GS010908312332.002 [DIRS 163555]
UE-25 JF #3	554498	4067974	791.1	PVA	GS010908312332.002 [DIRS 163555]
UE-29 UZN #91	555680	4088196	1,182.7	PVA	GS010908312332.002 [DIRS 163555]
USW VH-2	537738	4073214	585.5	TMVA	GS010908312332.002 [DIRS 163555]
UE-25 ONC #1	550472	4076600	1,133.7	TMVA	MO9906GPS98410.000 [DIRS 109059]
UE-25 NRG #2d	550781	4078602	1,154.2	TMVA	MO9906GPS98410.000 [DIRS 109059]
UE-25 NRG #2	550791	4078583	1,166.0	TMVA	MO9906GPS98410.000 [DIRS 109059]
UE-25 NRG #2c	550799	4078586	1,151.0	TMVA	MO9906GPS98410.000 [DIRS 109059]
UE-25 NRG #2b	550807	4078584	1,165.9	TMVA	MO9906GPS98410.000 [DIRS 109059]
UE-25 RF #3b	551371	4078565	1,083.4	TMVA	MO9906GPS98410.000 [DIRS 109059]
Felderhoff-25-1	552908	4052495	402.5	Upper VSU	MO0007BLFHF525.000 [DIRS 152892]
Felderhoff-5-1	555012	4049735	606.7	Upper VSU	MO0007BLFHF525.000 [DIRS 152892]
USW VH-2	537738	4073214	615.6	LFU	GS010908312332.002 [DIRS 163555]
USW VH-1	539976	4071714	934.9	LFU	GS010908312332.002 [DIRS 163555]
Felderhoff-25-1	552908	4052495	679.9	LFU	MO0007BLFHF525.000 [DIRS 152892]
Felderhoff-5-1	555012	4049735	690.5	LFU	MO0007BLFHF525.000 [DIRS 152892]

Source: DTN: MO0507SPAINHFM.000 [DIRS 174523].

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. See Table 6-2 for explanation of Hydrogeologic Unit abbreviations.

Table B-3. Borehole Lithostratigraphic Data from the Nye County Early Warning Drilling Program

Borehole ID	UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation
NC-EWDP-01DX	536848	4062509	803.8	OAA
NC-EWDP-01DX	536848	4062509	756.5	TMVA
NC-EWDP-01DX	536848	4062509	689.5	CFBCU
NC-EWDP-01DX	536848	4062509	439.5	CFTA
NC-EWDP-01DX	536848	4062509	402.9	OVU
NC-EWDP-01DX	536848	4062509	244.5	VSUL
NC-EWDP-2DB	547800	4057196	801.3	OAA
NC-EWDP-2DB	547800	4057196	520.6	PVA
NC-EWDP-2DB	547800	4057196	474.9	CFBCU
NC-EWDP-2DB	547800	4057196	449.3	CFTA
NC-EWDP-2DB	547800	4057196	386.8	VSUL
NC-EWDP-2DB	547800	4057196	−12.5	LCA
NC-EWDP-03D	541352	4059450	799.2	OAA
NC-EWDP-03D	541352	4059450	750.7	CFBCU
NC-EWDP-03D	541352	4059450	691.0	CFTA
NC-EWDP-03D	541352	4059450	407.5	OVU
NC-EWDP-03D	541352	4059450	229.2	VSUL
NC-EWDP-7SC	539632	4064317	837.0	OAA
NC-EWDP-7SC	539632	4064317	765.4	TMVA
NC-EWDP-7SC	539632	4064317	667.8	PVA
NC-EWDP-7SC	539632	4064317	664.8	CFPPA
NC-EWDP-7SC	539632	4064317	654.1	CFBCU
NC-EWDP-09SX	539118	4061010	798.0	OAA
NC-EWDP-09SX	539118	4061010	752.2	PVA
NC-EWDP-10SA	553140	4064899	903.4	OAA
NC-EWDP-15D	544955	4058152	787.0	OAA
NC-EWDP-15D	544955	4058152	698.6	CFBCU
NC-EWDP-15D	544955	4058152	631.5	CFTA
NC-EWDP-16P	545665	4064263	880.6	YAA
NC-EWDP-16P	545665	4064263	868.5	OAA
NC-EWDP-16P	545665	4064263	853.9	VSUU
NC-EWDP-16P	545665	4064263	830.3	TMVA
NC-EWDP-16P	545665	4064263	613.9	PVA
NC-EWDP-16P	545665	4064263	325.5	WVU
NC-EWDP-16P	545665	4064263	299.9	CFPPA
NC-EWDP-16P	545665	4064263	186.2	CFBCU
NC-EWDP-16P	545665	4064263	22.6	CFTA
NC-EWDP-18P	549416	4067233	964.7	YAA
NC-EWDP-18P	549416	4067233	951.0	PVA
NC-EWDP-19D1	549317	4058271	819.0	OAA
NC-EWDP-19D1	549317	4058271	569.1	PVA
NC-EWDP-19D1	549317	4058271	406.0	VSUL
NC-EWDP-22SA	552019	4062020	868.4	OAA
NC-EWDP-22SA	552019	4062020	548.3	VSUU
NC-EWDP-23P	553923	4059875	853.4	YAA

Table B-3. Borehole Lithostratigraphic Data from the Nye County Early Warning Drilling Program (Continued)

Borehole ID	UTM Easting (m)	UTM Northing (m)	Elevation of Top of Unit (m)	Hydrogeologic Unit Abbreviation
NC-EWDP-23P	553923	4059875	832.7	OAA
NC-EWDP-23P	553923	4059875	457.2	LFU
NC-EWDP-24P	549386	4062055	850.5	YAA
NC-EWDP-24P	549386	4062055	831.5	OAA
NC-EWDP-24P	549386	4062055	728.5	CFBCU
NC-EWDP-24P	549386	4062055	566.9	CFTA
NC-EWDP-24P	549386	4062055	432.8	OVU
NC-EWDP-27P	544935	4065276	906.5	YAA
NC-EWDP-27P	544935	4065276	879.0	OAA
NC-EWDP-27P	544935	4065276	859.2	VSUU
NC-EWDP-27P	544935	4065276	848.6	PVA
NC-EWDP-27P	544935	4065276	495.0	CFPPA
NC-EWDP-27P	544935	4065276	368.5	CFBCU
NC-EWDP-28P	545746	4062393	843.5	YAA
NC-EWDP-28P	545746	4062393	824.5	OAA
NC-EWDP-28P	545746	4062393	812.3	LFU
NC-EWDP-28P	545746	4062393	762.0	TMVA
NC-EWDP-28P	545746	4062393	563.3	PVA
NC-EWDP-29P	549396	4059606	830.3	OAA
NC-EWDP-29P	549396	4059606	735.9	VSUU
NC-EWDP-29P	549396	4059606	733.5	PVA
NC-EWDP-29P	549396	4059606	633.7	WVU

Source: See multiple DTNs listed in Table 4-1.

NOTES: Coordinates in UTM, Zone 11, NAD27, meters. See Table 6-2 for explanation of Hydrogeologic Unit abbreviations.

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APPENDIX C
MAPS SHOWING DISTRIBUTION AND VERTICAL THICKNESS OF HYDROGEOLOGIC UNITS

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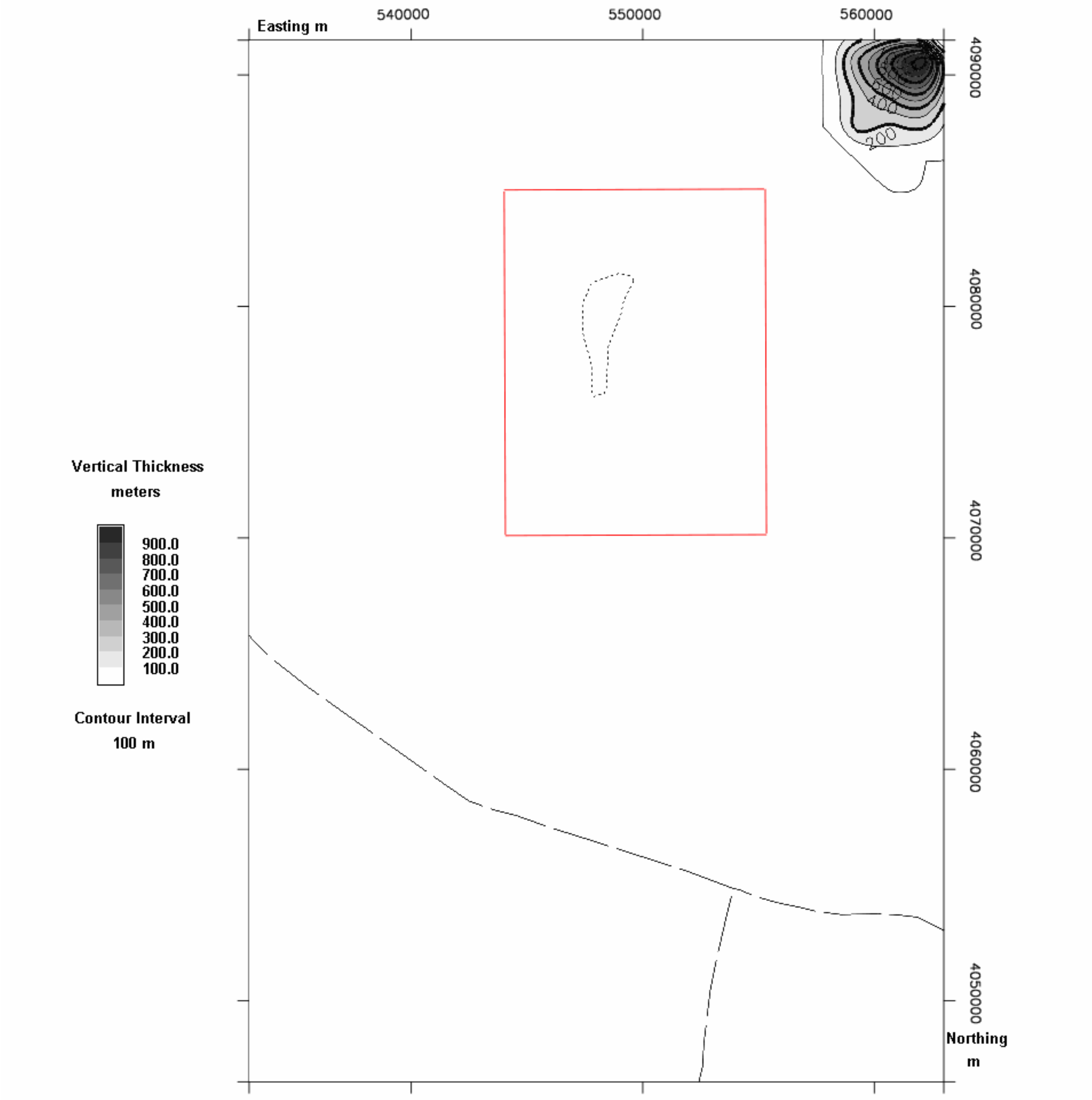
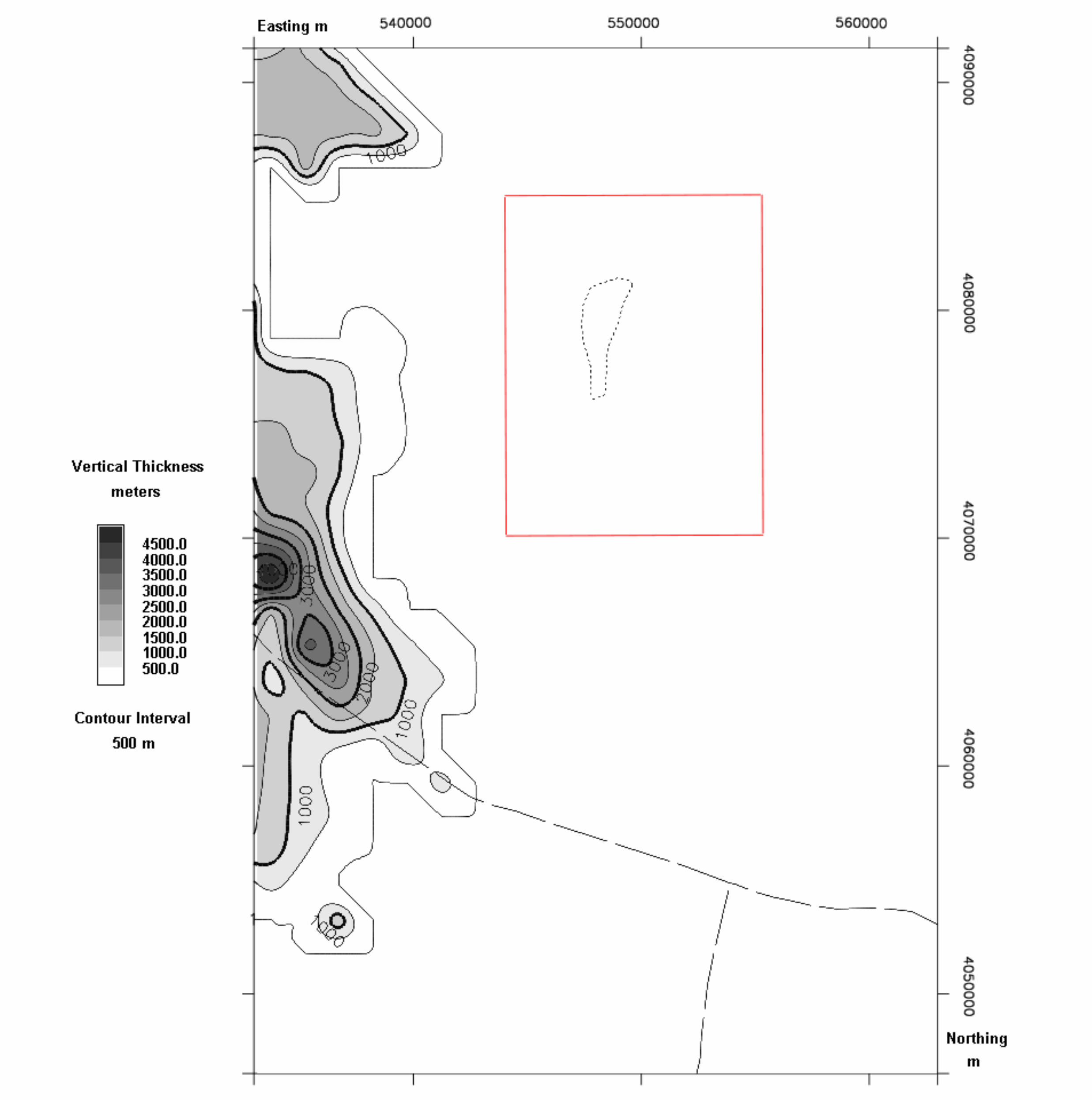


Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

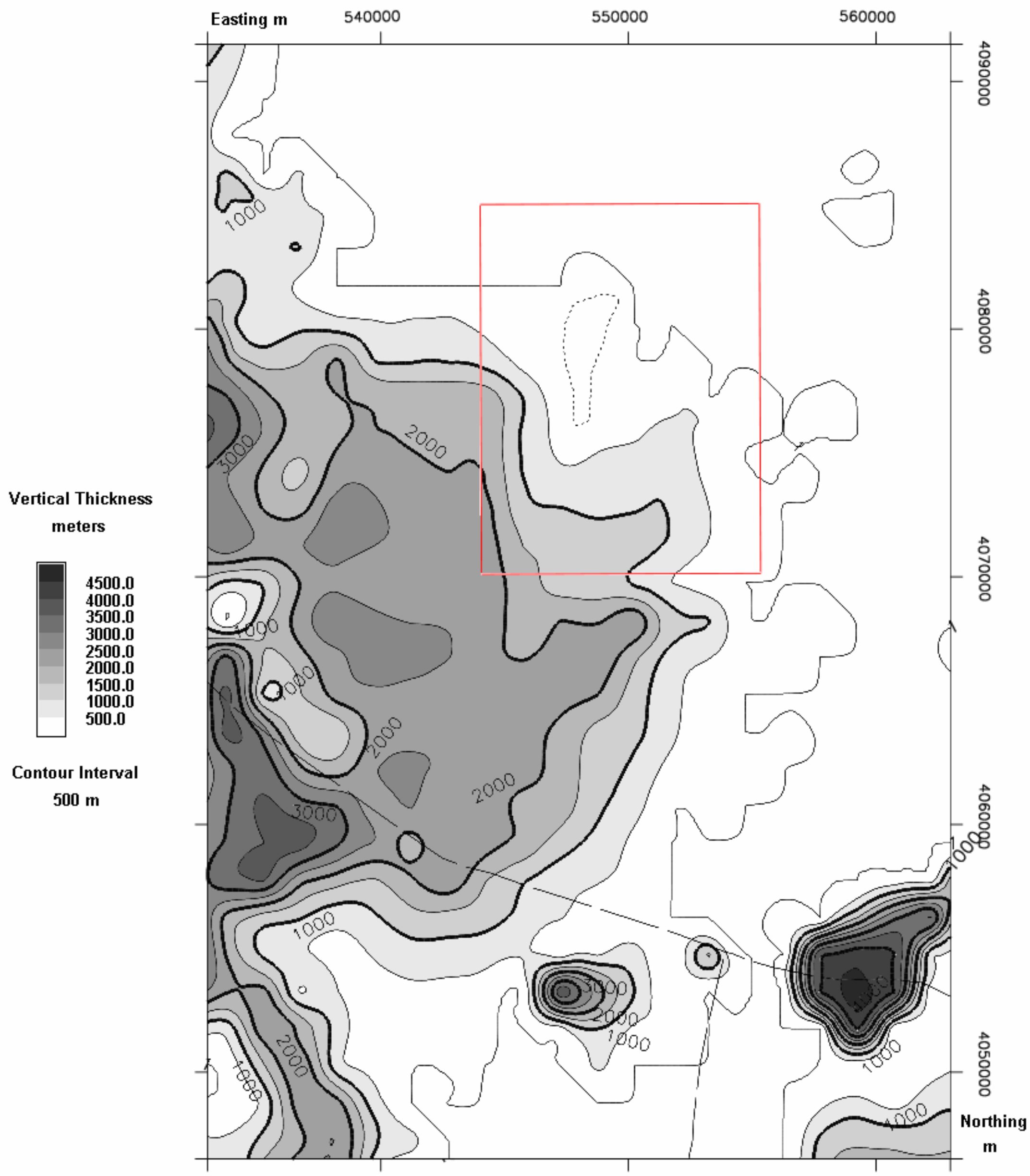
Figure C-1. Map Showing Distribution and Vertical Thickness of ICU, Intrusive Confining Unit (2)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

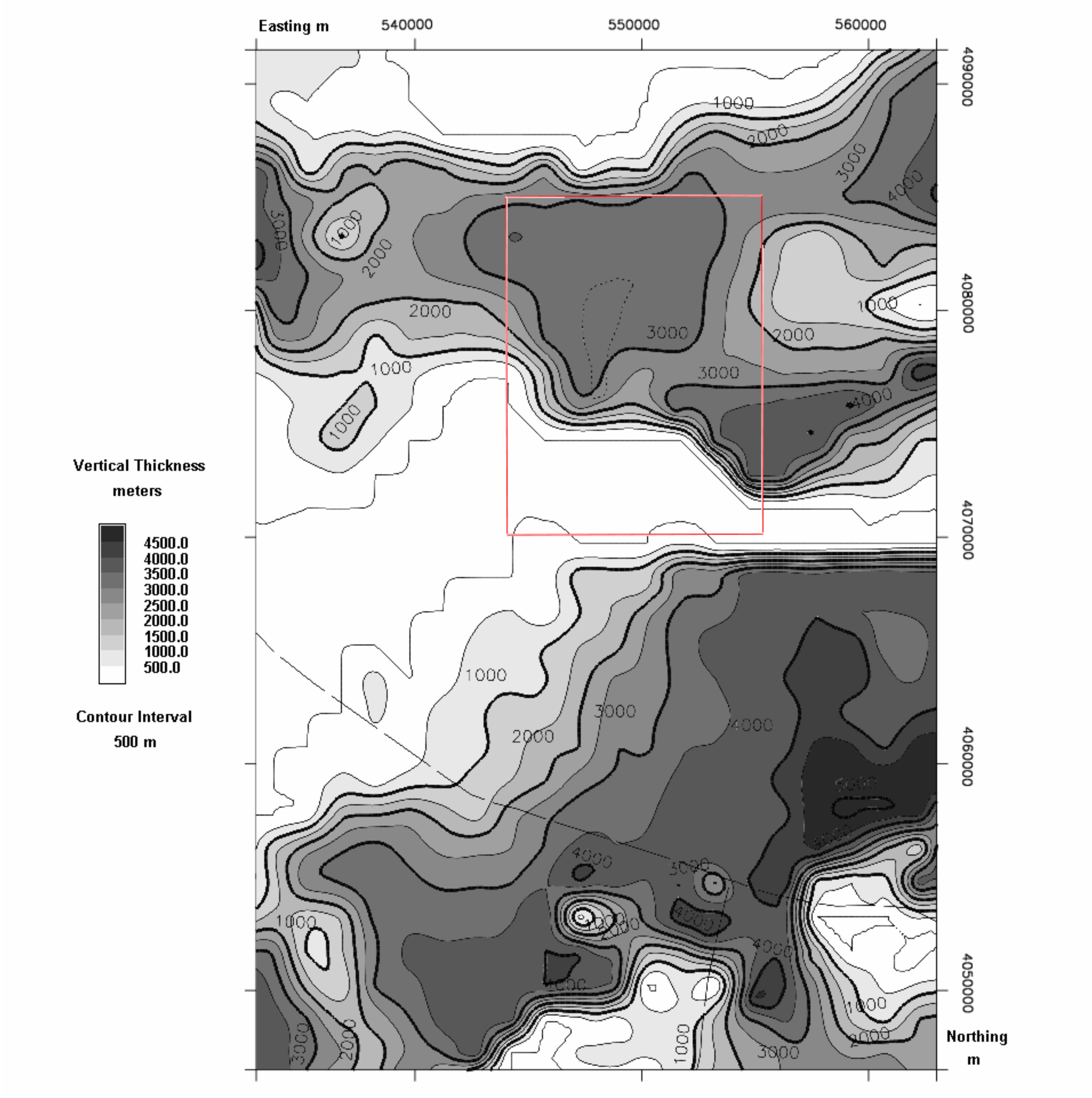
Figure C-2. Map Showing Distribution and Vertical Thickness of XCU, Crystalline-rock Confining Unit (3)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

