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11. Remarks

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T. Vogt and D. Gillies prepared Data Qualification Reports for DTN: MO0212GWLSSPAX.000; these are presented in Attachment IV.

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Revision History

12. Revision/ICN No.	13. Description of Revision/Change
00	Initial Issue Block 8: Jennifer Hinds prepared the entire document and performed analyses and (See Addendum 1)
00/01	Deficiency Report LVMO-00-D-039, Inaccurate Documentation And Validation of Software Routines And/or Macros, identified software issues that are addressed in MOL.20001016.0228 (See Addendum 2)
01	Entire scientific analysis documentation was revised. Changes were too extensive to use Step 5.7c)1) per AP-SIII.9Q/Rev.0/ICN 1.

Addendum 1
modeling except for the analyses utilizing the software Wingridder, which were performed by Lehua Pan.
Block 9: The entire document was checked by Richard Stover and Peter Persoff.

Addendum 2
(Hinds 2001), additional software documentation. The information in the record will be integrated into the AMR as part of the next revision or ICN.

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ACRONYMS

1-D	one dimensional
2-D	two dimensional
3-D	three dimensional
AC	Acceptance Criterion
ACC	Accession Number
AMR	Analysis/Model Report
AP	Administrative Procedure (DOE)
BSC	Bechtel SAIC Company, LLC
CFR	Code of Federal Regulations
CRWMS	Civilian Radioactive Waste Management System
DIRS	Document Input Reference System
DKM	Dual-Permeability Model
DOE	Department of Energy
DTN	Data Tracking Number
ECM	effective-continuum model
ECRB	Enhanced Characterization of Repository Block
ESF	Exploratory Studies Facility
FEPs	Features, Events, and Processes
FY	Fiscal Year
GFM	Geologic Framework Model
HGU	hydrogeologic unit
IED	Information Exchange Drawings
IFD	integral finite difference
ISM	Integrated Site Model
ITN	Input Tracking Number
Ksat	saturated hydraulic conductivity
LA	License Application
LBNL	Lawrence Berkeley National Laboratory
masl	meters above sea level
M&O	Management and Operating Contractor

ACRONYMS (Continued)

NRC	Nuclear Regulatory Commission
NSP	Nevada State Plane
OCRWM	Office of Civilian Radioactive Waste Management
ORD	Office of Repository Development
PA	Performance Assessment
QAP	Quality Administrative Procedure (M&O)
QARD	Quality Assurance Requirements and Description
QIP	Quality Implementing Procedure
RIS	Records Information System
RPM	Rock Properties Model
SCM	Software Configuration Management
STN	Software Tracking Number
TBV	To Be Verified
TDMS	Technical Data Management System
TWP	Technical Work Plan
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
UZ	unsaturated zone
YMP	Yucca Mountain Project
YMRP	Yucca Mountain Review Plan

1. PURPOSE

This Scientific Analysis report describes the methods used to develop numerical grids of the unsaturated hydrogeologic system beneath Yucca Mountain. Numerical grid generation is an integral part of the development of the Unsaturated Zone Flow and Transport Model (UZ Model), a complex, three-dimensional (3-D) model of Yucca Mountain. This revision incorporates changes made to both the geologic framework model and the proposed repository layout. The resulting numerical grids, developed using current geologic, hydrogeologic, and mineralogic data, provide the necessary framework to: (1) develop calibrated hydrogeologic property sets and flow fields, (2) test conceptual hypotheses of flow and transport, and (3) predict flow and transport behavior under a variety of climatic and thermal-loading conditions. The technical scope, content, and management of this Scientific Analysis report was initially controlled by the planning document, *Technical Work Plan (TWP) for: Unsaturated Zone Sections of License Application Chapters 8 and 12* (BSC 2002 [159051], Section 1.6.4). This TWP was later superseded by *Technical Work Plan for: Performance Assessment Unsaturated Zone* (BSC 2002 [160819]), which contains the Data Qualification Plan used to qualify the DTN: MO0212GWLSSPAX.000 [161271] (See Attachment IV).

Grids generated and documented in this report supersede those documented in previous versions of this report (BSC 2001 [159356]). The constraints, assumptions, and limitations associated with this report are discussed in the appropriate sections that follow. There were no deviations from the TWP scope of work in this report. Two software packages not listed in Table IV-2 of the TWP (BSC 2002 [159051]), ARCINFO V7.2.1 (CRWMS M&O 2000 [157019]; USGS 2000 [148304]) and 2kgrid8.for V1.0 (LBNL 2002 [154787]), were utilized in the development of the numerical grids; the use of additional software is accounted for in the TWP (BSC 2002 [159051], Section 13). The use of these software packages is discussed in Sections 3 and 6.1.1.

The steps involved in numerical grid development include: (1) defining the location of important calibration features, (2) determining model grid layers and fault geometry based on the Geologic Framework Model (GFM), the Integrated Site Model (ISM), and definition of HGUs, (3) analyzing and extracting GFM and ISM data pertaining to layer contacts and property distributions, (4) discretizing and refining the two-dimensional (2-D), plan-view numerical grid, (5) generating the 3-D grid, with finer resolution at the proposed repository horizon and within the Paintbrush nonwelded (PTn) and ch1 (Uppermost Calico Hills Formation (Table 11)) hydrogeologic units, and (6) formulating the dual-permeability mesh. The products of grid development include a set of one-dimensional (1-D) vertical columns of gridblocks for hydrogeologic-property-set inversions, a 2-D UZ Model vertical cross-sectional grid for fault hydrogeologic-property calibrations, and a 3-D UZ Model grid for additional model calibrations and generating flow fields for Performance Assessment (PA).

Note that the repository layout utilized in constructing the numerical grids (BSC 2002 [159527]) has been superseded by a revised repository design (BSC 2003 [161726]; BSC 2003 [161727]) that does not include the lower block area. Because the repository layout used for grid construction includes all of the area covered by the most recent repository design, the use of the older repository design for grid construction will not impact License Application (LA) model calculations that utilize these grids.

Numerical grid generation is an iterative process that must achieve a proper balance between desired numerical accuracy in terms of gridblock size and computational time controlled by the total number of gridblocks. Gridblock size should reflect the scale of the process to be modeled. For example, to capture flow and transport phenomena along individual waste emplacement drifts, gridblock thickness and width should not exceed the drift diameter or the drift spacing. For large models, such as the site-scale UZ Model of Yucca Mountain, flow and transport phenomena occurring on scales of less than a few meters cannot be captured. Rather, the model is intended to provide an overview of key UZ characteristics and processes potentially affecting repository performance.

Grids must also be adapted to the particular needs of the processes to be modeled because sharp gradients may occur in different domains for different flow processes. At Yucca Mountain, the heterogeneous, variably fractured layers are better represented by a dual-continuum (matrix and fracture) model, rather than a single-continuum approach. Once developed, the UZ Model numerical grids are evaluated for appropriate resolution, representation of important features, and proper gridblock connections.

The following list of Features, Events, and Processes (FEPs) was taken from the LA FEP List (DTN: MO0301SEPFEPS1.000 [161496]). The LA FEP List is a revision to the previous project FEP list (Freeze et al. 2001 [154365]) used to develop the list of included FEPs in the *Technical Work Plan for: Performance Assessment Unsaturated Zone* (BSC 2002 [160819], Table 2-6). The selected FEPs are those taken from the LA FEP List that are associated with the subject matter of this report, regardless of the anticipated status for exclusion or inclusion in Total System Performance Assessment for License Application (TSPA-LA) as represented in BSC (2002 [160819]). The results of this analysis are part of the basis for the treatment of FEPs as discussed in the *Total System Performance Assessment-License Application Methods and Approach* (BSC 2002 [160146], Section 3.2.2). The cross-reference for each FEP to the relevant sections of this report is also given below.

- Stratigraphy (LA FEP Number 1.2.02.02.0A). Stratigraphic information has been extracted from GFM2000 (DTN: MO0012MWDGFM02.002 [153777]), modified using the hydrogeologic unit (HGU) definitions of Flint 1998 [100033], and explicitly included in this report. See Sections 5.2, 6.3, 6.4 and 6.6.3 for discussion of stratigraphy.

- Faults (LA FEP Number 2.2.03.01.0A). Faults, which can focus flow, are included as discrete features in the unsaturated zone (UZ) Flow Model and the numerical grids generated in this report. See Sections 5.2, 6.2, 6.3, and 6.6.1 for discussion of faults.

2. QUALITY ASSURANCE

Development of this Scientific Analysis report and the supporting analyses have been determined to be subject to the Yucca Mountain Project's quality assurance program as documented in *Technical Work Plan for: Unsaturated Zone Sections of Licence Application Chapters 8 and 12* (BSC 2002 [159051], Attachment I, Work Package P421224UP2) and *Technical Work Plan for: Performance Assessment Unsaturated Zone* (BSC 2002 [160819], Section 8.2 Work Package AUZM06). Approved quality assurance (QA) procedures identified in the technical work plan (BSC 2002 [159051], Attachment IV; BSC 2002 [160819], Attachment II) have been used to conduct and document the activities described in this Scientific Analysis report. The technical work plan also identifies the methods used to control the electronic management of data (BSC 2002 [159051], Attachment II, Work Package P421224UP2; BSC 2002 [160819], Section 8.4) during the analysis and documentation activities.

The procedure AP-SIII.2Q, *Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data*, was utilized to qualify an input data file (DTN: MO0212GWLSSPAX.000 [161271]) used to delineate the water table. This file was derived from the unqualified DTN: MO0110MWDGFM26.002 [160565]. The derivative file was reviewed and qualified using the Data Qualification Plan found in the *Technical Work Plan for: Unsaturated Zone Performance Assessment* (BSC 2002 [160819], Attachment III). The data reviews for DTN: MO0212GWLSSPAX.000 [161271] are presented in Attachment IV.

This Scientific Analysis reports on hydrogeologic units (HGUs) that are identified as natural barriers that are included in the *Q-List* (YMP 2001 [154817]) as "Quality Level – 1" items important to waste isolation. The report contributes to the analysis and modeling data used to support performance assessment; the conclusions do not directly impact engineered features important to safety as defined in AP-2.22Q, *Classification Criteria and Maintenance of the Monitored Geologic Repository Q-List*.

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3. USE OF SOFTWARE

The software used in this study, listed in Table 1, was obtained from Software Configuration Management (SCM), was appropriate for the intended application, and was used only within the range of validation in accordance with applicable software procedures. The qualification and baseline status of each of these codes is given in the Document Input Reference System (DIRS).

Table 1. Qualified Software Used in Numerical Grid Development

Software Name	Version	Software Tracking Number (STN)	DIRS Reference Number
EARTHVISION	5.1	10174-5.1-00	152614
ARCINFO	7.2.1	10033-7.2.1-00	157019
ARCINFO	7.2.1	10033-7.2.1-01	148304
WINGRIDDER	2.0	10024-2.0-00	154785
2kgrid8.for	1.0	10503-1.0-00	154787
TOUGH2	1.4	10007-1.4-01	146496

The use of the codes identified in Table 1 is documented in Section 6 and in the supporting scientific notebooks identified in Section 6. EARTHVISION V5.1 (Dynamic Graphics 1998 [152614]) is used to evaluate and extract data from the Geologic Framework Model (GFM2000) and Integrated Site Model (ISM3.1) files listed in Attachment I, and to create grids utilizing the hydrogeologic units (HGUs) of Flint (1998 [100033], pp. 21–32). ARCINFO V7.2.1 (CRWMS M&O 2000 [157019]; USGS 2000 [148304]) was used to convert potentiometric contours into ACSII format for use in qualification of water table data used in this report (see Attachment IV). The WINGRIDDER V2.0 (LBNL 2002 [154785]) software program is used to generate 1-, 2-, and 3-D gridblock element and connection information in a TOUGH2 format (the primary mesh is an "effective-continuum model," or "ECM," mesh) (Pruess 1991 [100413]). Data extracted from the HGU grids generated by EARTHVISION V5.1 are used as input to WINGRIDDER V2.0 to construct the TOUGH2 grid files. WINGRIDDER V2.0 contains new functionality that allows for a proposed repository with multiple subregions. The software program 2kgrid8.for V1.0 (LBNL 2002 [154787]) generates a dual-permeability mesh from a primary ECM mesh for modeling applications, using the TOUGH2 family of codes. TOUGH2 V1.4 (LBNL 2000 [146496]) was used to perform a test simulation to check the 3-D grid, as described in Attachment III. EARTHVISION V5.1, WINGRIDDER V2.0, ARCINFO V7.2.1 and 2kgrid8.for V1.0 are qualified under AP-SI.1Q, *Software Management*.

Microsoft Excel (97 SR-2) and Adobe Illustrator V8.0 were used to plot data and illustrate information generated in the gridding process. Several computations were performed using this commercial off-the-shelf software and are exempt from AP-SI.1Q. All information needed to reproduce the work, including the input, computation, and output, is included in this Scientific Analysis report and the references specified.

A fault slope analysis was conducted in Section 6.3. The Slope Grid Calculation utility in EARTHVISION V5.1 was used to determine the slope (rise/run) of each fault within the UZ: this input is listed in the second column of Table 13. Excel97 (SR-2) was used to make the following conversions: (1) arctangent of slope = fault dip in radians, and (2) radians to degrees. The output of these conversion calculations is given in columns 3–5 of Table 13. The specific details of these calculations can be found in Wang 2002 ([159673], SN-LBNL-SCI-213-V1, pp. 73–74).

The relative proximity of all boreholes within the UZ Model grid area was examined to determine whether or not neighboring boreholes should be grouped as composite locations. Boreholes that were closer than 80 m to another borehole were paired with the neighboring borehole, and an average borehole location was determined for use in grid construction. All borehole coordinates were converted from Nevada State Plane (NSP) (feet) to NSP (meter) coordinates for the use in the UZ Model grid construction, as discussed in Section 6.2.