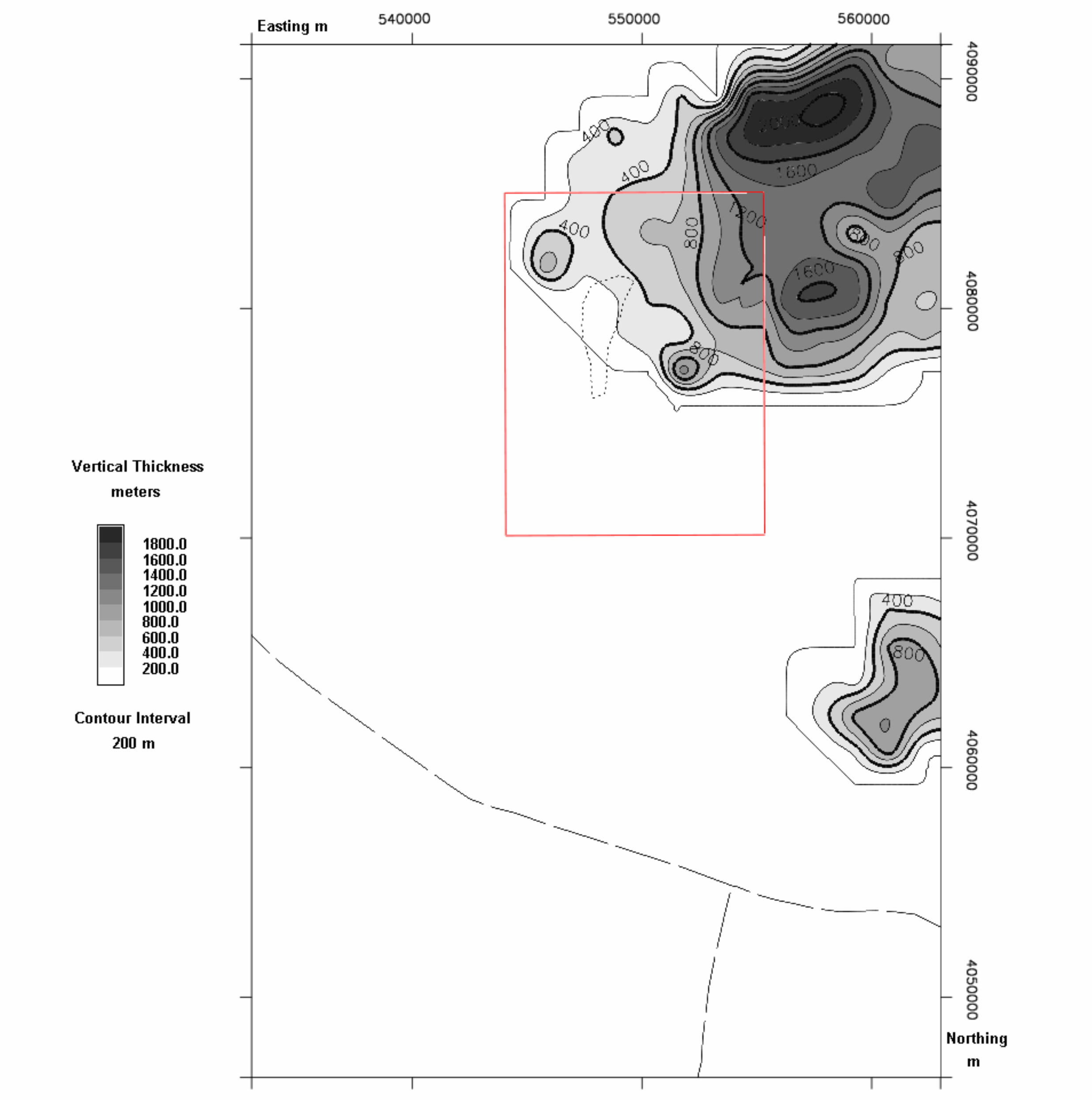
Figure C-3. Map Showing Distribution and Vertical Thickness of LCCU, Lower Clastic-rock Confining Unit (4)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

Figure C-4. Map Showing Distribution and Vertical Thickness of LCA, Lower Carbonate-rock Aquifer (5)



Source: Output DTN: MO0610MWDHFM06.002.

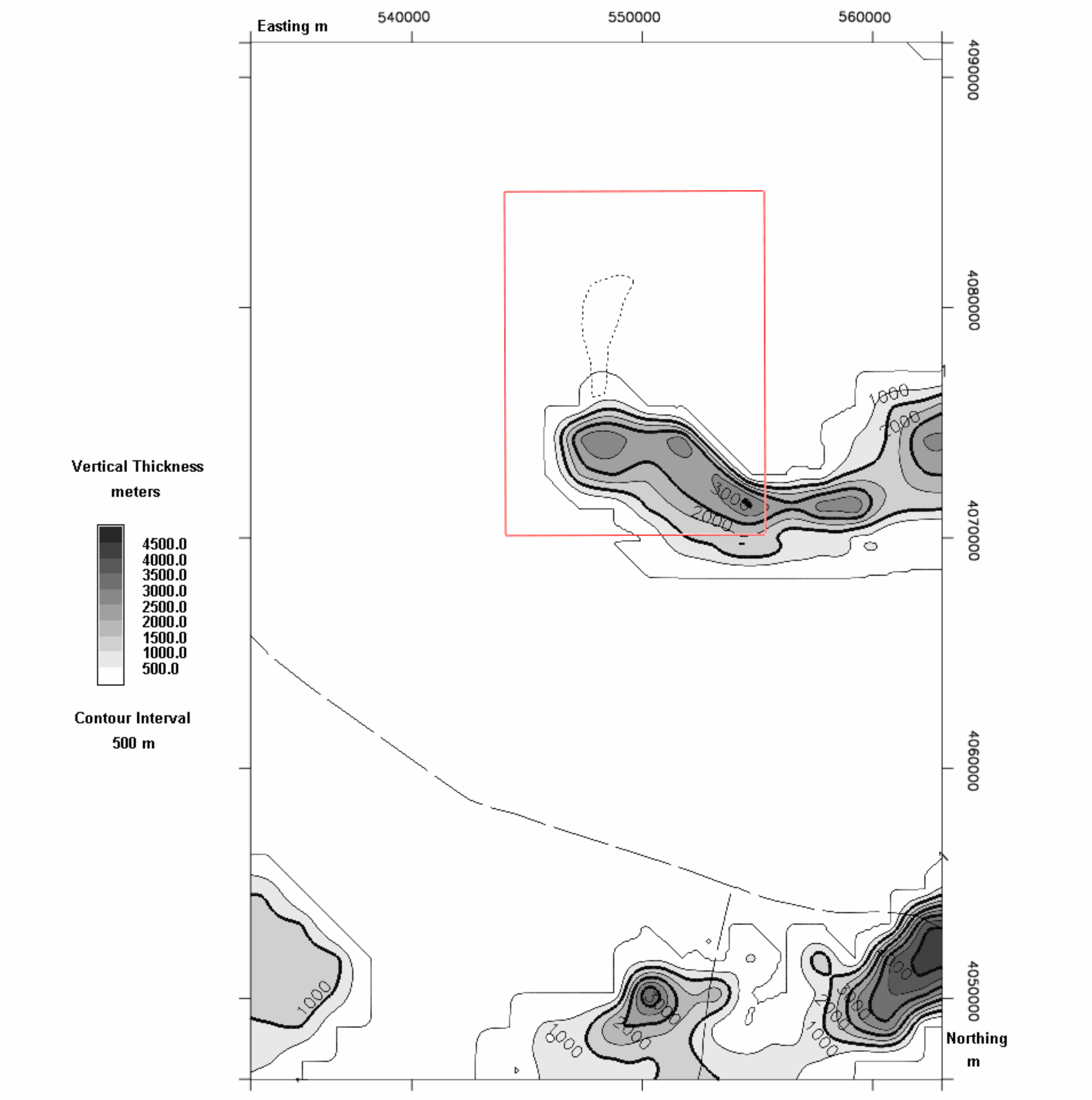
NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

Figure C-5. Map Showing Distribution and Vertical Thickness of UCCU, Upper Clastic-rock Confining Unit (thrusted) (6)

Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

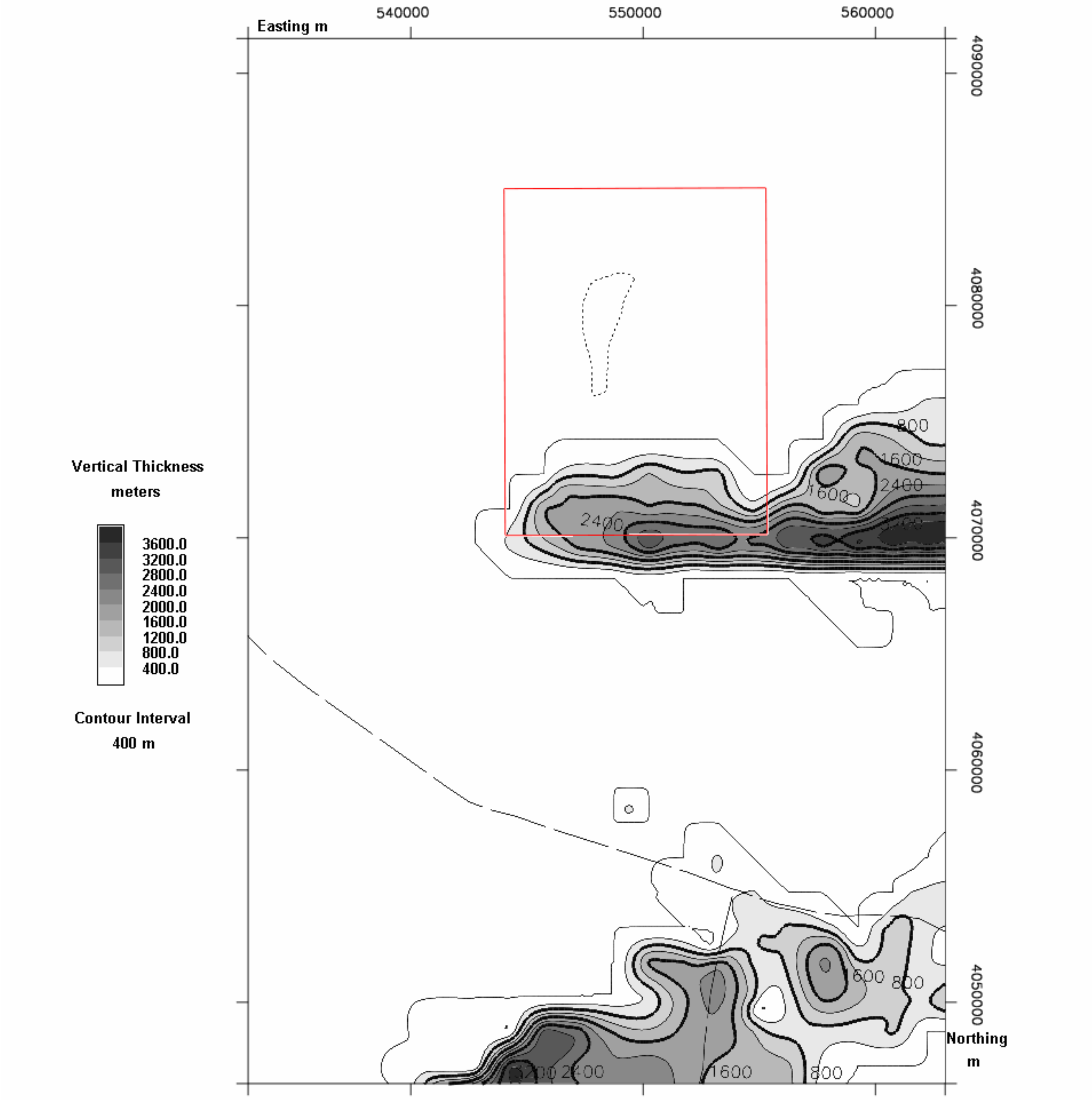
Figure C-6. Map Showing Distribution and Vertical Thickness of UCA, Upper Carbonate-rock Aquifer (thrusted) (7)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

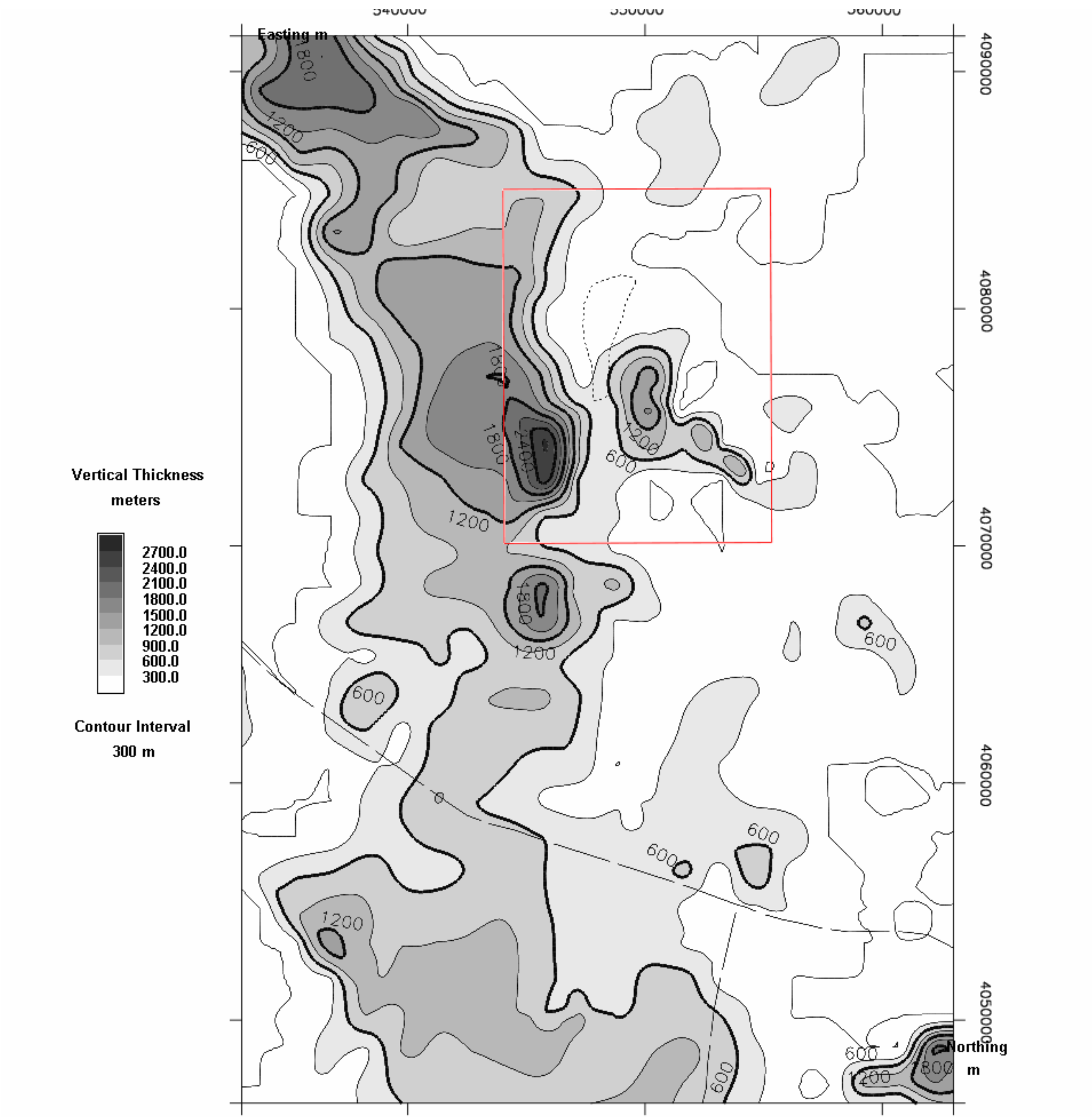
Figure C-7. Map Showing Distribution and Vertical Thickness of LCCU-T1, Lower Clastic-rock Confining Unit (8)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

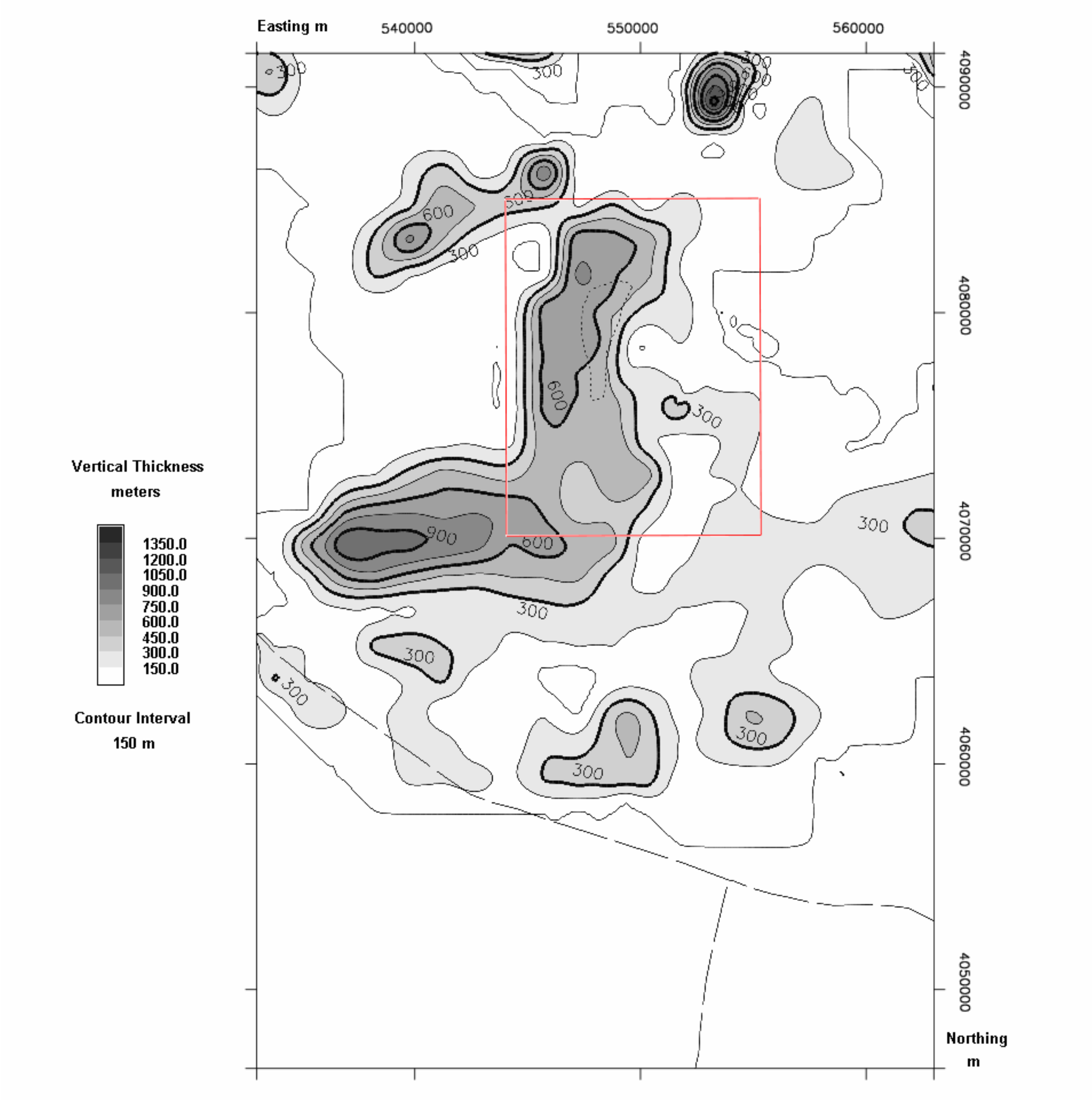
Figure C-8. Map Showing Distribution and Vertical Thickness of LCA-T1, Lower Carbonate-rock Aquifer (9)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

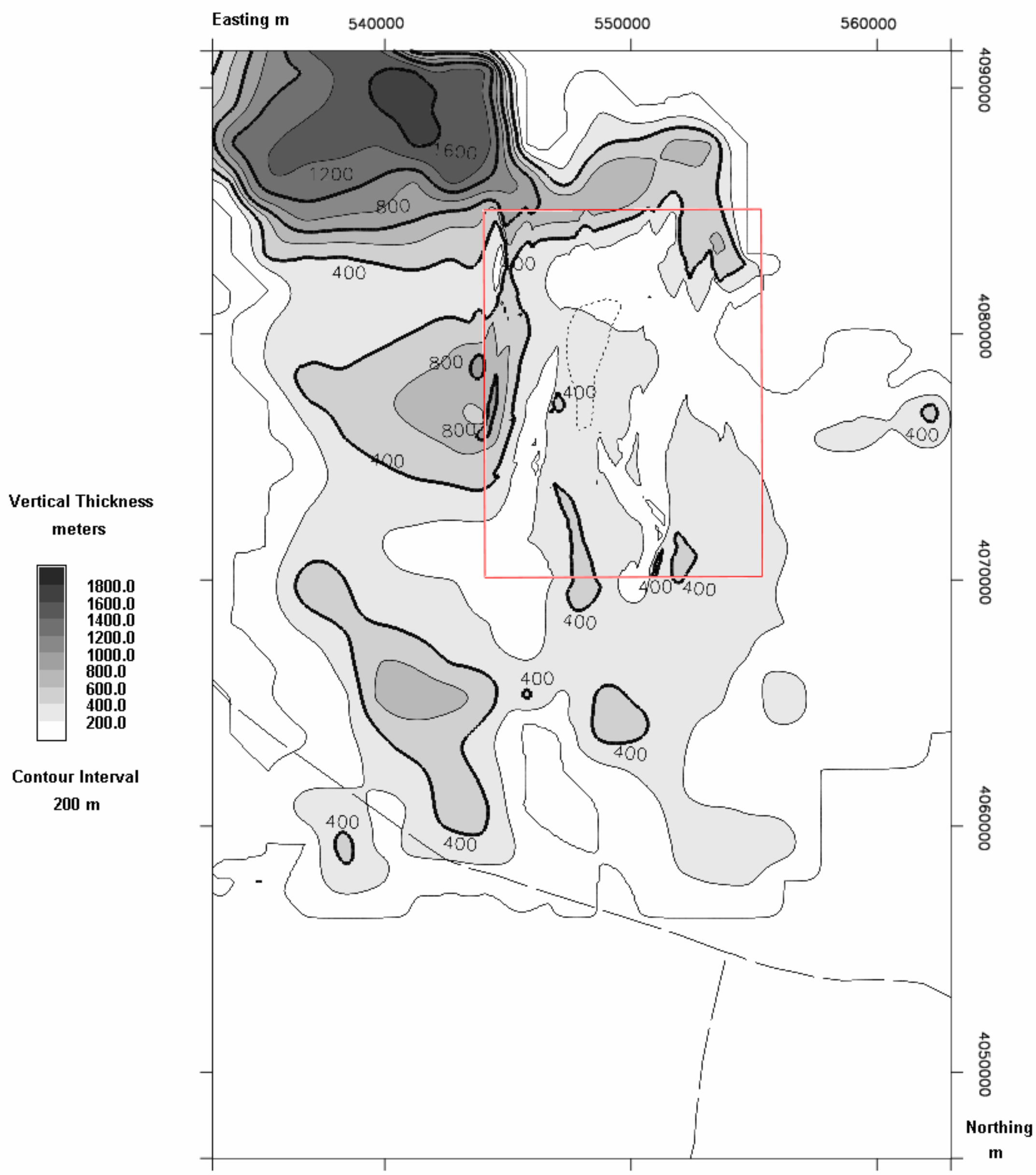
Figure C-9. Map Showing Distribution and Vertical Thickness of Lower VSU, Volcanic- and Sedimentary-rock Unit (11)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