These calculations are performed using Excel97 (SR-2) in the file “borehole loc.xls” (Output-DTN: LB0208HYDSTRAT.001). The input (NSP feet) coordinates for the boreholes are listed in columns A and B and rows 1 and 2 of the worksheet “All Boreholes” in the Excel file “borehole loc.xls” (Output-DTN: LB0208HYDSTRAT.001). For each borehole combination, where x_1, y_1 are the coordinates of borehole 1, and x_2, y_2 are the coordinates of borehole 2, the distance between the boreholes was calculated as the square root of the sum of the squares of the differences in x and y coordinates, given as the equation:

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad \text{(Eq. 1)}$$

This calculated distance was then converted from feet to meters using the conversion factor 1 ft = 0.3048 m, and the output values are listed in the worksheet “All Boreholes” in the Excel file “borehole loc.xls” (Output-DTN: LB0208HYDSTRAT.001). Boreholes that are within 80 m of one another were then paired together in the worksheet “Selected Boreholes (ft)” in the Excel file “borehole loc.xls” (Output-DTN: LB0208HYDSTRAT.001). Average x, y coordinates (NSP ft values from worksheet “All Boreholes” in the Excel file “borehole loc.xls” (Output-DTN: LB0208HYDSTRAT.001)) were calculated as $(x_1 + x_2)/2$ and $(y_1 + y_2)/2$. All of the borehole coordinates were then converted to meters using the conversion factor 1 ft = 0.3048 m. The output for this calculation is in the worksheet “Selected Boreholes (m)” in the Excel file “borehole loc.xls” and the file “boreholes_Rick_updated.hol” (Output-DTN: LB0208HYDSTRAT.001), and is also given in Table 10 and Figure 1b. The specific details of these calculations can be found in Wang 2003 ([162380], SN-LBNL-SCI-213-V1, p. 71).

Contact elevations from the input file “contacts00el.dat” (see GFM2000 files in Attachment I) were converted from feet to meters using the conversion factor 1 ft = 0.3048 m, and the resulting values are listed in Table II-1. These calculations were performed using Excel97 (SR-2).

As mentioned in Section 6.4.1, some of the GFM2000 isochore files were combined or subdivided using the EARTHVISION V5.1 Formula Processor to generate the UZ Model HGU isochores. For validation purposes (see Attachment II), the output UZ Model HGU contact elevations for boreholes in the file “Boreholes.mck” from Output-DTN: LB02081DKMGRID.001 were compared to layer contact elevations in the file “contacts00el.dat” from DTN: MO0012MWDGFM02.002 [153777]. The GFM2000 borehole elevations from “contacts00el.dat” were first converted to feet to meters using the conversion factor of 1 ft = 0.3048 m. The unit contact elevations were then adjusted in the same manner as described in Section 6.4.1 to make the GFM2000 stratigraphic units correspond to the UZ Model HGUs. These calculations were performed using Excel97 (SR-2). The output data for these calculations are recorded in Table II-1 under the columns labeled GFM2000.

There are actually two different "foot" units. One of these, the U.S. Survey foot, used for geodetic survey coordinates, is defined as 1,200 m = 3,937 ft, while the standard foot is equal to 0.3048 m (IEEE/ASTM SI 10-1997 [151762], pp. 18, 25). By using the standard foot-to-meter conversion factor (instead of the more appropriate U.S. Survey foot conversion), a small error is introduced into the model. For example, the NSP coordinates for the borehole G-1 (given as 561,000 E, 770,502 N in NSP ft in "contacts00el.dat") convert to 170,993.1 E, 234,849.0 N in NSP m using the conversion factor of 0.3048 m/ft, and to 170,993.4 E, 234,849.5 N using the more appropriate U.S. Survey feet conversion factor. The model grid is not sensitive to the magnitude of the maximum difference (0.5 m) resulting from the use of the 0.3048 m/ft conversion factor.

Models used in the development of the UZ Model numerical grids include the Geologic Framework Model (GFM2000) (DTN: MO0012MWDGFM02.002 [153777]), and the Rock Properties Model of the Integrated Site Model, Version 3.1 (RPM3.1) (DTN: MO9910MWDISMRP.002 [145731]). Data from the Mineralogic Model of the Integrated Site Model, Version 3.1 (MM3.1) (DTN: MO9910MWDISMMM.003 [119199]) and the Rock Properties Model 2000 (RPM2000) (DTN: SN0112T0501399.004 [159524]) were evaluated during grid development, but were not directly incorporated into the UZ Model grids (discussed in Section 6.6.3).

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4. INPUTS

The initial stage of grid development begins with the definition of lateral domain and proposed repository boundaries, along with the location of important calibration features (e.g., boreholes). In order to generate a 3-D grid, WINGRIDDER V2.0 (LBNL 2002 [154785]) requires specification of three reference horizons: an upper and lower model boundary (usually the bedrock surface and water table, respectively) and a structural reference horizon that defines layer displacement along fault traces and sets the elevation of the remaining layer interfaces. These reference horizon files consist of regularly spaced x, y, and elevation data. Isochore (borehole unit thickness) maps, consisting of regularly spaced x, y, and thickness data for each model layer, are then stacked above or below the structural reference horizon to build the vertical component of the UZ Model.

4.1 DATA AND PARAMETERS

The input data used directly in numerical grid development are summarized in Table 2. The Q-status of each of these Data Tracking Numbers (DTNs) can be determined by referring to the Document Input Reference System (DIRS). Uncertainty in the input data and parameters is discussed in Section 7.1.

Table 2. Summary of Direct Input Data Used in Numerical Grid Development

Description	DTN	Data Use[3]
Geologic Framework Model (GFM2000)	MO0012MWDGFM02.002 [153777]	6.1, 6.2, 6.4, Attachments I, II, III
Water Table Elevations	MO0106RIB00038.001 [155631] GS010608312332.001 [155307] MO0212GWLSSPAX.000 [161271][1]	6.3, 6.4.2, Attachment IV
Fracture Data for Hydrogeologic Units	LB0205REVUZPRP.001 [159525][2] LB0207REVUZPRP.001 [159526][2]	6.7

NOTE: [1] See Attachment IV for qualification of DTN MO0212GWLSSPAX.000 [161271]
[2] Use of these Qualified-Verification Level 2 DTNs as direct input is permissible because this report does not directly support any principal factor.
[3] Sections where the data used are described in detail.

The primary data feed for UZ Model grids is the Geologic Framework Model (GFM2000) (DTN: MO0012MWDGFM02.002 [153777]). The GFM2000 is a representation of lithostratigraphic layering and major fault geometry in the Yucca Mountain area that was created using geologic mapping and borehole data as primary input data (BSC 2002 [159124], Section 4.1). The model contains information about layer thickness and layer contact elevation, and defines major fault orientation and displacement. The data for each layer and each fault within GFM2000 are available on a regular horizontal grid spacing of 61 × 61 m over the model's domain (methodology described in BSC 2002 [159124], Section 6.4; data files in DTN: MO0012MWDGFM02.002 [153777]). A total of 50 geologic units and 44 faults are represented in GFM2000. As listed in Attachment I, 42 of these units and 19 faults (those that lie within the UZ Model domain) are incorporated into the 3-D UZ Model grids. Alternate geologic models are not available for use in the UZ Model, nor were they developed. The conceptual model used in the development of GFM2000 is founded on the observation that Yucca Mountain is composed of volcanic rocks originating from several calderas or vent sources (BSC 2002 [159124], Section 6.4.1). The resulting geologic interpretation it represents is the ORD's geologic model to be used in site-scale process models. GFM2000 files used in UZ Model grid development are listed in Attachment I.

As discussed in Sections 5.1 and 6.4.2, the lower UZ Model boundary is based on water table elevations given in DTN: MO0106RIB00038.001 [155631] and the contoured potentiometric surface (DTN: MO0212GWLSSPAX.000 [161271]). Table 3 includes water-level data from DTN: MO0106RIB00038.001 [155631], along with the water-level elevation for USW WT-24 as reported in DTN: GS010608312332.001 [155307].

Table 3. Water Levels in Selected Boreholes

Borehole ID[1]	Water Level Elevation (masl)
USW G-2 [2]	1020.2
USW G-3 [2]	730.5
USW H-1 [2]	730.8
USW H-3 [2]	731.5
USW H-4 [2]	730.4
USW H-5 [2]	775.5
USW H-6 [2]	776.0
USW WT-1 [2]	730.4
USW WT-2 [2]	730.6
UE-25 WT#3	729.6
UE-25 WT#4 [2]	730.8
UE-25 WT#6 [2]	1034.6
USW WT-7 [2]	775.8
USW WT-10	776.0
USW WT-11	730.7

Table 3. Water Levels in Selected Boreholes (cont.)

Borehole ID[1]	Water Level Elevation (masl)
UE-25 WT# 12	729.5
UE-25 WT#13	729.1
UE-25 WT#14	729.7
UE-25 WT#15	729.2
UE-25 WT#16 [2]	738.3
UE-25 WT#17	729.7
UE-25 WT#18 [2]	730.8
UE-25 WT-24 [2]	840.1[3]
UE-25 J#13	728.4
UE-25 b#1 [2]	730.6
UE-25 c#2	730.2
UE-25 c#3	730.2

Source: From DTN: MO0106RIB00038.001 [155631] (except data for WT-24). WT-24 datum from DTN: GS010608312332.001 [155307].

NOTES: [1] For simplicity, the borehole names used throughout the remainder of this document drop the USW and UE-25 prefixes.
[2] These boreholes lie within or along UZ Model boundaries.
[3] Elevation as reported in DTN: GS010608312332.001 [155307]).

Fracture hydrogeologic properties (DTNs: LB0205REVUZPRP.001 [159525] and LB0207REVUZPRP.001 [159526]) describing UZ Model layers are used to formulate the dual-permeability (dual-k) meshes for 1-D hydrogeologic-property-set inversions, for 2-D fault property calibration, and for 3-D UZ Model calibration and flow fields for PA. Fracture hydrogeologic properties used for dual-k grid generation are listed in Table 4.

Table 4. Fracture Hydrogeologic Properties

Model Layer	Fracture Porosity (m^3/m^3)	Fracture Aperture (m)	Fracture Frequency (m^{-1})	Fracture Interface Area (m^2/m^3)
tcw11	2.4E-02	7.3E-04	9.2E-01	1.6E+00
tcw12	1.7E-02	3.2E-04	1.9E+00	1.3E+01
tcw13	1.3E-02	2.7E-04	2.8E+00	3.8E+00
ptn21	9.2E-03	3.9E-04	6.7E-01	1.0E+00
ptn22	1.0E-02	2.0E-04	4.6E-01	1.4E+00
ptn23	2.1E-03	1.8E-04	5.7E-01	1.8E+00
ptn24	1.0E-02	4.3E-04	4.6E-01	3.4E-01
ptn25	5.5E-03	1.6E-04	5.2E-01	1.1E+00
ptn26	3.1E-03	1.4E-04	9.7E-01	3.6E+00
tsw31	5.0E-03	1.6E-04	2.2E+00	3.9E+00
tsw32	8.3E-03	2.0E-04	1.1E+00	3.2E+00
tsw33	5.8E-03	2.3E-04	8.1E-01	4.4E+00
tsw34	8.5E-03	9.7E-05	4.3E+00	1.4E+01
tsw35	9.6E-03	1.5E-04	3.2E+00	9.7E+00
tsw36	1.3E-02	1.6E-04	4.0E+00	1.2E+01
tsw37	1.3E-02	1.6E-04	4.0E+00	1.2E+01
tsw38	1.1E-02	1.3E-04	4.4E+00	1.3E+01
tsw39	4.3E-03	2.2E-04	9.6E-01	3.0E+00
ch1VI	6.1E-04	3.0E-04	1.0E-01	3.0E-01
ch2VI	7.7E-04	2.7E-04	1.4E-01	4.3E-01
ch3VI	7.7E-04	2.7E-04	1.4E-01	4.3E-01
ch4VI	7.7E-04	2.7E-04	1.4E-01	4.3E-01
ch5VI	7.7E-04	2.7E-04	1.4E-01	4.3E-01
ch6VI	7.7E-04	2.7E-04	1.4E-01	4.3E-01
ch1Ze	1.6E-04	2.0E-04	4.0E-02	1.1E-01
ch2Ze	3.7E-04	1.3E-04	1.4E-01	4.3E-01
ch3Ze	3.7E-04	1.3E-04	1.4E-01	4.3E-01
ch4Ze	3.7E-04	1.3E-04	1.4E-01	4.3E-01
ch5Ze	3.7E-04	1.3E-04	1.4E-01	4.3E-01
ch6Ze	1.6E-04	2.0E-04	4.0E-02	1.1E-01
pp4	3.7E-04	1.3E-04	1.4E-01	4.3E-01
pp3	9.7E-03	2.4E-04	2.0E-01	6.1E-01
pp2	9.7E-03	2.4E-04	2.0E-01	6.1E-01
pp1	3.7E-04	1.3E-04	1.4E-01	4.3E-01
bf3	9.7E-04	2.4E-04	2.0E-01	6.1E-01
bf2	3.7E-04	1.3E-04	1.4E-01	4.3E-01
tr3	9.7E-04	2.4E-04	2.0E-01	6.1E-01
tr2	3.7E-04	1.3E-04	1.4E-01	4.3E-01
tcwf[1]	2.9E-02	5.5E-04	1.9E+00	1.3E+01
ptnf[1]	1.1E-02	4.1E-04	5.4E-01	1.3E+00
tswf[1]	2.5E-02	4.6E-04	1.7E+00	8.7E+00
chnf[1]	1.0E-03	3.3E-04	1.3E-01	4.6E-01

Source: DTN: LB0205REVUZPRP.001 [159525] and LB0207REVUZPRP.001 [159526]

NOTES: [1]Values for fault fracture properties within the Tiva Canyon welded (tcwf), Paintbrush nonwelded (ptnf), Topopah Spring welded (tswf), and Calico Hills nonwelded (chnf) units.

VI = Vitric Subunit, Ze = Zeolitic Subunit

4.1.1 Other Inputs

The inputs in Table 5 are associated with scientific analyses and interpretations of assumptions listed and discussed in Section 5. The first five rows of inputs are collectively used to assign hydrogeologic nomenclature to layers in the numerical grids. The last two rows of inputs in Table 5 are used to represent the location of the proposed repository and to interpret hydrologic features away from the repository area.

Table 5. Summary of Other Inputs Used in Numerical Grid Development

Description	Reference	Use
Hydrogeologic Unit Definitions	Flint 1998 [100033][1]	Assumption 3
Rock Properties Model (RPM3.1) of Integrated Site Model (ISM3.1)	MO9910MWDISMRP.002 [145731]	Assumptions 4, 5
Mineralogic Model (MM3.1) of Integrated Site Model (ISM3.1)	MO9910MWDISMMM.003 [119199]	Assumption 5
Rock Properties Model (RPM2000)	SN0112T0501399.004 [159524]	Assumptions 4, 5
Rock Property Data (saturation, porosity, hydraulic conductivity)	Boreholes SD-6, SD-7, SD-9, SD-12, UZ-14, UZ-16, NRG-7a, and WT-24: LB0207REVUZPRP.002 [159672] All other boreholes: MO0109HYMXPROP.001 [155989] SD-6: GS980808312242.014 [106748], GS980908312242.038 [107154] SD-7: GS951108312231.009 [108984] SD-12: GS960808312231.004 [108985]	Assumptions 4, 5
Repository Layout Configuration[2]	BSC 2002 [159527]	Assumption 8
Perched-Water Elevations	GS010608312332.001 [155307] MO0106RIB00038.001 [155631]	Assumption 2

NOTE: [1] Hydrogeologic unit definitions (Flint 1998 [100033]) used qualitatively; individual sample data not used.
[2] The latest version of the repository layout (BSC 2003 [161726]; BSC 2003 [161727]) does not include the lower block area.

Geologic data alone cannot adequately capture all important features that affect flow and transport in the UZ at Yucca Mountain. Hydrogeologic rock-property data have also been considered, as discussed in Section 5.2 (Assumption 3). Based on analyses of several thousand rock samples performed by the U.S. Geological Survey (USGS), 30 hydrogeologic units (HGUs) have been identified, based on "limited ranges where a discrete volume of rock contains similar hydrogeologic properties" (Flint 1998 [100033], p. 1, Table 1). Since the hydrogeologic property sets to be calculated with the UZ Model grid use, to a large extent, the matrix-property data collected and analyzed by Flint (1998 [100033]), layering within the numerical grid was chosen to correspond as closely as possible to HGUs to facilitate data usage. The boundaries of HGUs are not defined by regularly spaced data, but are more qualitative in nature. The qualitative descriptions (but not any sample or other data) given in Flint (1998 [100033], pp. 21–32), when correlated with GFM2000 data (DTN: MO0012MWDGFM02.002 [153777]), are used to develop a set of hydrogeologic layers whose thickness and elevation are described by regularly spaced data for the UZ Model.

Because of the importance of mineral (especially zeolitic) alteration for flow and transport calculations, boundaries between vitric and zeolitic areas are defined within certain UZ Model grid layers below the proposed repository horizon. Alteration to zeolites has been shown to greatly reduce permeability (Flint 1998 [100033], p. 32; Loeven 1993 [101258], pp. 18–19, 22) and may increase the rock's ability to adsorb some radionuclides. As discussed in Section 5.2 (Assumptions 4 and 5), the data considered in the numerical grid development for defining low-permeability, zeolitic volumes of rock are obtained from the Rock Properties Model of the Integrated Site Model, Version 3.1 (RPM3.1) (DTN: MO9910MWDISMRP.002 [145731]), along with supporting information from the Rock Properties Model (RPM2000) (DTN: SN0112T0501399.004 [159524]) and the Mineralogic Model of the Integrated Site Model, Version 3.1 (MM3.1) (DTN: MO9910MWDISMMM.003 [119199]). The specific Integrated Site Model (ISM3.1) files used in UZ Model grid development are listed in Attachment I.

As discussed in Section 5.2 (Assumption 8), an assumed proposed repository layout configuration, based on Data Sheets 2 and 3 from *Repository Design, Repository/PA IED Subsurface Facilities Plan Sht. 1 of 5, Sht. 2 of 5, Sht. 3 of 5, Sht. 4 of 5, and Sht. 5 of 5* (BSC 2002 [159527]), is used during numerical grid generation to locate areas of fine spatial resolution. The repository layout used in the formulation of the numerical grids consists of an extended upper repository area (consisting of two parts) that covers much of the footprint of the previous repository as presented in REV 00 ICN 01 (BSC 2001 [159356], Figure 1), and an additional lower repository area that is situated just east of the upper repository area. The areal boundary coordinates for, and elevations of the proposed repository (in meters above sea level, [masl]) are summarized in Table 6 and the proposed repository outline is shown in Figure 1a (Section 6.2). As noted in Section 5.2 (Assumption 8), the proposed repository layout may be subject to future design modifications. The most recent version of the repository layout (BSC 2003 [161726]; BSC 2003 [161727]), created after the formulation of the numerical grids described in this report, does not include the lower block area designated in Table 6.

Table 6. Proposed Repository Boundary Coordinates Used for UZ Model Grids

NSP Easting (m)	NSP Northing (m)	Elevation (masl)
Upper Block, Part A		
170861.2	236062.5	1037.7
170656.9	235911.0	1038.8
170479.8	235768.2	1040.0
170140.8	235061.9	1048.2
170072.5	234017.7	1062.2
170116.0	233520.8	1069.3
170126.2	233438.9	1070.5

Table 6. Proposed Repository Boundary Coordinates Used for UZ Model Grids (cont.)

NSP Easting (m)	NSP Northing (m)	Elevation (masl)
170158.7	233364.4	1071.6
170217.3	233298.2	1072.8
171227.6	233626.5	1072.8
171259.4	234233.0	1064.6
171742.0	234475.0	1063.4
171858.7	235023.9	1056.4
172309.4	235936.8	1045.9
172230.8	236081.7	1043.5
172140.2	236137.4	1038.8
171577.8	236039.8	1041.2
171619.7	236138.6	1040.0
171665.6	236323.9	1037.7
Upper Block, Part B		
171214.0	233366.5	1076.3
170482.2	233128.8	1076.3
170482.2	233128.8	1076.3
170468.6	232357.8	1086.8
170490.0	231513.1	1098.6
170487.4	231341.9	1100.9
170496.4	231089.3	1104.4
170523.6	231013.0	1105.6
170572.7	230943.8	1106.8
171018.4	231088.6	1106.8
171062.8	231188.2	1105.6
171098.4	231284.9	1104.4
Lower Block*		
172628.5	235345.4	1001.3
172613.7	235425.7	1001.9
172084.8	235253.9	1001.9
172012.0	235145.1	1001.3
171890.6	234850.1	999.3
171870.2	234588.0	997.4
171836.4	234491.8	996.7
171339.5	234245.2	996. 1
171225.9	232079.1	979.8
171431.4	232060.7	979.2

Table 6. Proposed Repository Boundary Coordinates Used for UZ Model Grids (cont.)

NSP Easting (m)	NSP Northing (m)	Elevation (masl)
171816.0	232100.5	978.5
171907.2	232045.0	977.9
172369.7	232195.2	977.9
172437.3	233239.2	985.7
172655.8	233906.4	990.2
172414.2	234594.4	996.1
172435.7	234771.7	997.4
172444.1	235030.0	999.3
172542.7	235232.3	1000.6

Source: Repository layout obtained from BSC (2002 [159527]). The coordinates in this table were chosen to represent the basic outline of the proposed repository footprint (as depicted in Figures 1a and 1b). The complete IED coordinate set was utilized to construct the numerical grids.

NOTE: * The latest version of the repository layout (BSC 2003 [161726]; BSC 2003 [161727]) does not include the lower block area which is being used in AMRs supporting License Application (LA) documents.

4.2 CRITERIA

Technical requirements to be satisfied by performance assessment (PA) are based on 10 CFR 63.114 [156605] (*Requirements for Performance Assessment*) and identified in the Yucca Mountain *Project Requirements Document* (Curry and Loros 2002 [157916]). The acceptance criteria that will be used by the Nuclear Regulatory Commission (NRC) to determine whether the technical requirements have been met are identified in the *Yucca Mountain Review Plan, Information Only* (YMRP; NRC 2003 [162418]).

For this Scientific Analysis report, the pertinent requirement is PRD-002/T-015 from Curry and Loros (2002 [157916]), which is linked to 10 CFR 63.114(a-c) [156605]. The acceptance criterion for *Flow Paths in the Unsaturated Zone*, identified in Section 2.2.1.3.6.3 of the YMRP (NRC 2003 [162418]) is Criterion 1, *System Description and Model Integration are Adequate*. As applied to this Scientific Analysis report, the criterion is: The aspects of geology and hydrology that may affect flow paths in the unsaturated zone are adequately considered. Conditions and assumptions in the abstraction of flow paths in the unsaturated zone are readily identified and consistent with the body of data presented in the description.

4.3 CODES AND STANDARDS

No specific formally established codes or standards have been identified as applying to this Scientific Analysis activity.

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5. ASSUMPTIONS

The assumptions presented below are necessary to develop the UZ Model numerical grids. This section presents the rationale and supporting data for the assumptions, and references the section of this report in which each assumption is used. The assumptions presented in this section are similar to those presented in REV00 ICN01 (BSC 2001 [159356], Section 5), and are based on interpretation and synthesis of a variety of geologic and hydrologic inputs. The enhancement in justification of the original assumptions (primarily associated with the inputs in Table 5 presented in Section 4.1.1) is discussed in this section to substantiate interpretations used for the basis of development of numerical grids representing the Yucca Mountain site. The basis of grid development is presented in this section and serves as an overview of detailed scientific analyses presented in Section 6.

Assumptions used in developing the numerical grids are of two kinds: assumptions made about the physical world, and assumptions made about the effects of certain features of the grid upon the results of model calculations. None of the assumptions listed below requires confirmation. No hydrologic and rock property values are assigned, justified, or qualified for gridblocks in this Scientific Analysis report.

Certain features of the grid are simplifications known to be different from the physical prototype. These simplifications are necessary for calculations to be done with existing computers and qualified software. Assumptions about the effects of such simplifications upon the results of calculations can be verified through sensitivity analyses; that is, by running simulations with the assumptions as stated and with alternative assumptions. The effects of numerical grid resolution on flow and transport model simulation results are discussed through the utilization of previous studies.

5.1 ASSUMPTIONS REGARDING PHYSICAL CONDITIONS EXTERIOR TO THE MODELING PROCESS

The following two assumptions pertain to the elevation of the water table, which defines the lower UZ Model boundary.

1. The lower boundary for the UZ Model was established using the regional water table as represented by the potentiometric surface presented in DTN: MO0212GWLSSPAX.000 [161271]. This surface is consistent with borehole water level measurements (DTNs: MO0106RIB0038.001 [155631] and GS010608312332.001 [155307]), but does not represent a unique interpretation of the data (see Sections 6.4.2 and 7.1.1 and Attachment IV for discussion). The water table rises to the west and north, with a base elevation of approximately 730 m above sea level (masl) in the vicinity of the North and South Ramps. The potentiometric surface elevations are based upon reported water table elevations for boreholes in the Yucca Mountain area (see Table 3). The contoured water table elevations, derived from EARTHVISION V5.1 (Dynamic Graphics 1998 [152614]) gridding of the borehole water table elevation and digitized potentiometric map contours taken from DTN:

MO0212GWLSSPAX.000 [161271], are presented in Section 6.2 (Figure 1b) and discussed in Sections 6.4.2 and 7.1.1.

2. It is assumed that the observed water levels in boreholes WT#6 and G-2 (at 1,034 and 1,020 masl, respectively) can be interpreted to be perched water (Section 6.2).

Observed water levels in these two boreholes from northern Yucca Mountain (located east of the Solitario Canyon fault) are much higher than 840 masl, the elevation of the water level encountered in the nearby USW WT-24 borehole, which is interpreted to represent the regional water table. In boreholes WT#6 and USW G-2, water levels measure about 1,034 masl and 1,020 masl, respectively (Table 3). The UZ Model simulates and calibrates to perched-water data under selected portions of northern Yucca Mountain. These two assumptions are supported by a variety of studies on the water table at Yucca Mountain (e.g., BSC 2001 [155950], Figure 12.3.1.2–2; Ervin et al. 1994 [100633], p. 15; Czarnecki et al. 1994 [142594]; Czarnecki et al. 1995 [103371]), as discussed in more detail in Section 6.2.

5.2 ASSUMPTIONS REGARDING NUMERICAL GRID CONSTRUCTION

The geologic data provided in Geologic Framework Model (GFM2000) (DTN: MO0012MWDGFM02.002 [153777]) cannot, by themselves, adequately capture all important features that affect flow and transport in the UZ at Yucca Mountain. Hydrogeologic rock-property data must also be considered.

3. It is assumed that the 30 hydrogeologic units (HGUs) identified by the USGS (Flint 1998 [100033], p. 1, Table 1) based on similarities in rock hydrogeologic properties are adequate to define the layering scheme used for the UZ Model grids (Section 6.3).

Since the hydrogeologic property sets to be utilized in UZ flow and transport modeling use, to a large extent, the matrix properties data collected and analyzed by Flint (1998 [100033]), layering within the numerical grid was chosen to correspond as closely as possible to HGUs to facilitate data usage. The boundaries of HGUs are defined by irregularly spaced data and thus additional borehole data could lead to future adjustments to HGU contact locations. The qualitative descriptions given in Flint (1998 [100033], pp. 21–32), when correlated with GFM2000 data (DTN: MO0012MWDGFM02.002 [153777]), are used to develop a set of hydrogeologic layers (whose thickness and elevation are described by regularly spaced data) for the UZ Model grids. The detailed analysis of hydrogeologic properties and definition of HGUs by Flint (1998 [100033]) provides justification for the use of these units in development of the UZ Model grids.

The distribution of low-permeability zeolites within the Topopah Spring welded (specifically, tsw39) and Calico Hills nonwelded (CHn) HGUs impacts flowpaths and groundwater travel times from the proposed repository horizon to the water table and is, therefore, an important feature to capture in the UZ Model grids. The data considered in numerical grid development for defining low-permeability, zeolitic volumes of rock come from the Rock Properties Model of the Integrated Site Model, Version 3.1 (RPM3.1) (DTN: MO9910MWDISMRP.002 [145731]), from measurements of borehole rock matrix hydrologic properties (DTNs: LB0207REVUZPRP.002 [159672], MO0109HYMXPROP.001 [155989], GS980808312242.014

[106748], GS980908312242.038 [107154], GS951108312231.009 [108984], GS960808312231.004 [108985]), and from corroborative evidence using data from Rock Properties Model (RPM2000) (DTN: SN0112T0501399.004 [159524]) and the Mineralogic Model of the Integrated Site Model, Version 3.1 (MM3.1) (DTN: MO9910MWDISMMM.003 [119199] [see Assumptions 4 and 5]).