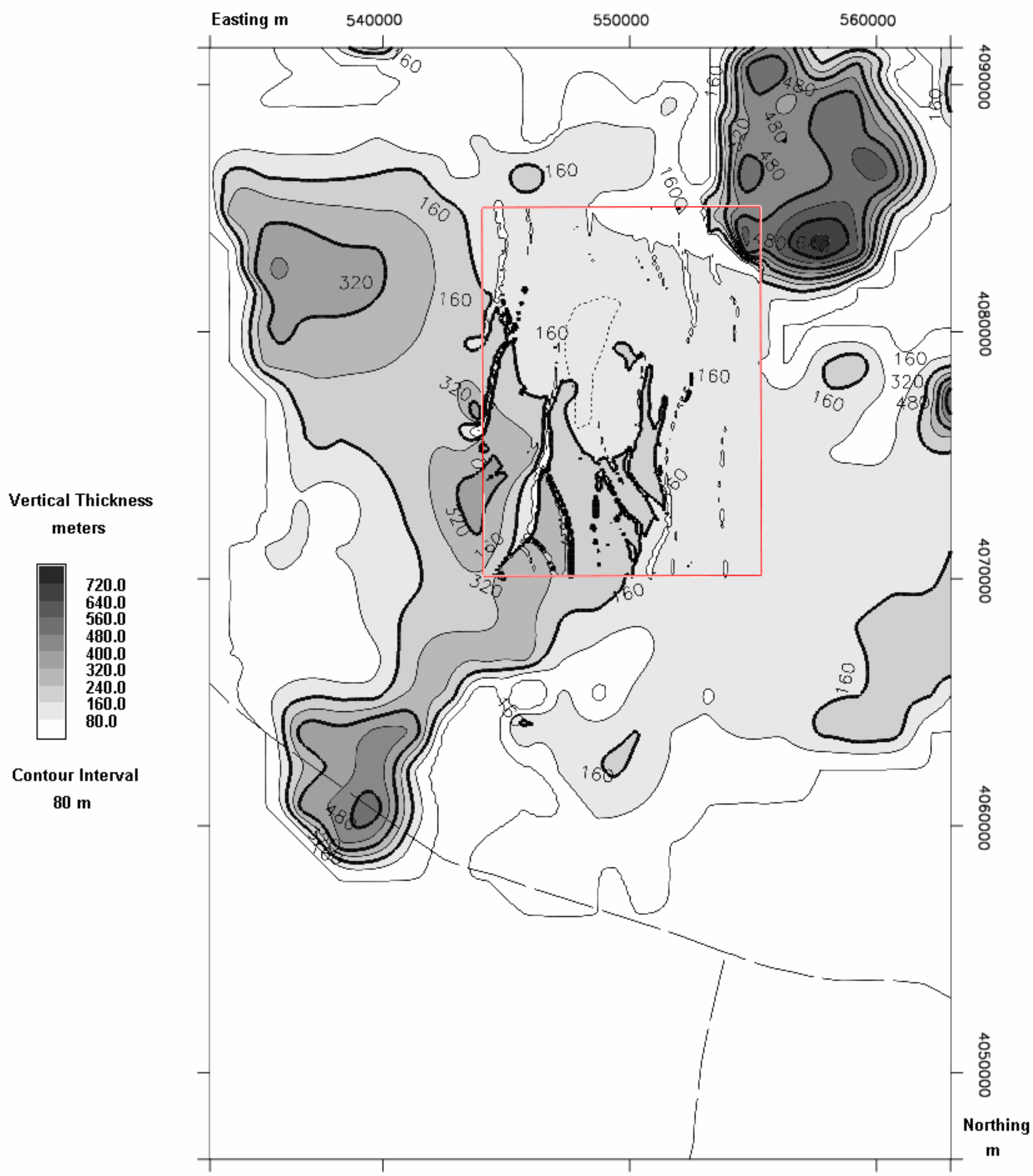
Figure C-10. Map Showing Distribution and Vertical Thickness of OVU, Older Volcanic-rock Unit (12)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

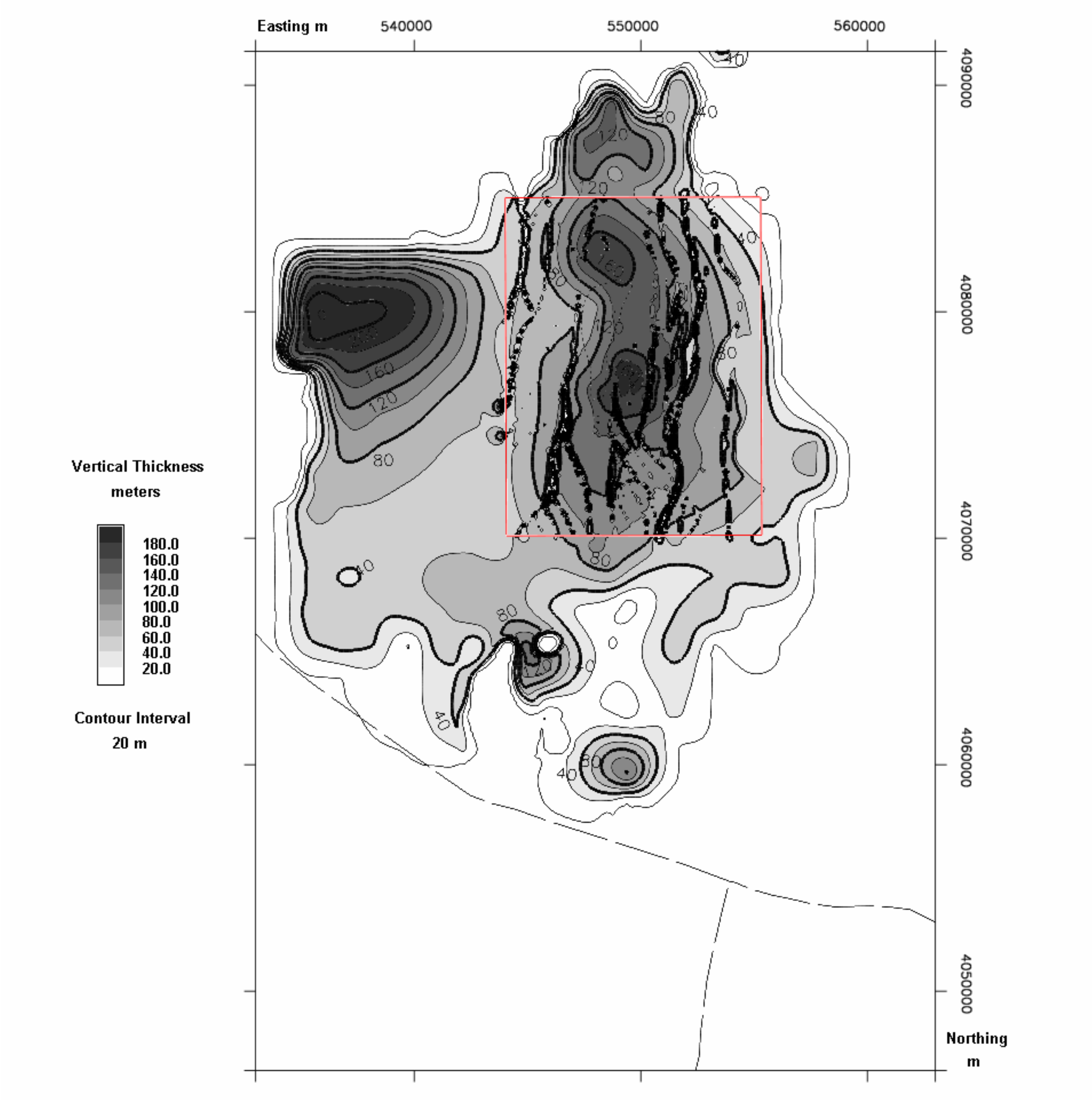
Figure C-11. Map Showing Distribution and Vertical Thickness of CFTA, Crater Flat-Tram Aquifer (14)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Some construction and contouring artifacts are present within the GFM area due to the additional detail present in the input data from coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

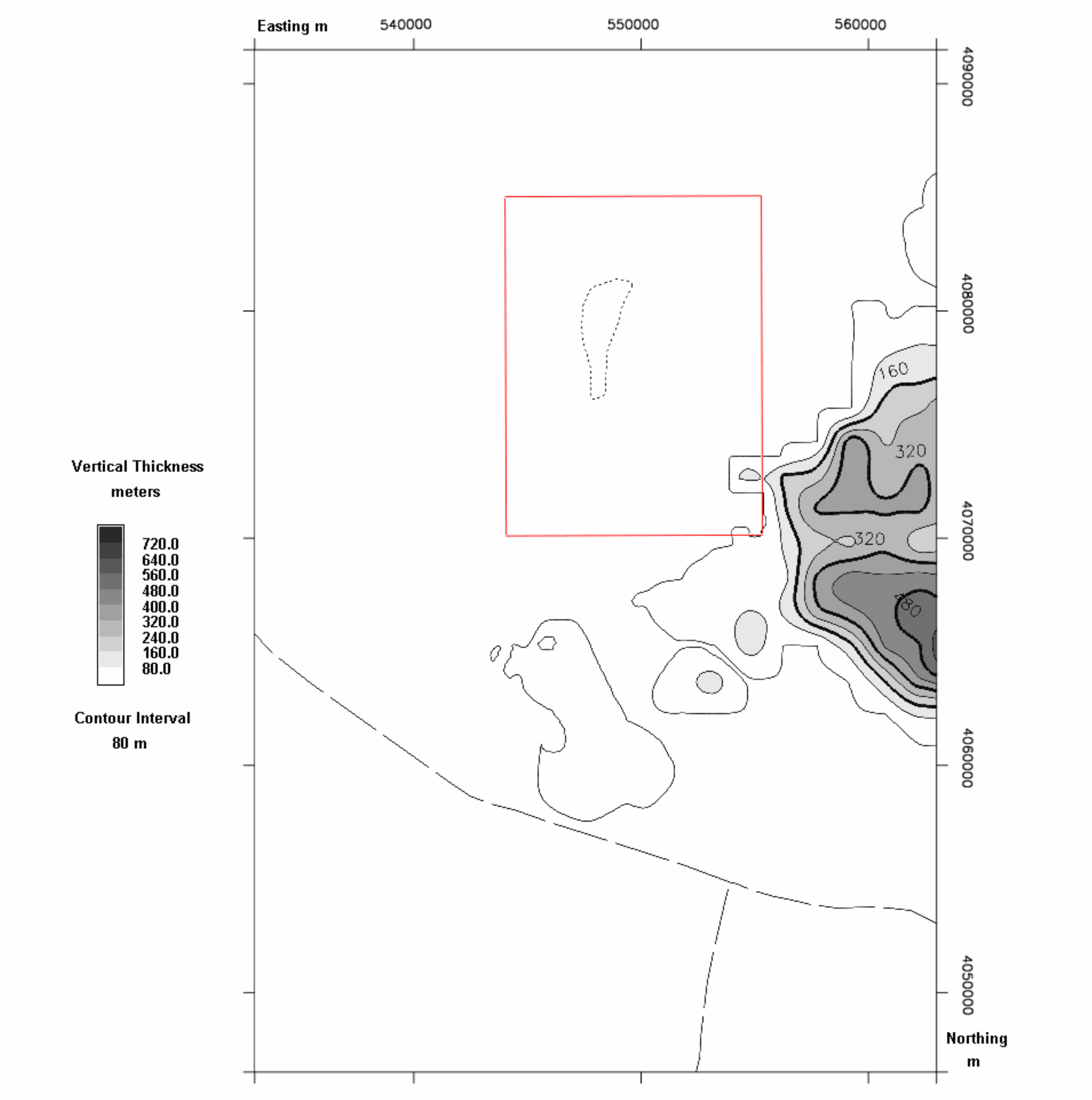
Figure C-12. Map Showing Distribution and Vertical Thickness of CFBCU, Crater Flat-Bullfrog Confining Unit (15)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Some construction and contouring artifacts are present within the GFM area due to the additional detail present in the input data from coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

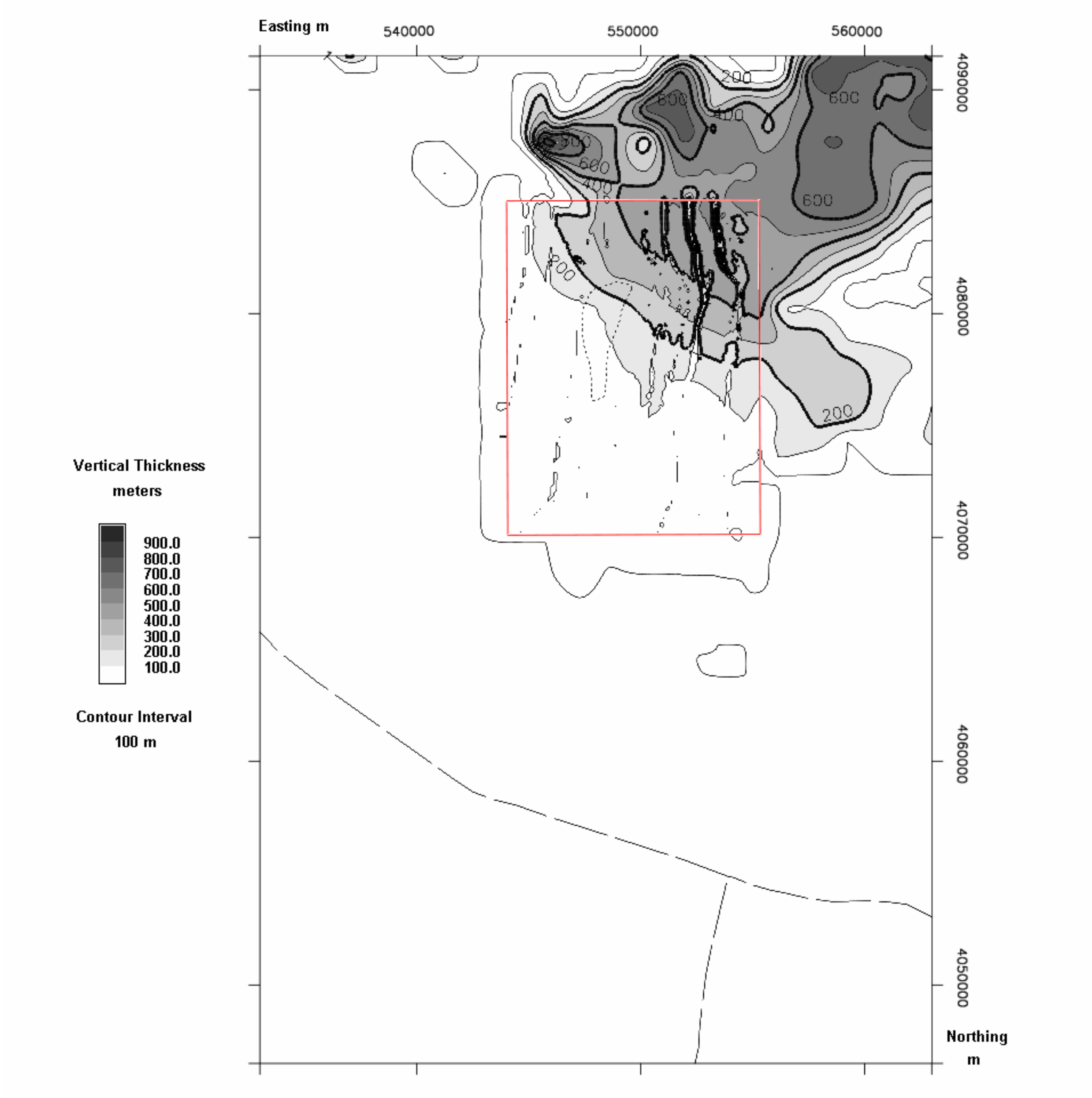
Figure C-13. Map Showing Distribution and Vertical Thickness of CFPPA, Crater Flat-Prow Pass Aquifer (16)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

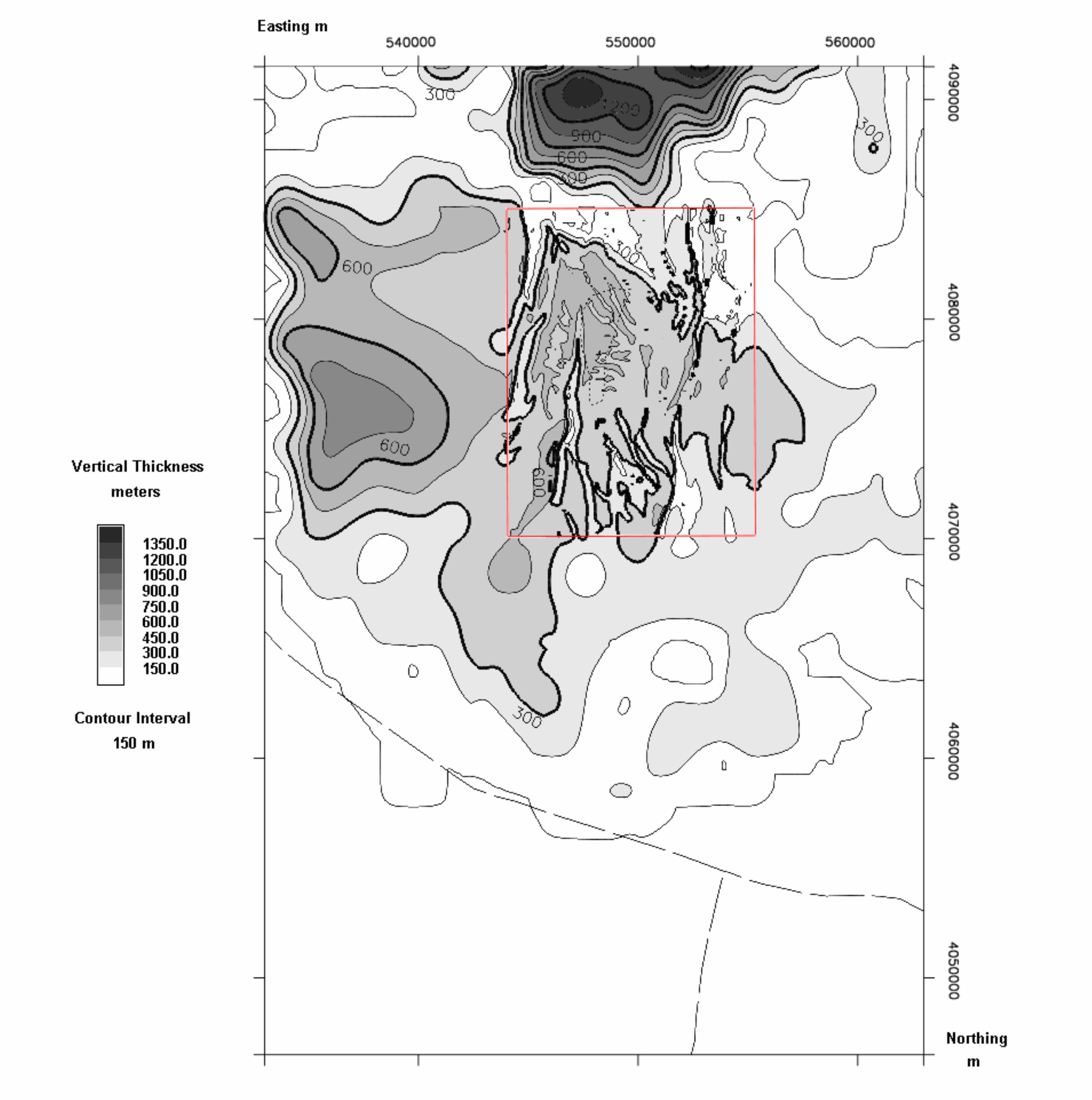
Figure C-14. Map Showing Distribution and Vertical Thickness of WVU, Wahmonie Volcanic-rock Unit (17)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Some construction and contouring artifacts are present within the GFM area due to the additional detail present in the input data from coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

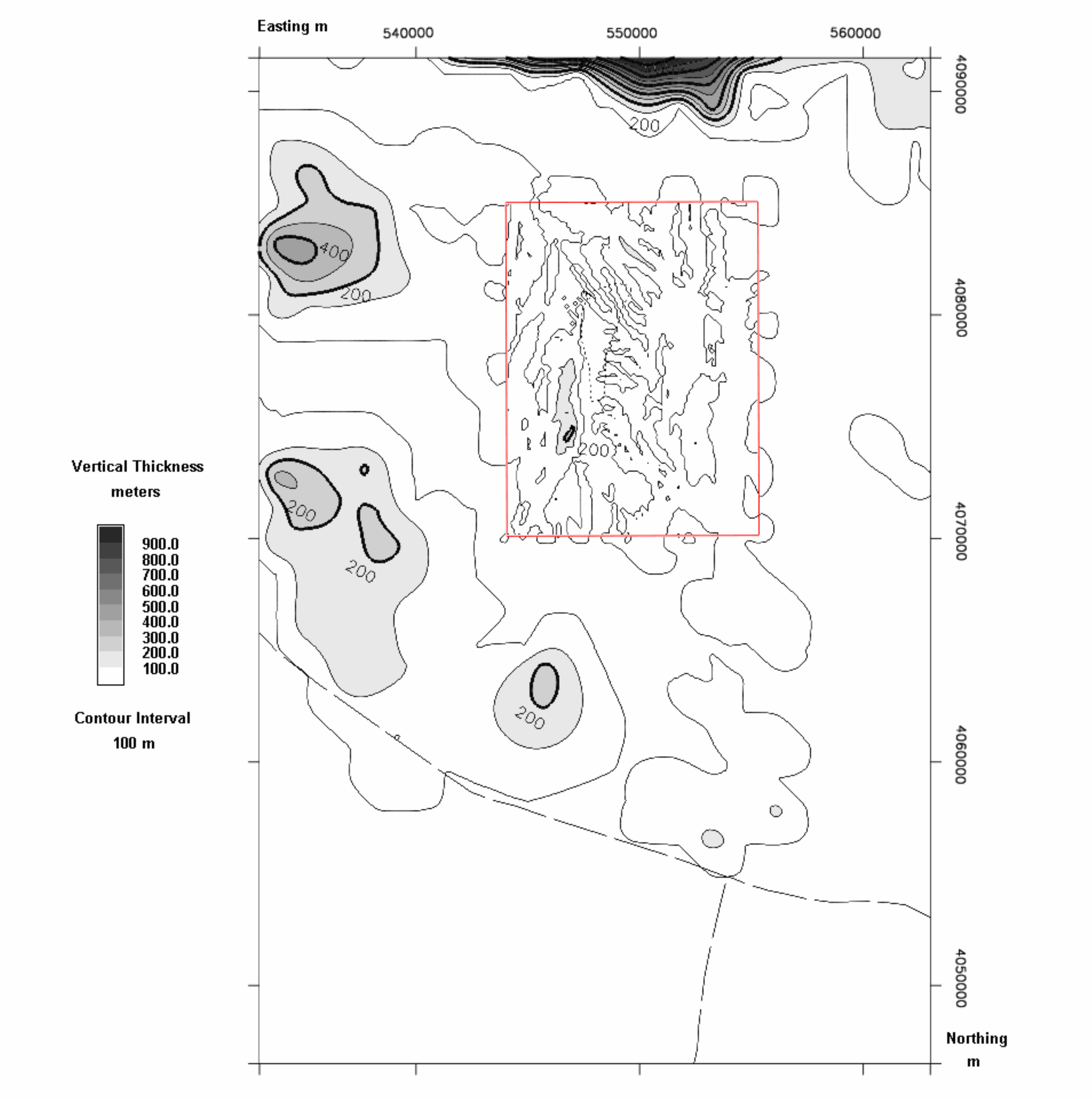
Figure C-15. Map Showing Distribution and Vertical Thickness of CHVU, Calico Hills Volcanic-rock Unit (18)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Some construction and contouring artifacts are present within the GFM area due to the additional detail present in the input data from coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