The following three assumptions pertain to the definition of low-permeability, zeolitic regions within UZ Model layers corresponding to portions of the TSw and CHn. Within UZ Model layers tsw39, ch1, ch2, ch3, ch4, ch5, and ch6, the tuff has been altered from vitric to zeolitic in some areas and remains unaltered in other areas. For the purposes of flow and transport modeling, the principal differences between these two types of tuff are the adsorptive properties and the saturated hydraulic conductivity. Each gridblock within these UZ Model layers is assigned to either the vitric or zeolitic material. A combination of geologic data is used to define vitric-zeolitic boundaries, including saturated hydraulic conductivity values, matrix saturation measurements, the difference between oven-dried and relative-humidity porosities, and the relative structural position of these layers within the UZ Model area. The assumptions associated with these data are described below.

4. It is assumed that saturated hydraulic conductivity (Ksat) data from the RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) can be used as a surrogate for assigning gridblocks either vitric or zeolitic material names (and thus, separate hydrogeologic properties) within certain layers of the Topopah Spring welded (TSw) and Calico Hills nonwelded (CHn) hydrogeologic units. Vitric rock properties are assigned for areas within UZ Model layers tsw39, ch1, ch2, ch3, ch4, ch5, and ch6 where Ksat is greater than 10^{-10} m/s, whereas zeolitic properties are used where Ksat is less than 10^{-10} m/s (Section 6.6.3).

There are two main reasons why Ksat data are used as a surrogate to assign gridblocks either vitric or zeolitic material names. First, existing data show that the Ksat of vitric tuff is orders of magnitude greater than that of zeolitic tuff (Flint 1998 [100033], Table 7). Also, there are much more available data on Ksat values than on mineralogic alteration (e.g., percentage of zeolite). Results from analyses by Flint (1998 [100033], Table 7) indicate that vitric Ksat values are on the order of 10^{-7} m/s, while zeolitic Ksat values are on the order of 10^{-10} to 10^{-11} m/s. No definitive Ksat cutoff value exists by which to distinguish vitric from zeolitic material, because this transition occurs over about three orders of magnitude. The Ksat-value cutoff of 10^{-10} m/s is somewhat arbitrarily chosen; however, the sensitivity of the 10^{-10} m/s cutoff is not expected to be significant compared to using a 10^{-9} m/s or 10^{-8} m/s cutoff, since these contours are closely spaced in the proposed repository footprint within the RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) (see Figure 3). Based on these observations, no additional confirmation of this assumption is required.

5. It is assumed that, in UZ Model layers tsw39, ch1, ch2, ch3, ch4, ch5, and ch6, tuff is vitric where matrix saturations are relatively low (< ~90%) and the difference between oven-dried (105°C) and relative-humidity porosities are less than 5% (Section 6.6.3).

Results from analyses by Flint (1998 [100033], p. 29) indicate that altered (i.e., zeolitic) nonwelded tuffs have oven-dried porosities that are typically more than 5% higher than relative-humidity porosities. The loss of water from hydrous secondary minerals (such as zeolites and clays) from oven-dried altered tuffs results in higher estimates of the matrix porosity (relative to those obtained using the relative-humidity method) for these samples. Boreholes where oven-dried porosities exceed relative-humidity porosities by more than 5% for each of the UZ Model layers in question (tsw39, ch1-ch6) generally coincide with zeolite-rich zones, as predicted by MM3.1 (DTN: MO9910MWDISMMM.003 [119199]). Based on these observations, no additional confirmation of this assumption is required.

6. It is assumed that major faults with significant vertical displacement may serve as lateral boundaries for vitric (unaltered) areas within UZ Model layers tsw39, ch1, ch2, ch3, ch4, ch5, and ch6 (Section 6.6.3).

Vitric portions of the CHn and Tsw may be laterally continuous within fault blocks that have a higher structural position above the water table compared to adjacent structural blocks. For example, the Solitario Canyon fault offsets the CHn by more than 300 m in the southern part of the UZ Model domain. CHn layers west of the Solitario Canyon fault lie near or below the water table in this area, and thus these tuffs likely have abundant zeolitic alteration. The correlative CHn layers on the east side of the fault may be over 300 m above the water table and are much less likely to have undergone zeolitization, owing to limited water-rock interaction. Because major faults (i.e., Solitario Canyon and Dune Wash faults) determine the proximity of the CHn layers to the water table, they are used as boundaries between vitric and zeolitic areas, where appropriate. The observed structural offsets provide sufficient justification for this assumption.

The next assumption pertains to the representation of faults within the UZ Model grids.

7. It is assumed that the simplification of (a) representing steeply dipping faults as vertical in the UZ Model grids and (b) representing related, near-parallel faults as a single feature that incorporates the cumulative offset (e.g., the Solitario Canyon and Solitario Canyon (west) faults) will not significantly affect model calculations (Sections 6.3, 6.6.1, Attachment III).

The use of a single fault to represent the offset observed for the Solitario Canyon and the Solitario Canyon (west) faults is in part required by the use of wide vertical columns to model dipping faults. If the projection of near-parallel dipping faults overlap over the depth interval of the UZ Model, then separate faults are difficult to portray in the UZ Model grids without the use of very fine gridding. By accomodating the cumulative offset along a single structural feature, the overall structural and stratigraphic integrity of the UZ geology (as represented by GFM2000 in DTN: MO0012MWDGFM02.002 [153777]) is preserved, albeit in a somewhat simplified manner. The representation of structural offset by the UZ Model grids is evaluated in Attachment III, and the results of the grid verification studies indicate that this assumption is justified.

The configuration of the proposed repository layout constitutes the final assumption.

8. It is assumed that the proposed repository layout configuration presented on Data Sheets 2 of 5 and 3 of 5 from *Repository Design, Repository/PA IED Subsurface Facilities Plan Sht. 1 of 5, Sht. 2 of 5, Sht. 3 of 5, Sht. 4 of 5, and Sht. 5 of 5* (BSC 2002 [159527]) is appropriate to define those areas within the numerical grid that require enhanced numerical resolution (Section 6.6.2).

The proposed repository design used was the most recent representation of the repository layout at the time the numerical grids presented in this document were generated and was considered to be the best source for this information. This design consists of an upper (primary) block located west and north of the ESF, and a lower elevation region located east of the primary repository block and areally overlapping part of the ESF. It is recognized that the proposed repository design is still undergoing change, and that future adjustments to the grid resolution may be necessary, depending on final design decisions. As noted in Section 4.1.1, a revised version of the proposed repository layout was created after the formulation of the numerical grids described in this report. The new layout does not include the lower block area delineated in Table 6 and Figures 1a and b. As discussed in Section 3.3.4.8.1 of *FY 01 Supplemental Science and Performance Analyses, Volume 1: Scientific Bases and Analyses* (BSC 2001 [155950]), the use of more refined gridding in the area of the proposed repository layout (see Section 6.6.2, Figures III-3 and III-4) provides needed resolution for flow models. Based on these observations, no additional confirmation of this assumption is required.

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6. SCIENTIFIC ANALYSIS DISCUSSION

6.1 NUMERICAL GRID DEVELOPMENT—OVERVIEW & APPROACH

Numerical grids of the UZ beneath Yucca Mountain are used to develop calibrated hydrogeologic property sets and flow fields, to test conceptual hypotheses of flow and transport, and to predict flow and transport behavior under a variety of climatic and thermal-loading conditions. This report describes the development of three different sets of grids. The purpose and general characteristics of each grid set are summarized in Table 7. A description of the steps involved in the generation of these grids is provided in the following sections and in scientific notebooks. Key scientific notebooks used for numerical grid generation activities described in this Scientific Analysis report, along with relevant page numbers and accession numbers, are listed in Table 8.

Table 7. Summary of Grids Developed for FY02 UZ Modeling Activities

Output DTN (filename)	Purpose	Grid Description
LB02081DKMGRID.001 (Boreholes.mesh)[1] (Mesh_1d.dkm)[2] (Boreholes_NF.mesh)[3] (Boreholes.mck)	1-D hydrogeologic property set inversions and calibrations	Consists of 1-D columns centered at borehole locations. Uses borehole contact elevation picks based on the GFM2000 file "contacts00el.dat" (DTN: MO0012MWDGFM02.002 [153777]) and HGU boundaries defined by Flint (1998 [100033]) and Assumption 3. Hydrogeologic data and fault locations used to define the vitric-zeolitic boundary (Assumptions 4-6). Borehole locations used in the 1-D meshes include: b#1, G-1, G-2, G-4, H-1, H-3, H-4, H-5, H-6, SD-6, SD-7, SD-9, SD-12, NRG#4, NRG#5, NRG-6, NRG-7a, N-11, N-15/16, N-17, N-27, N-31/32, N-33, N-36, N-37, N-38, N-53-54, N-55, N-57/58, N-59/61, N-62, N#63, N-64, UZ#4/5, UZ-6, UZ-7a, UZ-1/14, UZ#16, WT-1, WT-2, WT#4, WT#6, WT-7, WT#18 and WT-24. Uses fracture hydrogeologic data in Table 4 to generate the dual-permeability meshes. *See Attachment II for additional details*.
(EWUZ7a.mesh)[1] (Mesh_2d.dkm)[2] (EWUZ7a_NF.mesh)[3] (EWUZ7a.mck)	2-D fault hydrogeologic property calibration	East-west, cross-sectional grid through borehole UZ-7a. Grid columns are generated using GFM2000 isochore and elevation data provided on a regular grid spacing of 61 × 61 m (DTN: MO0012MWDGFM02.002 [153777]). Uses fracture hydrogeologic data in Table 4 to generate the dual-permeability meshes. *See Section 6.5 and Attachment III for additional details*.
LB03023DKMGRID.001 (Grid_LA_3D.mesh)[1] (Mesh_3dn.dkm)[2] (Grid_LA_3D_NF.mesh)[3] (Grid2002_3D.mck)	3-D UZ Site Scale Modeling	Three-dimensional site-scale model with enhanced discretization along major faults and proposed repository drifts. The 3-D grids are generated using GFM2000 isochore and elevation data provided on a regular grid spacing of 61 × 61 m. Uses fracture hydrogeologic data in Table 4 to generate the dual-permeability meshes. *See Sections 6.6 and 6.7 and Attachment III for additional details*.

NOTES: [1] The primary mesh represents matrix blocks only; also referred to as an effective-continuum model (ECM) grid.

[2] Dual-permeability model (DKM) mesh generated with fracture properties from Table 4 and a 1-D fracture continuum (Type #1 fractures: See Section 6.7 for details).

[3] The "*_NF.mesh" files were used to generate the DKM mesh files, and are not considered output files.

Table 8. YMP Scientific Notebooks Used for FY02 Numerical Grid Development and Grid Verification Analyses

LBNL Scientific Notebook ID	M&O Scientific Notebook ID	Relevant Pages	Citation
YMP-LBNL-YSW-JH-2	SN-LBNL-SCI-143-V1	137–140	Hinds 2001 [155955]
YMP-LBNL-YSW-WZ-1	SN-LBNL-SCI-115-V1	52–56, 66–72	Zhang 2000 [159531]
YMP-LBNL-YSW-JH-3	SN-LBNL-SCI-213-V1	7–34, 63–99	Wang 2002 [159673]
		67, 71, 100-134	Wang 2003 [162380]
YMP-LBNL-GSB-LP-2	SN-LBNL-SCI-103-V1	111–115, 122, 134–141, 145–151	Wang 2002 [159673]
		139	Wang 2003 [162380]
YMP-LBNL-YSW-3	SN-LBNL-SCI-199-V1	82–92	Wang 2002 [159673]
		86, 88-89, 237–238	Wang 2003 [162380]
YMP-LBNL-GSB-LP-2.1	SN-LBNL-SCI-103-V2	17–28	Wang 2003 [162380]

Data extracted from Geologic Framework Model (GFM2000) (DTN: MO0012MWDGFM02.002 [153777]) and Rock Properties Model of the Integrated Site Model, Version 3.1 (RPM3.1) (DTN: MO9910MWDISMRP.002 [145731]) form the basis for numerical grid development. With these data, an initial 2-D (plan-view) grid is developed (see Section 6.5) defining borehole, fault, and repository column locations, where appropriate. Using the 2-D grid as the basis for column locations, a 3-D effective-continuum model (ECM) grid is constructed (see Section 6.6) using layer reference and bounding horizons, along with thickness data from GFM2000 (DTN: MO0012MWDGFM02.002 [153777]). Initial grid generation is followed by an iterative process of grid evaluation and modification to achieve appropriate spatial resolution and representation of important features, such as the proposed repository, faults, and calibration boreholes, and to ensure proper connections between the various elements of the grid. Revisions are made accordingly until these criteria are met. Next, the 3-D ECM grid is modified to allow for modeling dual-continuum processes (matrix and fracture flow) using a dual-permeability (dual-k) mesh maker, 2kgrid8.for V1.0 (LBNL 2002 [154787]). The 2kgrid8.for V1.0 software program incorporates information (i.e., fracture porosity, spacing, aperture, and fracture-matrix interaction area) from fracture data analyses (see Table 4) into the grids.

The computer code WINGRIDDER V2.0 (LBNL 2002 [154785]) is used to generate 1-, 2- and 3-D integral finite difference (IFD) grids for the UZ Model domain. The type of grid generated by WINGRIDDER V2.0 is consistent with the computational requirements for V1.4 and later versions of the TOUGH2 numerical code simulator (Pruess 1991 [100413], pp. 27–30, 41–42). TOUGH2 and the inverse modeling code iTOUGH2 (Finsterle 1999 [104367]) use cells, or gridblocks, and connections between those gridblocks to represent the flow system without requiring the global location of each gridblock or connection. This approach provides great flexibility in describing complex flow geometry and relationships between individual objects within the system.

Unlike other gridding software, WINGRIDDER V2.0 has the capability of designing complex, irregular grids with large numbers of cells and connections, and it can incorporate nonvertical faults and other embedded refinements, such as waste emplacement drifts within the proposed repository area at Yucca Mountain. WINGRIDDER V2.0 can generate a grid that includes a repository with multiple subregions and drifts. A bilinear interpolation between points of known elevation of a regular grid is used in WINGRIDDER V2.0 to determine the thickness or elevation at intermediate points, thus helping to conserve layer discontinuity resulting from faulting.

The grids produced by this work are integral finite difference (IFD) grids. Alternative gridding methods include finite difference and finite element methods, but IFD was chosen for compatibility with the TOUGH2 family of codes employed by downstream users. Compatibility with TOUGH2 for flow and transport simulations is a requirement of this work.