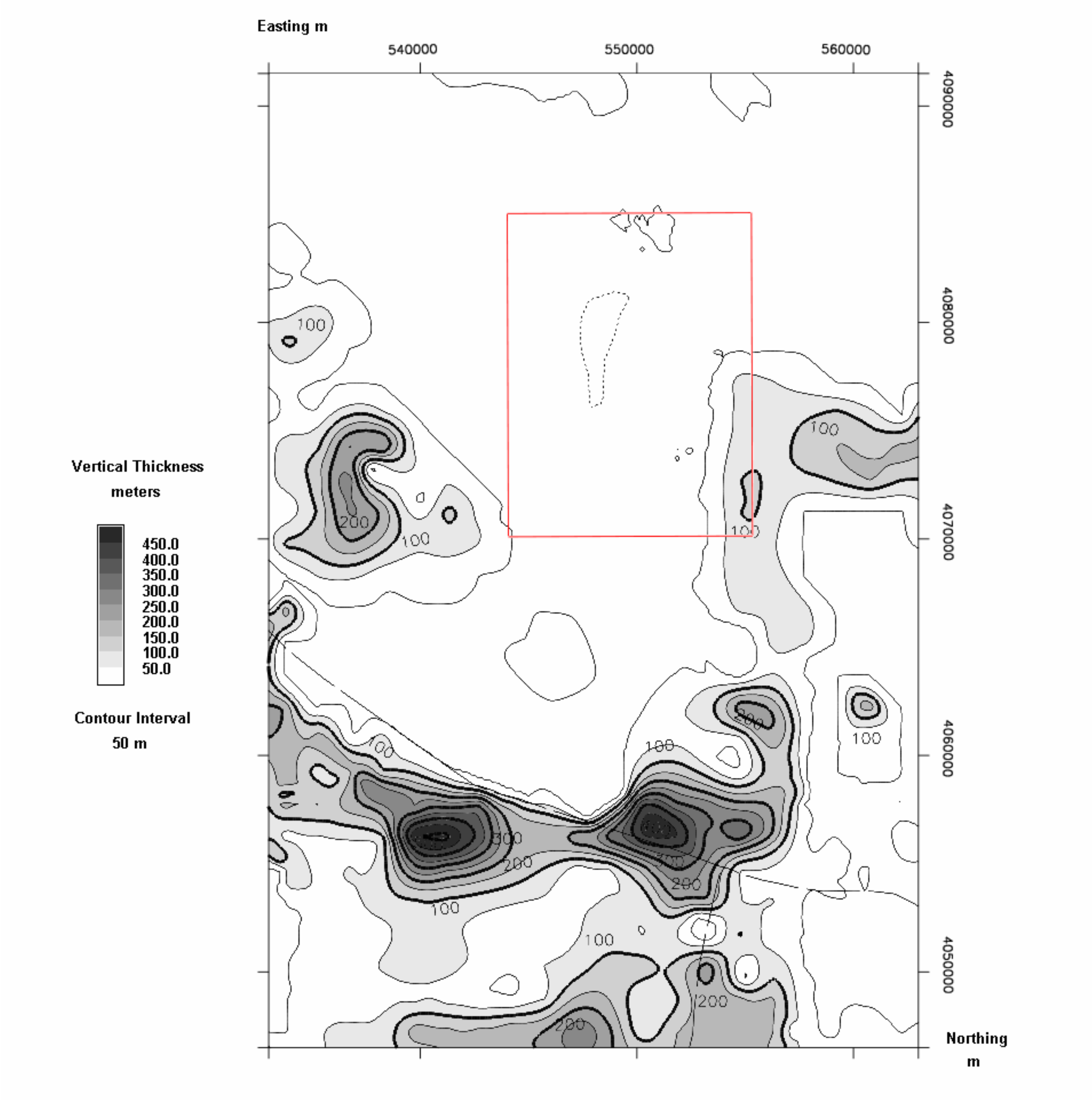
Figure C-16. Map Showing Distribution and Vertical Thickness of PVA, Paintbrush Volcanic-rock Aquifer (19)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Some construction and contouring artifacts are present within the GFM area due to the additional detail present in the input data from coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

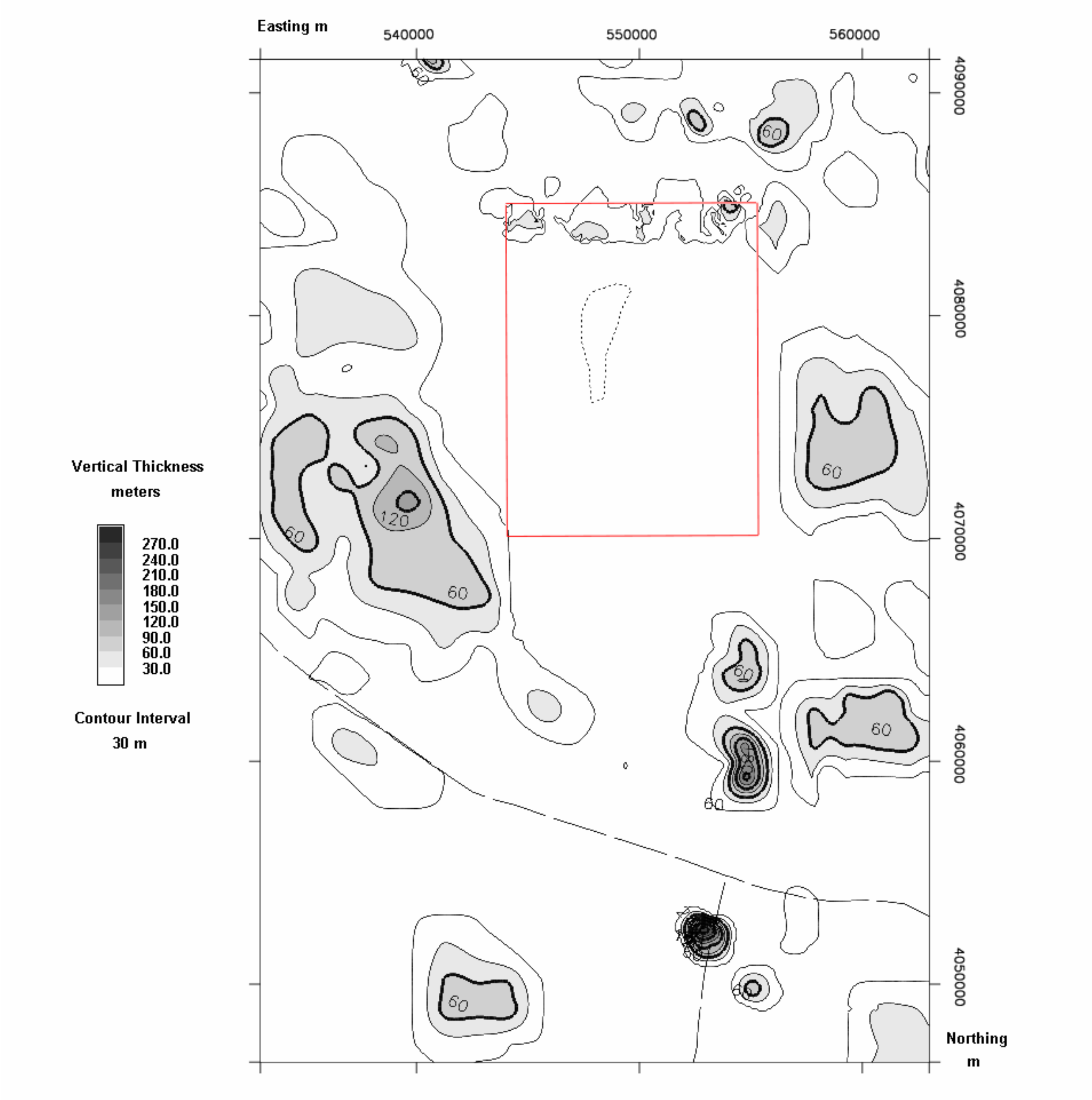
Figure C-17. Map Showing Distribution and Vertical Thickness of TMVA, Thirsty Canyon-Timber Mountain Volcanic-rock Aquifer (20)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

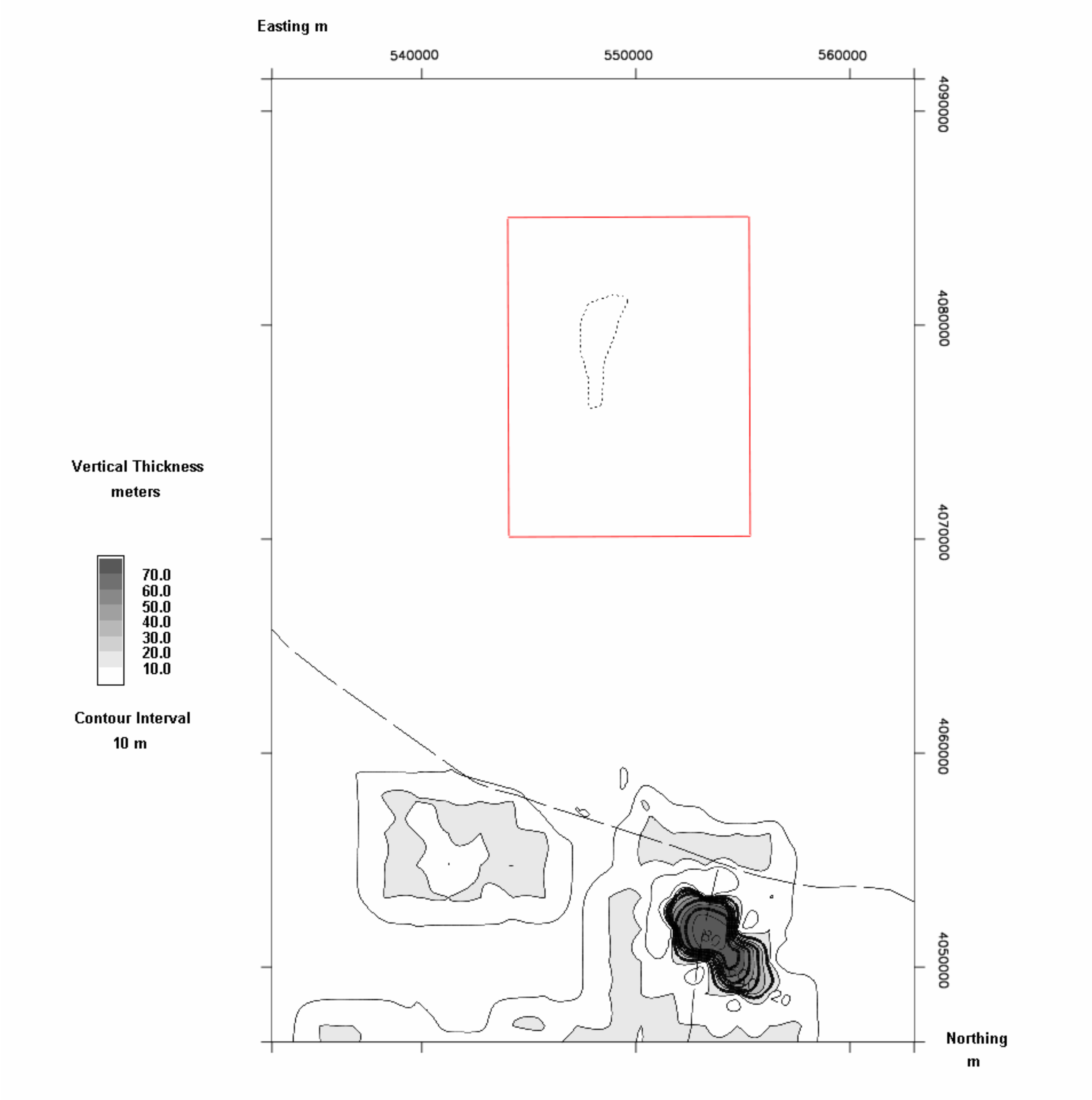
Figure C-18. Map Showing Distribution and Vertical Thickness of Upper VSU, Volcanic- and Sedimentary-rock Unit (21)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