Described in this report are the methods used to develop numerical grids for hydrogeologic-property-set inversions, for model calibration, and for calculation of 3-D UZ flow fields for PA. The stages of grid development include the following:

1. Establish domain boundaries and location of important calibration features such as boreholes (Section 6.2).

2. Determine UZ Model layers and fault geometries based on GFM2000 (DTN: MO0012MWDGFM02.002 [153777]), RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]), and correlation with Flint's (1998 [100033]) HGUs (Section 6.3).

3. Extract and format GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) and RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) data for incorporation into 3-D grids (Section 6.4).

4. Generate a 2-D grid, incorporating information from Steps 1 and 2, and refine as needed to capture spatial variability (Section 6.5).

5. Generate a 3-D (ECM) grid, based on the column locations established in the 2-D grid and data from Step 3 (Section 6.6).

6. Combine the results of fracture analyses with the ECM grid from Step 5 to generate a dual-permeability mesh (Section 6.7).

The process of verifying that appropriate gridblock material names, gridblock volumes and locations, connection lengths and directions, and interface areas between gridblocks are used in the UZ Model numerical grids is documented in Section 6.8 and in Attachments II and III. Section 6.8 also summarizes results from corroborative studies that support the use of fairly coarse numerical grids to model flow and transport processes.

6.1.1 Summary of Changes to the UZ Model Grids

Some of the input data, software, and assumptions used in this revision differed from those used in REV00 ICN01 (BSC 2001 [159356]), thus resulting in changes to the UZ Model grids generated. These include the following items:

- Use of GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) instead of GFM3.1 (DTN: MO9901MWDGFM31.000 [103769]) for construction of UZ Model grids
- Change in UZ Model areal boundaries
- Change in position of water table (forms base of UZ)
- Change in proposed repository layout
- Enhanced resolution in vertical gridding
- Change in software
- Test simulation to verify connections in 3-D grid
- Addition of vitric and zeolitic subunits to tsw39 and ch6, and modification of vitric/zeolitic boundaries for layers ch1-ch5
- Addition of Bow Ridge/Toe fault and simplification of Solitario Canyon fault system
- Use of additional boreholes for 1-D properties calibration
- ESF and ECRB not incorporated into formulation of 3-D grid
- Changes in fracture hydrogeologic properties.

The primary change in the development of numerical grids for UZ flow and transport modeling is the change of geologic input data. Revision 00, ICN01 of this report (BSC 2001 [159356]) utilized GFM3.1 (DTN: MO9901MWDGFM31.000 [103769]), while the grids generated in this report are based on GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) (see Section 4.1). As noted in the *Geologic Framework Model (GFM2000)* (BSC 2002 [159124], Section 6.1), the changes between GFM3.1 and GFM2000 relating to elevation changes in geologic layers are relatively small in magnitude, rarely as large as 7.6 m (25 feet), and are primarily near the margins of the GFM boundaries. Thus, changes in HGU thicknesses and contact elevations should also be relatively minor.

The current UZ Model area has also undergone modifications, with an extension made to the east to allow for an expanded proposed repository footprint (Section 6.2). The proposed repository layout used for numerical grid generation consists of two different layers (Section 4.1.1) and includes regions north and east of the repository layout used in prior versions of the UZ Model grids. Note that the eastern extension to the proposed repository (the lower block) has been removed from the most recent revision of the repository layout (BSC 2003 [161726]; BSC 2003 [161727]), and is not used in any LA calculations presented in this report.

The maximum thickness of any gridblock was reduced from 60 to 20 m (5 m for ch1, ptn22, ptn24, ptn25, and ptn26, and 2 m for ptn21 and ptn23 HGUs), and the minimum grid thickness was reduced from 1.5 m to 1.0 m. Another modification consists of using the contoured regional water table instead of using two fixed elevations to define the water table, and thus the base of the UZ (Section 5.1, Assumptions 1 through 3 of BSC 2001 [159356]; Section 5.1, (Assumptions 1 and 2) and sections 6.2 and 6.4.2 of this Scientific Analysis report). This modification results in little change to the portion of the model near the ESF and to the SE, but it does impact the region to the north, where elevated water levels in boreholes were previously all interpreted as representing perched water. The current UZ Model grids will have a thinner UZ interval in the northern part of the model area as a result of this change.

The current UZ Model was constructed using updated software versions (Sections 3 and 6.1). EARTHVISION V5.1 (Dynamic Graphics 1998 [152614]) was used instead of V4.0 (Dynamic Graphics 1997 [134134]), and the updated version of WINGRIDDER V2.0 was utilized to construct the UZ Model grids. The macro DKMgenerator V1.0 (LBNL 1999 [140702]) was replaced with the qualified software program 2kgrid8.for V1.0. The use of updated software provides some additional functionality, but does not result in significant modifications to the generated grids.

Some additional software packages were utilized in the water table data qualification and review process (see Attachment IV). ARCINFO V7.2.1 (CRWMS M&O 2000 [157019]; USGS 2000 [148304]) was utilized to convert potentiometric contours from the ARCINFO file "pot_contours_e00" (DTN: GS010608312332.001 [155307]) into an ASCII format that could be used to qualify data from DTN: MO0212GWLSSPAX.000 [161271]. To facilitate comparison with the USGS contour data, coordinate data from the new DTN (MO0212GWLSSPAX.000 [161271]) were converted from Nevada State Plane coordinates (NAD27 datum) to UTM coordinates to using ARCINFO V7.2.1.

This updated report also includes a test simulation using TOUGH2 V1.4 (LBNL 2000 [146496]) to verify the connections of the ECM 3-D grid (Attachment III).

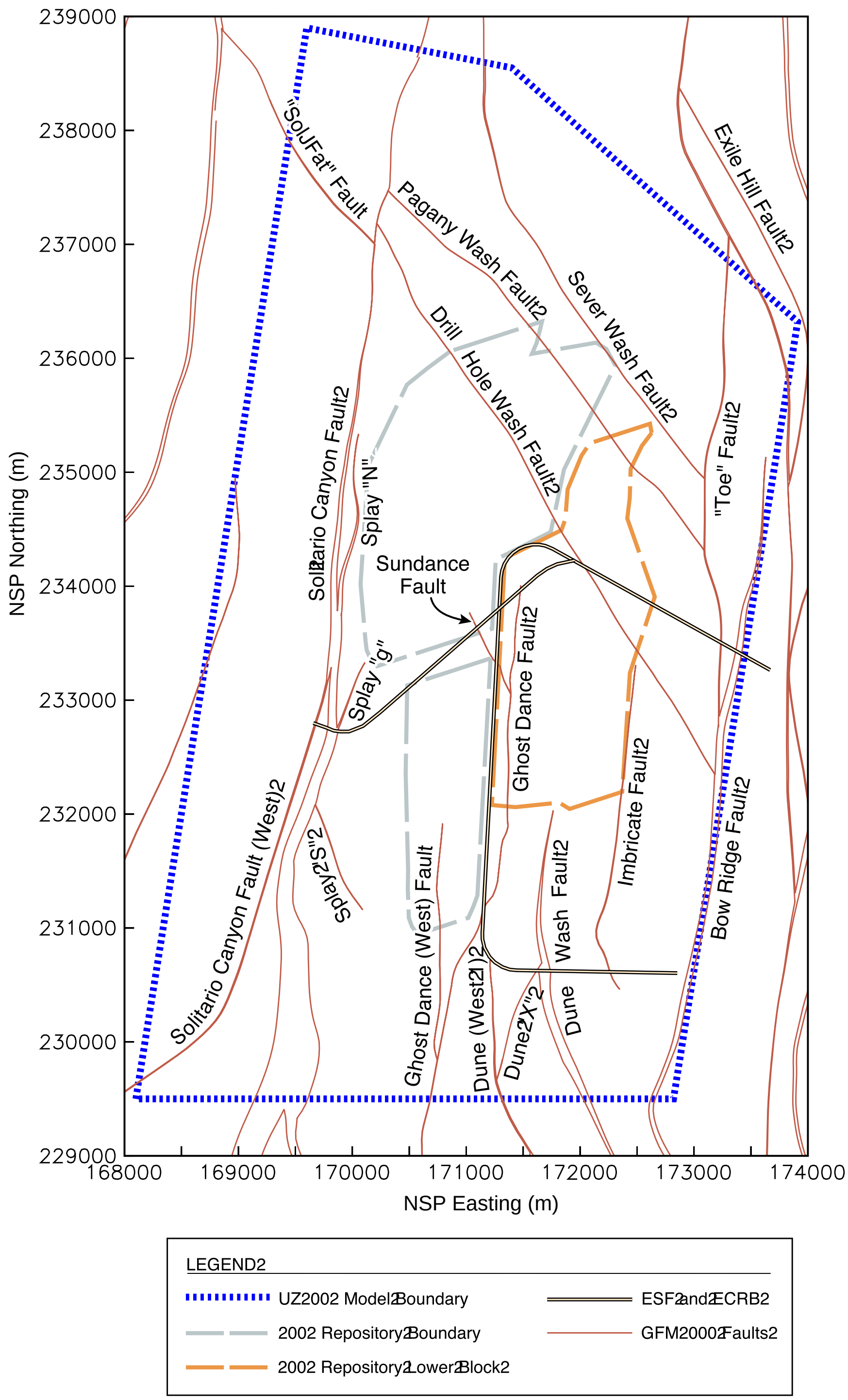
Several modifications were made to the delineation of vitric and zeolitic zones within the UZ Model grid (Section 5.2, Assumptions 4 through 6; Section 6.6.3). The primary data source used to delineate the vitric and zeolitic zones, RPM3.0 (DTN: MO9901MWDISMRP.000 [103771]), was superseded by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]). In addition to the information obtained from RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]), the location of major faults, rock-property data from boreholes, and corroborative information from MM3.1 (DTN: MO9910MWDISMMM.003 [119199]) and RPM2000 (DTN: SN0112T0501399.004 [159524]) were used to modify the vitric/zeolitic boundaries for the layers ch1-ch5. New vitric and zeolitic subunits were created for the layers tsw39 and ch6. The main impact of these changes is the modification of rock properties for layers tsw39 and ch6, and an overall enlargement of the vitric subunit for layers ch2-ch5.

Two changes were made to the faults within the UZ Model grids. One new fault (a combination of the Bow Ridge and Toe faults) was added to the model; this change resulted from the eastward extension of the UZ Model boundary. This fault is located away from the current proposed repository, and its addition to the UZ Model grids should not significantly impact subsequent users. The second change relates to the simplification of the Solitario Canyon fault system (Solitario Canyon, Splay "N", Splay "G", Splay "S", and Solitario Canyon [west]) into a single structural feature (Section 5.2, Assumption 7). The splay faults are relatively small features with minor offsets, but the Solitario Canyon (west) fault has significant (up to more than 300 m) vertical offset. However, this feature is very close to the Solitario Canyon fault, and given the coarsely spaced gridding used in the SW portion of the UZ Model area where the Solitario Canyon (west) fault is located, a single feature containing the cumulative offset of the two faults was used for the UZ Model. This simplification does not retain all of the structural details contained within GFM2000 (DTN: MO0012MWDGFM02.002 [153777]), but it preserves the general stratigraphic and structural relations, and is also located away from the current proposed repository area. These changes in modeling the Solitario Canyon fault system should not impact downstream users, provided that the proposed repository area is not subsequently shifted into the areas where the Solitario Canyon (west) and Splay faults are situated.

Over 40 boreholes were used to calibrate matrix properties (Section 6.2), more than twice the number used in REV00 ICN01 of this report (BSC 2001 [159356]). Because of the increased number of boreholes used for calibration, the ESF, ECRB, and associated niches and alcoves were not used in the calibration process, and therefore it was not necessary to incorporate these features into the 3-D grid. Updated fracture properties (Section 4.1) were utilized in the construction of the dual-permeability 2-D and 3-D grids.

6.2 BOUNDARIES AND CALIBRATION FEATURES

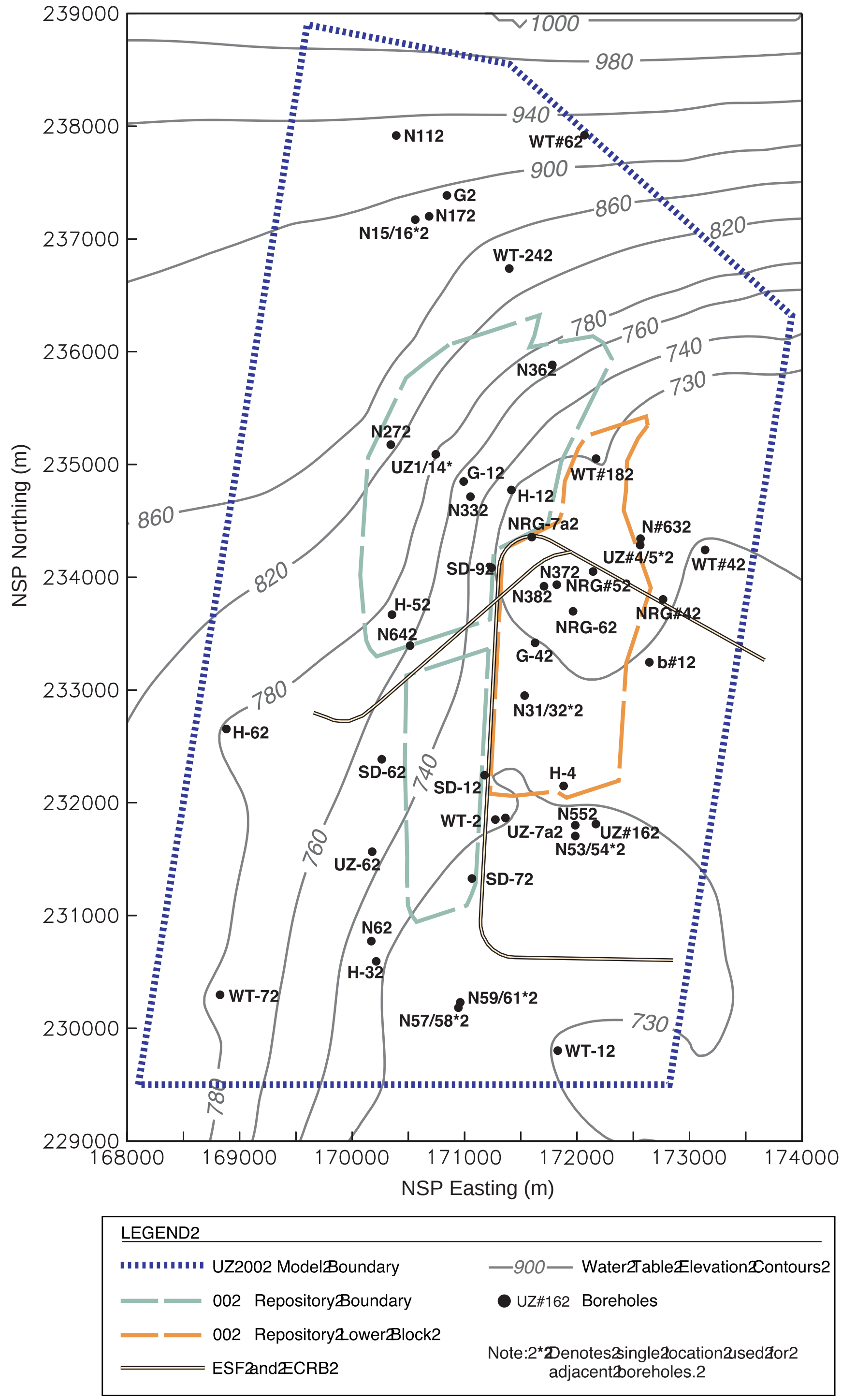
The areal domain of the UZ Model encompasses approximately 40 km^2 of the Yucca Mountain area. Yucca Wash lies near the northern model boundary, while the approximate latitude of borehole G-3 defines the southern boundary. The eastern model boundary lies just to the east of the Bow Ridge fault, and the western boundary lies approximately 1 km west of the Solitario Canyon fault. These boundaries encompass many of the existing hydrology wells for which extensive moisture saturation and water potential data are used as calibration points for determining layer properties. One important objective of selecting these boundaries was to minimize potential boundary effects on numerical simulation results within the proposed repository footprint. Figures 1a and 1b show map views of the model domain, including the proposed repository boundary, the paths of the ESF and ECRB, major faults defined in GFM2000 (DTN: MO0012MWDGFM02.002 [153777]), calibration boreholes, and the contoured regional water table. Table 9 lists the NSP coordinates for the domain boundary.



Source: (Proposed Repository Design) BSC 2002 [159527]; (GFM2000 Faults) DTN: MO0012MWDGFM02.002 [153777]

NOTE: 2002 Repository Lower Block will not be used in any LA calculations.

Figure 1a. Plan-View Schematic Showing the UZ Model Boundary, the Proposed Repository Outline, Major Faults from GFM2000, the ESF, and the ECRB



Source: (Proposed Repository Design) BSC 2002 [159527]; Output-DTNs: LB0208HYDSTRAT.001 (UZ2002 Model Boundary, Modified Borehole Locations); LB02092DGRDVER.001 (Water Table).

NOTE: 2002 Repository Lower Block will not be used in any LA calculations.

Figure 1b. Plan-View Schematic Showing Boreholes, the Contoured Water Table (Elevations in m), the UZ Model Boundary, the Proposed Repository Outline, the ESF, and the ECRB

Table 9. UZ Model Areal Boundary Coordinates

NSP Easting (m)	NSP Northing (m)
168100	229500
169600	238900
171400	238550
173910	236320
172820	229500

Output-DTN: LB0208HYDSTRAT.001

The upper boundary of the UZ Model is the bedrock surface (topography minus alluvium), which is defined by the GFM2000 file "s00bedrockRWC.2grd" (see Attachment I, GFM2000 files). The lower boundary is the water table, or potentiometric surface, derived from water-level-elevation data (Assumption 1). Borehole water-level elevations beneath northern Yucca Mountain suggest a large hydraulic gradient, as seen in the contoured potentiometric surface (BSC 2001 [155950], Figure 12.3.1.2–2) and the water-level data contained in DTN: MO0106RIB00038.001 [155631], with water levels increasing northward from about 730 masl at the south end of the proposed repository area to 840 m (USW WT-24; see DTN: GS010608312332.001 [155307]) less than a kilometer north of the proposed repository area. Two boreholes north of WT-24, G-2 and WT#6, have significantly higher water levels (>1000 masl). One explanation for the fairly abrupt water-level difference between WT-24 and the G-2 and WT#6 boreholes is the occurrence of perched or semi-perched water under portions of northern Yucca Mountain (USGS 2001 [157611]; Ervin et al. 1994 [100633], p. 15; Czarnecki et al. 1994 [142594]; Czarnecki et al. 1995 [103371]). For the purpose of developing UZ Model grids, water table elevations beneath portions of northern Yucca Mountain are assumed to represent perched water, as stated in Section 5.1, Assumption 2. The contoured regional water table elevations (Figure 1b) are represented by the surface defined in the file "gwl_sspac_60.96.2grd" (see Attachment III, Table III-1). Details on how this surface was generated are presented in Section 6.4.2 and Attachment IV.

UZ Model borehole calibration features, represented as column centers in the 1-D inversion and 3-D calibration grids, are listed in Table 10. For simplicity, the borehole names used throughout the remainder of this document drop the USW and UE-25 prefixes. Where boreholes are closer than 80 m to one another, the boreholes (as indicated on Table 10 by an asterisk) are jointly represented by an intermediate location calculated by averaging the coordinates of the two boreholes. Because borehole UZ-7a is located adjacent to a fault, the position of the column center associated with the borehole was shifted slightly to accommodate the fault geometry.

Table 10. Borehole Locations Used in the UZ Inversion and Calibration Models

NSP Easting (m)	NSP Northing (m)	Feature
170993	234849	G-1
170842	237386	G-2
171627	233418	G-4
171416	234774	H-1
170216	230594	H-3
171880	232149	H-4
170355	233670	H-5
168882	232654	H-6
172767	233806	NRG#4
172142	234053	NRG#5
171964	233698	NRG-6
171598	234355	NRG-7a
171178	232245	SD-12
171066	231328	SD-7
170264	232386	SD-6
171242	234086	SD-9
170744	235090	UZ-1/14*
172168	231811	UZ#16
172559	234286	UZ#4/5*
170178	231566	UZ-6
171363	231866	UZ-7a[1]
171398	236739	WT-24
171828	229802	WT-1
171274	231850	WT-2
173138	234243	WT#4
172067	237920	WT#6
168826	230298	WT-7
172168	235052	WT#18
172644	233246	b#1
170390	237919	N11
170563	237171	N15/16*
170687	237203	N17
170344	235175	N27
171534	232951	N31/32*
171051	234717	N33
171780	235885	N36
171820	233934	N37
171707	233924	N38
171983	231704	N53/54*
171983	231801	N55
170946	230186	N57/58*
170960	230230	N59/61*
170171	230772	N62
172568	234342	N#63
170516	233394	N64

Source: Output-DTN: LB0208HYDSTRAT.001 (file “boreholes_Rick_updated.hol”).

NOTES: *Single location used for boreholes in close proximity to one another, as explained in text. Original northing and easting values (in feet) converted to meters by multiplying by 0.3048. See discussion of metric conversion in Section 3.

[1] Location of UZ-7a shifted to accommodate fault grid geometry.

Borehole locations used for 1-D column construction. See file “Boreholes.mck” in Output-DTN: LB02081DKMGRID.001.
A subset of the listed boreholes was used for property inversion and calibration.

For the earlier versions of this report, many fewer boreholes were used for the calibration, but these were supplemented by the ESF, ECRB, and associated alcoves and niches. Because more boreholes were used for the UZ 2002 grid model calibration, the ESF and ECRB features were not needed for the present model calibrations, and thus these features were not discretized in the UZ 2002 Model grids. The GFM2000 file "contacts00el.dat" (see Attachment I, GFM2000 files) is used to define the location of most of the boreholes that serve as column centers within the various UZ Model grids. Since the coordinates contained within this file are listed in feet, rather than meters (which is the desired unit of measure in the UZ Model), a simple unit conversion was performed (1 ft = 0.3048 m; see metric conversion discussion in Section 3). The locations of the N-series boreholes not listed in this file (N15/16, N17, N27, N36, N57/58, N59/61, N#63, and N64) that were used for model calibration were obtained from the *Yucca Mountain Site Characterization Project Site Atlas 1995* (DOE 1995 [102884], vol. 1, p. 9.14). Where boreholes were located within 80 m of one another, the boreholes were listed as a pair, and the average location of the two boreholes was used for property calibration.

The spatial relationship between boreholes and faults (determination of fault locations in the 2-D grid is described in Sections 6.3, and 6.5, and 6.6.1) is such that these features may intersect or lie within 30 m of each other (which is typically less than the desired lateral resolution of the grid). As a result, the location of certain features (e.g., column centers) is prioritized. In general, the location of column centers at boreholes was given highest priority, followed by the proposed repository layout, followed by faults.

6.3 UZ MODEL LAYERS AND FAULT GEOMETRIES

As discussed previously in Section 4, layering within the UZ Model grid is chosen to correspond as closely as possible to HGUs, to facilitate usage of rock-property data. Table 11 provides a correlation between major HGUs, GFM2000 lithostratigraphic units (BSC 2002 [159124], Table 4), UZ Model layers, and Flint's (1998 [100033]) HGUs. In many cases, HGUs correlate 1-to-1 with, or are simple combinations of, GFM2000 layers. In a few instances, multiple HGUs can be present within one GFM2000 layer, such as within the Yucca Mountain Tuff (Tpy), the lower nonlithophysal zone of the Topopah Spring Tuff (Tptpln), or the Calico Hills Formation (Tac). Using Table 11 as a basis for UZ Model layering, GFM2000 layer-thickness (isochore) grid files (DTN: MO0012MWDGFM02.002 [153777]) are combined or subdivided, as appropriate (see Section 6.4.1), to correspond to Flint's (1998 [100033]) HGUs.

Table 11. GFM2000 Lithostratigraphy, UZ Model Layer, and Hydrogeologic Unit Correlation

Major Unit (Modified from Montazer and Wilson 1984 [100161])	**GFM2000 Lithostratigraphic Nomenclature***	**FY02 UZ Model Layer**	**Hydrogeologic Unit (Flint 1998 [100033], Table 1)**
Tiva Canyon welded (TCw)	Tpcr	tcw11	CCR, CUC
	Tpcp	tcw12	CUL, CW
	TpcLD		
	Tpcpv3	tcw13	CMW
	Tpcpv2		
Paintbrush nonwelded (PTn)	Tpcpv1	ptn21	CNW
	Tpbt4	ptn22	BT4
	Tpy (Yucca)		
		ptn23	TPY
		ptn24	BT3
	Tpbt3		
	Tpp (Pah)	ptn25	TPP
	Tpbt2	ptn26	BT2
	Tptrv3		
	Tptrv2		
Topopah Spring welded (TSw)	Tptrv1	tsw31	TC
	Tptrn		
		tsw32	TR
	Tptrl, Tptf	tsw33	TUL
	Tptpul, RHHtop		
	Tptpmn	tsw34	TMN
	Tptpll	tsw35	TLL
	Tptpln	tsw36	TM2 (upper 2/3 of Tptpln)
		tsw37	TM1 (lower 1/3 of Tptpln)
	Tptpv3	tsw38	PV3
	Tptpv2	tsw39 (vit, zeo)	PV2

Table 11. GFM2000 Lithostratigraphy, UZ Model Layer, and Hydrogeologic Unit Correlation (cont.)

Major Unit (Modified from Montazer and Wilson 1984 [100161])	**GFM2000 Lithostratigraphic Nomenclature***	**FY02 UZ Model Layer**	**Hydrogeologic Unit (Flint 1998 [100033], Table 1)**
Calico Hills nonwelded	Tptpv1	ch1 (vit, zeo)	BT1 or
(CHn)	Tpbt1		BT1*a* (altered)
	Tac (Calico)	ch2 (vit, zeo)	CHV (vitric)
		ch3 (vit, zeo)	or
		ch4 (vit, zeo)	CHZ (zeolitic)
		ch5 (vit, zeo)	
	Tacbt (Calicobt)	ch6 (vit, zeo)	BT
	Tcpuv (Prowuv)	pp4	PP4 (zeolitic)
	Tcpuc (Prowuc)	pp3	PP3 (devitrified)
	Tcpmd (Prowmd)	pp2	PP2 (devitrified)
	Tcplc (Prowlc)		
	Tcplv (Prowlv)	pp1	PP1 (zeolitic)
	Tcpbt (Prowbt)		
	Tcbuv (Bullfroguv)		
Crater Flat undifferentiated	Tcbuc (Bullfroguc)	bf3	BF3 (welded)
(CFu)	Tcbmd (Bullfrogmd)		
	Tcblc (Bullfroglc)		
	Tcblv (Bullfroglv)	bf2	BF2 (nonwelded)
	Tcbbt (Bullfrogbt)		
	Tctuv (Tramuv)		
	Tctuc (Tramuc)	tr3	Not Available
	Tctmd (Trammd)		
	Tctlc (Tramlc)		
	Tctlv (Tramlv)	tr2	Not Available
	Tctbt (Trambt) and below		

NOTE: * Buesch et al. (1996 [100106]) define the units in the Paintbrush Group (layers beginning with "Tp"). Moyer et al. (1995 [103777]) describe the Tac and Tacbt. Buesch and Spengler (1999 [107905]) describe the symbols for the Crater Flat Tuffs. GFM2000 nomenclature (BSC 2002 [159124], Table 4) uses the symbols that are included parenthetically below layer Tpbt1. Additional details on how the GFM2000 units were combined or subdivided to obtain the UZ Model units are found in Wang 2002 ([159673], SN-LBNL-SCI-213-V1, pp. 11–15).

Faults are important features to include in the UZ Model grids, because they may provide fast pathways for flow or serve as barriers to flow. A fault can be a surface with arbitrary shape in the 3-D UZ Model domain and is represented as a surface (defined by a set of x, y, z data on a regular grid spacing) in GFM2000 (BSC 2002 [159124], Sections 6.4.2 and 6.4.4). In UZ Model grids, fault surfaces are represented by a series of connected columns of gridblocks. Faults can be represented in the grid as either vertical or nonvertical features. Many of the faults at Yucca Mountain are steeply dipping, particularly within the UZ. For UZ flow and transport modeling studies of Yucca Mountain, it is believed that flow through faults is much more sensitive to the rock properties assigned to fault zones than to slight variations in fault dip. Since large numbers of gridblocks are needed to discretize nonvertical fault zones (which adds significantly to the computational time of model calibration and forward simulations), certain criteria have been developed under Assumption 7 (Section 5) to reduce the total number of gridblocks along faults in order to simplify the UZ Model grids. Faults are modeled as vertical if they meet any of the following criteria: (1) their average dip exceeds 85 degrees, (2) their average dip exceeds 80 degrees and they lie sufficiently far (>1 km) from the proposed repository layout area so as not to significantly affect flow and transport calculations, (3) they lie west of the Solitario Canyon fault, (4) they are adjacent to UZ Model boundaries, or (5) they pass through or abut the proposed repository (see Figure 1a). Fine-resolution gridding of the repository is deemed to be more important than incorporating dipping faults, which require larger gridblocks (see Section 6.6.1). Table 12 lists the GFM2000 faults that lie within or along UZ Model boundaries.