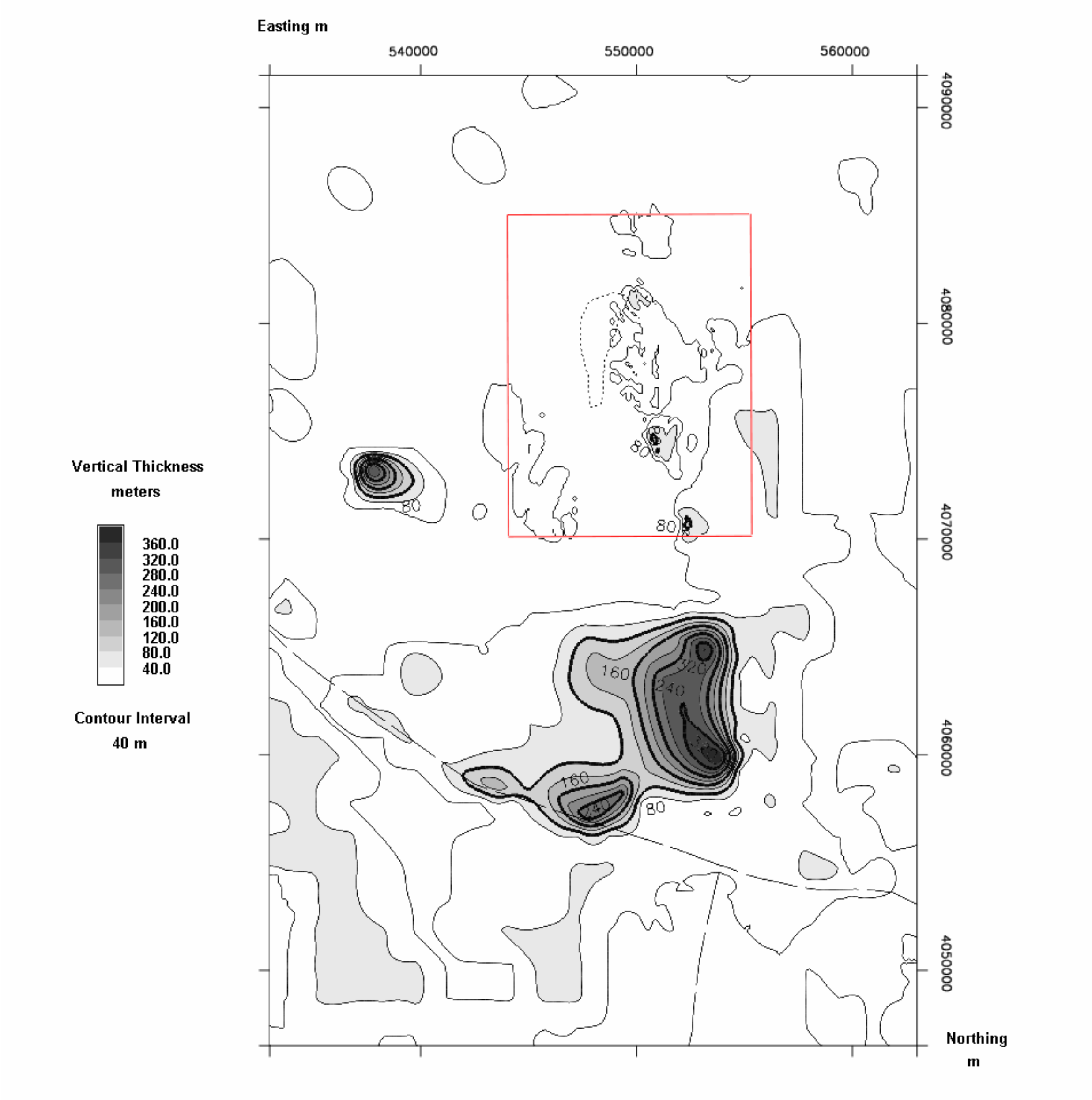
Figure C-19. Map Showing Distribution and Vertical Thickness of LFU, Lava-flow Unit (23)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

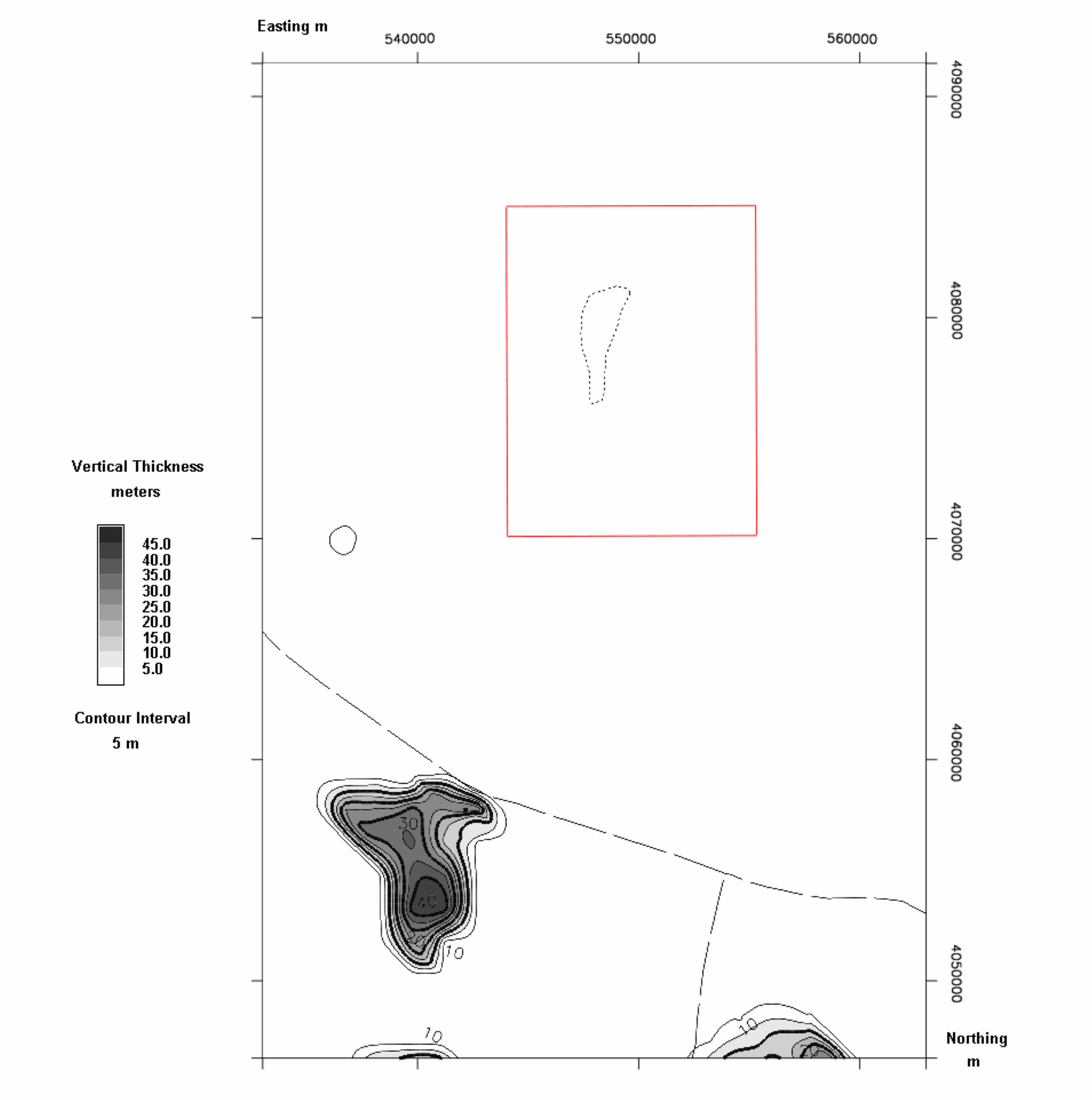
Figure C-20. Map Showing Distribution and Vertical Thickness of LA, Limestone Aquifer (24)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

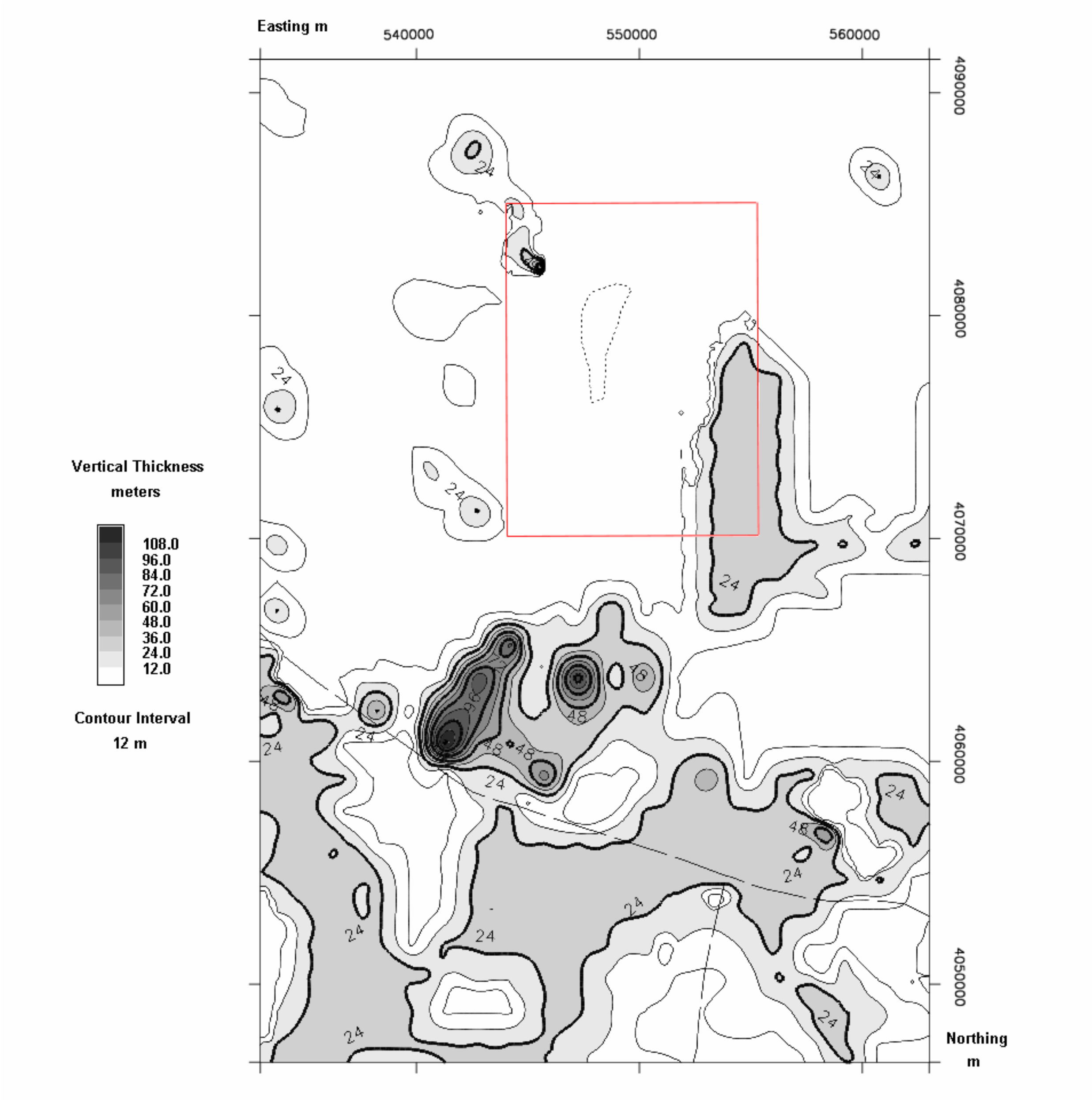
Figure C-21. Map Showing Distribution and Vertical Thickness of OAA, Older Alluvial Aquifer (26)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

Figure C-22. Map Showing Distribution and Vertical Thickness of YACU, Younger Alluvial Confining Unit (27)



Source: Output DTN: MO0610MWDHFM06.002.

NOTE: Coordinates in UTM, Zone 11, NAD27, meters. Solid line shows GFM2000 area. Dotted lines show emplacement outline (BSC 2003 [DIRS 165572]). Dashed lines show Highways 95 and 373.

Figure C-23. Map Showing Distribution and Vertical Thickness of YAA, Younger Alluvial Aquifer (28)

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