Table 12. Faults Within the UZ Model Domain

Fault Name	GFM2000 File Name
Solitario Canyon	f00sol.2grd
Solitario Canyon (west)	f00solwest.2grd
Unnamed joins Solitario Canyon & Fatigue Wash faults	f00soljfat.2grd
Splay “G”	f00splayg.2grd
Splay “N” (north)	f00splayn.2grd
Splay “S” (south)	f00splays.2grd
Sundance	f00sundance.2grd
“Toe”	f00toe.2grd
Sever Wash	f00sever.2grd
Pagany Wash	f00pagany.2grd
Drill Hole Wash	f00drill.2grd
Ghost Dance	f00ghost.2grd
Ghost Dance (west)	f00ghostw.2grd
Dune Wash	f00dune.2grd
Dune Wash “X”	f00dunex.2grd
Dune Wash (west 1)	f00dunew1.2grd
“Imbricate”	f00imb.2grd
Bow Ridge	f00bow.2grd
Exile Hill (or Bow Ridge east)	f00exile.2grd

Source: DTN: MO0012MWDGFM02.002 [153777]

The average slope of each fault was evaluated to determine which faults can be reasonably approximated by vertical columns of gridblocks in UZ Model grids. This task involves the calculation of slope along each fault (as it transects the UZ) using the Slope Grid Calculation utility in EARTHVISION V5.1 (Dynamic Graphics 1998 [152614]). Refer to the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, pp. 73–74) for details regarding this calculation. The results are summarized in Table 13.

Table 13. Results of GFM2000 Fault-Slope Analysis

Fault Name	Slope Range (average)	Minimum Dip (degrees)	Maximum Dip (degrees)	Average Dip (degrees)
Solitario Canyon	1.0–6.8 (2.4)	44.7	81.7	67.5
Solitario Canyon (west)	5.3–10.5 (6.4)	79.3	84.6	81.1
“Soljfat”	3.2–4.5 (3.8)	72.9	77.4	75.1
Splay “G”	1.6–2.9 (2.2)	58.7	70.8	65.4
Splay “N”	1.3–4.1 (2.0)	53.0	76.4	63.2
Splay “S”	1.3–2.7 (2.0)	52.1	69.7	63.8
Sundance	7.1–12.3 (11.9)	82.0	85.4	85.2
"Toe"	3.6–5.2 (4.2)	74.3	79.1	76.6
Sever Wash	5.6–8.4 (7.0)	79.9	83.2	81.8
Pagany Wash	8.8–13.8 (11.5)	83.5	85.8	85.1
Drill Hole Wash	10.7–14.0 (11.9)	84.7	85.9	85.2
Ghost Dance	8.4–14.5 (11.6)	83.2	86.1	85.1
Ghost Dance (west)	10.0–13.4 (11.7)	84.3	85.7	85.1
Dune Wash	1.4–3.0 (1.9)	55.0	71.3	62.5
Dune Wash “X”	3.7–5.0 (4.5)	75.0	78.6	77.5
Dune Wash (west1)	3.1–4.4 (3.7)	72.2	77.1	74.7
"Imbricate"	9.2–15.8 (12.2)	83.8	86.4	85.3
Bow Ridge	0.4–36.9 (3.8)	23.4	88.4	75.1
Exile Hill	0.02–6.5 (4.7)	1.0	81.3	78.0

Output-DTN: LB0208HYDSTRAT.001

In accordance with Assumption 7, the following faults are represented by vertical columns of gridblocks (i.e., are assumed to be vertical) in the UZ Model grids: “Soljfat,” Sundance, “Toe,” Sever Wash, Pagany Wash, Drill Hole Wash, Ghost Dance, Ghost Dance (west), and “Imbricate” faults. The “Toe” and Bow Ridge faults are represented by a single structural feature, which, due to its proximity to the eastern boundary of the UZ Model area, is considered as a vertical fault. The remaining faults (Solitario Canyon, Dune Wash, Dune Wash “X,” and Dune Wash [west1]) are represented by nonvertical columns of gridblocks in the 3-D grids. Splay faults “N”, “S”, and “G” lie close to the Solitario Canyon fault and intersect it at a relatively shallow depth. This presents complications when generating the 3-D grids because of the preferred numerical grid resolution and fault representation method (described in Section 6.6.1). Thus, these three splay faults are considered part of the Solitario Canyon fault zone and are not explicitly defined. However, after grid generation, fault properties can be assigned to the gridblocks closest to the location of these faults, as needed. As mentioned in Assumption 7, the Solitario Canyon (west) fault was not depicted as a distinct feature in the UZ Model grids. The relatively coarse gridding used in the SW portion of the UZ Model area (resulting from its location away from the proposed repository area) precludes the individual portrayal of these closely spaced west-dipping normal faults. However, the cumulative vertical offset observed in the GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) for the Solitario Canyon and Solitario Canyon (west) faults is captured by the single nonvertical fault (Solitario Canyon) and the adjacent columns used in the UZ Model grids, thus preserving the general stratigraphic and structural relations of GFM2000.

Preparation of GFM2000 fault data (DTN: MO0012MWDGFM02.002 [153777]) for incorporation into UZ Model grids first involves a simple unit conversion from feet to meters. The spatial position of the faults is then determined by intersecting each fault surface (*.2grd, listed in Table 12) with one or more horizontal planes, producing data files describing fault-trace locations at prescribed elevations. Faults represented as vertical features in the UZ grids use fault-trace information at an arbitrary elevation of 1,100 masl, chosen because it is just above the proposed repository and near the middle of the UZ. During grid generation, vertical columns of gridblocks are assigned along each fault trace.

Faults represented as nonvertical features (i.e., by nonvertical columns of gridblocks) use fault-trace information at three elevations (one near the land surface, one near the water table, and one located approximately midway between the other two) to capture variations in dip. The UZ Model gridding process interpolates the location of each nonvertical fault using data points at the three prescribed elevations. With this approach, the dip of a fault within a given fault column is uniform in the upper interval between the highest and middle elevations, and is again uniform in the lower interval between the middle and lowest elevations. This allows the dip in the upper interval to be different from the dip in the lower interval (which may occur if the fault surface is curved, rather than planar). Furthermore, dip angles within the same vertical interval can be different in different columns (i.e., laterally along a fault). Thus, even a fault with variable dip along its trace can be represented with this method. In some cases, the upper and lower portions at dipping faults have been adjusted to a vertical orientation to ensure appropriate grid resolution and comply with the requirement that gridblock columns adjacent to fault columns be at least as wide as the fault columns (see Dune Wash fault in Figure III-4). For specific details regarding manipulation of fault data, refer to the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, p. 19) and Hinds 2001 ([155955], pp. 137–140).

6.4 EXTRACTION OF GFM2000 AND ISM3.1 DATA

6.4.1 Isochores

Geologic layers are correlated with Flint (1998 [100033]) HGUs in Table 11, and UZ Model layers are determined based on this correlation (Assumption 3). Because of its large thickness beneath northern Yucca Mountain, layer Tac is vertically subdivided equally into four layers throughout the UZ Model domain. Based on the relationships provided in Table 11, certain GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) layers (represented by isochore grids) are combined, while others were subdivided, to create hydrogeologic model layers for the UZ grids.

GFM2000 isochore grids (DTN: MO0012MWDGFM02.002 [153777]) used in FY02 UZ grid development include those lying between the upper Tpcpv3 contact and the lower Trambt contact. Layers are combined if (1) they have similar hydraulic properties based on analyses by Flint (1998 [100033]), (2) they are very thin across Yucca Mountain, or (3) property data are very limited for the rock units. GFM2000 isochores (DTN: MO0012MWDGFM02.002

[153777]) are subdivided if rock-property data exist that suggest two or more distinct hydrogeologic layers within a geologic unit.

For specific details describing the manipulation and formatting of GFM2000 isochore files (DTN: MO0012MWDGFM02.002 [153777]), refer to the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, pp. 11–15). Below is a brief summary of the steps taken.

GFM2000 isochore files (DTN: MO0012MWDGFM02.002 [153777]) that are not combined or subdivided include:

- ia00cpv1RWC.2grd
- ia00tppRWC.2grd
- ia00tpmnRWC.2grd
- ia00tpllRWC.2grd
- ia00tpv3RWC.2grd
- ia00tpv2RWC.2grd
- ia00tacbtRWC.2grd
- ia00prowuvRWC.2grd
- ia00prowucRWC.2grd

These grids, which contain regularly spaced (61 × 61 m) data, require no manipulation other than simple formatting for incorporation into the UZ grids. EARTHVISION V5. (Dynamic Graphics 1998 [152614]) is used to export the regularly spaced data and to convert the units (x, y, and thickness) from feet to meters. Since GFM2000 data coverage (BSC 2002 [159124], Figure 1) extends well beyond the UZ Model boundaries, each data file is reduced to the approximate UZ Model domain, using the EARTHVISION V5.1 Graphic Editor to remove data points lying south of N 228,820 m and east of E 174,860 m.

GFM2000 isochore files (DTN: MO0012MWDGFM02.002 [153777]) that are combined include:

- ia00cpv3RWC.2grd + ia00cpv2RWC.2grd
- ia00bt4RWC.2grd + part of ia00tpyRWC.2grd (see discussion of Tpy below)
- ia00bt3RWC.2grd + part of ia00tpyRWC.2grd (see discussion of Tpy below)

- ia00bt2RWC.2grd + ia00trv3RWC.2grd + ia00trv2RWC.2grd
- ia00trv1RWC.2grd + part of ia00trnRWC.2grd (see discussion of Tptrv1 and Tptrn below)
- ia00trltfRWC.2grd + ia00tpulRWC.2grd
- ia00tpv1RWC.2grd + ia00bt1RWC.2grd
- ia00prowmdRWC.2grd + ia00prowlcRWC.2grd
- ia00prowlvRWC.2grd + ia00prowbtRWC.2grd + ia00bulluvRWC.2grd
- ia00bullucRWC.2grd + ia00bullmdRWC.2grd + ia00bulllcRWC.2grd
- ia00bulllvRWC.2grd + ia00bullbtRWC.2grd + ia00tramuvRWC.2grd
- ia00tramucRWC.2grd + ia00trammdRWC.2grd + ia00tramlcRWC.2grd

The EARTHVISION V5.1 (Dynamic Graphics 1998 [152614]) Formula Processor is used to add the *.2grd files as shown above. The resulting files are then formatted as previously described for uncombined isochores.

Subdivided GFM2000 isochore files (DTN: MO0012MWDGFM02.002 [153777]) are described below and include:

- ia00tpyRWC.2grd
- ia00trv1RWC.2grd + ia00trnRWC.2grd
- ia00tplnRWC.2grd
- ia00tacRWC.2grd

GFM2000 layer Tpy (Yucca Mountain Tuff)—Based on the HGUs defined by Flint (1998 [100033]), GFM2000 layer Tpy is subdivided vertically into three layers (see Table 11). The upper portion is typically nonwelded and has properties similar to Tpbt4 (BT4); therefore, it is combined with layer Tpbt4 (GFM2000 isochore file "ia00bt4RWC.2grd" (see Attachment I, GFM 2000 files)) to make UZ02 Model layer "ptn22." The middle portion can become moderately welded to the north (porosity <30%), where layer Tpy is generally thicker. This middle portion corresponds to HGU "TPY" and is designated "ptn23" in the UZ02 grid. The lower portion is typically nonwelded and has properties similar to Tpbt4 and Tpbt3, and is therefore combined with layer Tpbt3 (GFM2000 isochore file "ia00bt3RWC.2grd" (see Attachment I, GFM2000 files)) to make UZ02 Model layer "ptn24." Because the presence of the hydrologically distinct middle portion of layer Tpy depends on the overall thickness of the unit, the isochore for layer Tpy is subdivided as follows:

- Where Tpy is <6 m thick, the total Tpy thickness is combined with layer Tpbt4 to create UZ02 Model layer “ptn22” (corresponding to HGU “BT4”).
- Where Tpy thickness is between 6 and 9 m, the thickness is split in half: the upper half is combined with Tpbt4 to make UZ Model layer “ptn22,” while the lower half is combined with Tpbt3 to make UZ02 Model layer “ptn24” (corresponding to HGU “BT3”).
- Where Tpy thickness is between 9 and 12 m, 2 m is assigned to UZ02 Model layer “ptn23” (corresponding to HGU “TPY”); the remainder is split in half, and these equal portions are combined with Tpbt4 to make UZ02 layer “ptn22” and TPbt3 to make layer “ptn24.”
- Where Tpy thickness is between 12 and 15 m, 3 m is assigned to UZ02 Model layer “ptn23” (corresponding to HGU “TPY”); the remainder is split in half, and these equal portions are combined with Tpbt4 to make UZ02 layer “ptn22” and TPbt3 to make layer “ptn24.”
- Where Tpy thickness is greater than 15 m, the unit is divided in thirds, with one third assigned (in combination with Tpbt4) to “ptn22,” one third to “ptn23,” and the remaining third is combined with Tpbt3 to make “ptn24.”

GFM2000 layers Tptrv1 and Tptrn (upper Topopah Spring Tuff)—The densely welded Tptrv1 is relatively thin (0–2 m thick, typically <0.5 m) across Yucca Mountain (Flint 1998 [100033], p. 27). Given a minimum vertical resolution of 1.0 m for the UZ Model grids, this layer would be missing from UZ simulations across most of Yucca Mountain. To capture this potentially important flow unit at the PTn/TSw interface (see Table 11), GFM2000 isochores (DTN: MO0012MWDGFM02.002 [153777]) for Tptrv1 and Tptrn were combined, and then the upper 2 m of this combined unit were assigned a distinct model layer name corresponding to Flint’s “TC” HGU. The remaining thickness of the combined unit (Tptrv1 + Tptrn - 2 m) corresponds to Flint’s “TR” HGU. Where the combined thickness of Tptrv1 and Tptrn is less than 0.5 m, the isochore for the “TC” HGU is assigned zero thickness.

GFM2000 layer Tptpln (Topopah Spring, lower nonlithophysal)—Tptpln is characterized by HGUs “TM2” and “TM1” (see Table 11). According to the proportions given in Flint (1998 [100033], p. 3), GFM2000 layer Tptpln is vertically subdivided into an upper portion (with 2/3 the total thickness of Tptpln) and a lower portion (with 1/3 the total thickness of Tptpln) for incorporation into the UZ Model.

GFM2000 layer Tac (Calico Hills Formation)—The Tac is subdivided vertically into four equal layers because of its large thickness beneath northern Yucca Mountain (see Table 11). After the isochores have been subdivided according to the specified criteria/proportions, they are formatted using the same steps that were used to format the uncombined isochores.

6.4.2 Reference Horizons, and Top and Bottom UZ Model Boundaries

WINGRIDDER V2.0 (LBNL 2002 [154785]) generates a numerical grid based on the elevations of three major horizons: (1) a top boundary (e.g., the topographic or bedrock surface), (2) a structural reference horizon, which identifies faults and their associated offsets, and (3) a bottom boundary (i.e., the water table). The reference horizon is a surface from which elevations of all hydrogeologic-unit interfaces are calculated by stacking layer thicknesses above or below it, based on their stratigraphic position. All offsets resulting from faulting are described by the reference horizon data. Any portions of HGUs lying above the top boundary or below the bottom boundary after stacking are removed (clipped).

GFM2000 horizons used (see Attachment I, GFM2000 files):

- s00bedrockRWC.2grd (bedrock/present-day erosional surface; UZ Model top boundary)
- s00TpcpEXuncut.2grd (top of Tpcp; surface used in the absence of Tpcp isochore)
- s00Tptpv3EXuncut.2grd (top of Tptpv3; primary structural reference horizon for UZ grids).

The top of layer Tpcp (the contact between the crystal-rich and crystal-poor tuffs of the Tiva Canyon, defined as a surface in GFM2000) (DTN: MO0012MWDGFM02.002 [153777]) is used to separate UZ Model layers “tcw11” and “tcw12” (see Table 11), since no GFM2000 isochore grids (DTN: MO0012MWDGFM02.002 [153777]) exist for these layers.

As with the isochore grids, the horizon grids, which also contain regularly spaced (61 × 61 m) data, require no manipulation other than simple formatting for incorporation into the UZ Model. EARTHVISION V5.1 is used to export the regularly spaced data and to convert the units (x, y, and elevation) from feet to meters. The complete details for formatting these GFM2000 horizon grids (DTN: MO0012MWDGFM02.002 [153777]) are documented in the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, pp. 20–22).

The lower boundary of the UZ Model (the water table) was discussed previously in Sections 5.1 and Section 6.2. The input data set (gwl_sspac2.asc) used to define the water table at the base of the UZ was obtained from DTN: MO0212GWLSSPAX.000) [161271]. These input data consist of borehole water-level elevations (consistent with qualified data in DTNs: MO0106RIB00038.001 [155631] and GS010608312332.001 [155307]) along with interpreted potentiometric surface contour lines. This surface was constructed under the assumption that the water levels in G-2 and WT-6 represent perched water, and the level in WT-24 represents the regional groundwater surface (USGS 2001 [157611]; also see Assumptions 1 and 2 in Section 5.1). The data were derived from the Vulcan GFM2000 layer “GWL_SSPAC” (DTN: MO0110MWDGFM26.002 [160565]). The review and qualification process for this data set is documented in Attachment IV. The file containing the water table data was then edited to make it compatible with EARTHVISION V5.1.

The resulting data were gridded using the 2-D minimum tension gridding function in EARTHVISION V5.1 to produce a surface defined by a regularly spaced (182.88 by 182.88 m) data set. The data defining this surface were then exported using the 2-D and 3-D grid export function in EARTHVISION V5.1, and subsequently regridded using the 2-D minimum tension gridding function to produce a surface defined by a regularly spaced (60.96 by 60.96 m) data set ("gwl_sspac_60.96.2grd" in output-DTN LB02092DGRDVER.001). The 2-D and 3-D grid export function was then utilized again to produce a file with the 60.96 by 60.96 m regularly spaced data set required as input for grid generation using WINGRIDDER V2.0. The file was edited to ensure that a minimum elevation of 730 m was used, thus revising lower elevations that resulted from the minimum tension gridding process (Wang 2003 [162380], SN-LBNL-SCI-213-V1, p. 117). This file was then edited (by cropping the data, removing xy coordinates, and modifying the header) to create a reference horizon file ("REF_wt_sspac.dat" in output DTN: LB0208HYDSTRAT.001) suitable as input for WINGRIDDER V2.0. The details of these steps can be found in the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, pp. 21–22).

The gridding procedure used to define the water table in EARTHVISION V5.1 was conducted using a two-step process (irregularly spaced data to a coarsely spaced grid, followed by a finely spaced grid) to avoid generating large deviations from the contoured potentiometric surface as represented by the contours from DTN: MO0212GWLSSPAX.000 [161271]. However, this gridding process, which is required to produce the data input needed for numerical grid generation using WINGRIDDER V2.0 does result in small deviations in the water table relative to the surface initially defined by DTN: MO0110MWDGFM26.002 [160565]. The deviations in water table elevation are typically < 5 m in the area of the proposed repository footprint. Further minor modification to this surface occurs when the reference horizon file "REF_wt_sspac.dat" (Output-DTN: LB0208HYDSTRAT.001) is used to constrain the lower bounds for each column of the numerical grids produced by WINGRIDDER V2.0. However, there are larger (up to 60 m) observed discrepancies in the original (USGS 2001 [157611], Figure 6-1) and output (Figure 1b) water table elevations that may result from errors associated with contour digitization prior to generation of the Vulcan water table representation (See Attachment IV). Further discussion of the uncertainties associated with the definition of the water table is presented in Section 7.1.1 and Attachment IV.

6.5 2-D GRID GENERATION

Used by WINGRIDDER V2.0 (LBNL 2002 [154785]) to organize grid information, the 2-D (map-view) grid (Figure III-3) defines the structure of columns and segments that provide the basis for projecting the 3-D grid. Each column is represented by a node in map-view indicating the column's position in the x-y plane. Additionally, the shape of each column is a polygon in the x-y plane whose boundaries consist of segments defined prior to 3-D grid generation.

Grid development begins with the assignment of nodes in map view for each object (e.g., domain nodes, fault nodes, repository nodes) with specified orientation and density. Based on the location of these nodes, a primary 2-D grid is generated using Voronoi tessellation techniques (e.g., Aurenhammer 1991 [160333]) embedded in the WINGRIDDER V2.0 numerical code. The 2-D grid is then improved systematically and interactively by deleting physically incorrect or unnecessary connections. A few iterations of these steps, including adding, moving, and deleting certain nodes, are necessary to create a final 2-D grid, or column scheme, that serves as the basis for generating the vertical component of the grid.

Two-dimensional grid generation for the UZ Model incorporates the location of domain and proposed repository boundaries, borehole locations, and map-view traces of major faults. As mentioned in Section 6.3, the fault trace information taken from an elevation of 1,100 masl (DTN: MO0012MWDGFM02.002 [153777]), from GFM 2000 was used to define the map-view traces for the 2-D grid. Various subsets of these features are included in the different UZ Model grids, depending on their intended use. Because the 1-D hydrogeologic-property-set inversions only consider rock-property data from vertical boreholes, only borehole locations are relevant when generating this particular grid. The 3-D UZ Model grid assigns nodes in 2-D to the location of all data sources (i.e., boreholes), as well as within domain and proposed repository boundaries and along faults.

Another issue considered in 2-D grid generation is spatial resolution. Grid resolution (node spacing) is a compromise between computational efficiency and a need to capture spatial variability in rock properties and boundary conditions (such as infiltration rate). As discussed in Section 6.6, additional grid resolution was added to the PTn units and the repository, two features that previous Yucca Mountain flow model studies identified as needing enhanced numerical resolution to capture the effects of spatial variability on flow (BSC 2001 [155950], Section 3.3.4.8.1). The 3-D grid captures the needed spatial variability in the infiltration rate at the bedrock surface for calibration purposes, while containing sufficient numerical resolution within the proposed repository boundary, the area most important to PA studies.

6.6 3-D GRID GENERATION

Once UZ Model grid nodes are assigned in plan view and polygons are generated representing the lateral extent of each grid column, model layer contact elevations are determined for each vertical column within the UZ Model grid, using a bilinear interpolation method to determine values between the regularly spaced (61 x 61 m) nodes of the GFM2000 grid (DTN: MO0012MWDGFM02.002 [153777]). The estimated maximum error in layer contact elevations at UZ Model column centers associated with this interpolation method is about 5 m, except in areas affected by faulting (see Attachments II and III for grid verification), assuming that the hydrogeologic layers dip 10 degrees. Dips are generally less than 10 degrees (BSC 2002 [159124], Section 6.4), and thus a value of 10 degrees was used to calculate the maximum error value. This amount of potential error is considered insignificant to grid development and subsequent site-scale UZ Model simulation activities because lateral column dimensions almost always exceed 61 × 61 m (except along faults), thus encompassing the nearest GFM2000 data point.

The 3-D grid describes the location, rock material name, and connection information for each 3-D gridblock in the UZ Model domain. All 3-D gridblocks are generated column by column with WINGRIDDER V2.0 (LBNL 2002 [154785]), based on the 2-D (plan-view) grid design, to ensure that each vertical connection occurs between adjacent gridblocks and that each gridblock has at least one vertical connection. Lateral connections are then generated segment by segment within a model layer, with each segment joining two neighboring columns. This ensures that only gridblocks in two adjacent columns have lateral connections and that no connections between two adjacent columns are missing.

For a given column, 3-D gridblocks are built for each HGU, first above the Tptpv3 structural reference surface until reaching the bedrock surface, and then below this reference surface down to the water table. The interfaces of the generated gridblocks are located exactly at the interfaces of the corresponding hydrogeologic layers. Vertical connections within the column are generated after each gridblock is built. A dummy gridblock is added to the top and bottom of each column to enable assignment of model boundary conditions.

When building lateral connections, each pair of two adjacent columns are searched top-to-bottom. If gridblocks in the adjacent columns belong to the same layer, a lateral connection is built for them. The lateral interface area is determined by the length of the shared side multiplied by the height of the shorter of the two gridblocks that are connected. If the layer is missing in one of the two neighboring columns (resulting from a layer pinching out), the gridblock representing the last occurrence of the pinch-out layer is laterally connected to the adjacent gridblock, now occupied by the next hydrogeologic layer. The height of that interface at the pinch-out margin is reduced to 0.10 m (10% of the minimum gridblock height). This value was chosen assuming that the pinch-out layers are not just layer discontinuities, and that permeable connections are preserved. If one of the two adjacent columns is a fault, the lateral connections are built based on elevations only.

The maximum thickness of any cell within the UZ grids is 20 m (Wang 2002 [159673], SN-LBNL-SCI-103-V1, pp. 135–136). If the thickness of a model layer within a column exceeds 20 m, the layer is subdivided equally into two layers. Minimum vertical grid resolution is 1.0 m; thus, if the thickness of a hydrogeologic layer is less than 1.0 m within a column, the layer is considered absent, and no gridblock is generated for the layer at this location. To conserve the total thickness of the UZ, layer thicknesses below this cutoff are added to the overlying layer if they lie above the structural reference horizon (i.e., top of Tptpv3), or are added to the underlying layer if they lie below the reference horizon. Still, this may lead to a significant discontinuity if many thin, adjacent layers exist. Within UZ Model boundaries, however, no more than two adjacent hydrogeologic layers, each with a thickness less than 1.0 m, occur in any vertical column, except for a few locations near the land surface where erosion has removed most of the crystal-poor Tiva Canyon Tuff (Tpcp), and the underlying Tpcpv units (model layers tcw13 and ptn21) are also less than 1.0 m thick. In this rare case, the small layer thicknesses are added to the underlying layer, ptn22.

Further vertical grid resolution is added within the Ptn units ptn22, ptn24, ptn25, and ptn26, as well as the unit ch1 and the proposed repository horizon, where a maximum cell thickness of 5 m is used (Wang 2002 [159673], SN-LBNL-SCI-103-V1, pp. 135–136). Sensitivity studies examining the effects of grid refinement on flow and transport models indicate that a vertically refined grid is needed to capture lateral flow caused by capillary barriers formed by the layers ptn21 and ptn23 (BSC 2001 [155950], Sections 3.3.3.4.2 and 3.3.4.8.1; Wu et al. 2002 [161058], pp. 7–8, 11, Fig. 7), and thus enhanced grid refinement (maximum cell thickness of 2 m) was assigned to ptn21 and ptn23. Detailed grid resolution to the repository footprint (Assumption 8) allows flow models to better capture spatial variability (BSC 2001 [155950], Section 3.3.4.8.1). The proposed repository itself is represented by five grid layers, each 5 m thick.

Material properties are assigned to gridblocks depending on the hydrogeologic layer to which the gridblock corresponds. For layers with multiple properties, such as the vitric and zeolitic zones within the lowermost Topopah Spring and Calico Hills units, polygons defining the areal extent of these zones are created (see Section 6.6.3). Assignment of material properties (i.e., vitric or zeolitic) to model gridblocks is then confined to the appropriate polygon.

6.6.1 Faults

Although faults may occur as displacement surfaces only or as deformation zones of variable width, each fault within the current UZ Model domain is represented by columns of gridblocks having an arbitrary width of 30 m. Nevertheless, adjustments can be made within a grid to assign appropriate rock properties to each fault zone to handle various fault configurations. Conceptually, there are three important features of a fault that are conserved in the numerical grid. First, a fault is a separator that causes discontinuity of geological layers and may serve as a structural barrier to lateral flow. Second, a fault zone is continuous and may serve as a fast path for vertical flow depending on its hydraulic properties. Third, a fault may or may not be vertical, and its angle of inclination may vary spatially. To implement these features in the UZ grids, three parallel rows of fault-related columns are built for each fault. Each section of a fault in map view consists of three connected columns, with the fault column located in the middle (Figure 2). Each fault column is connected to two side columns and two neighboring fault columns only. Columns on opposite sides of a fault are always separated by a fault column.

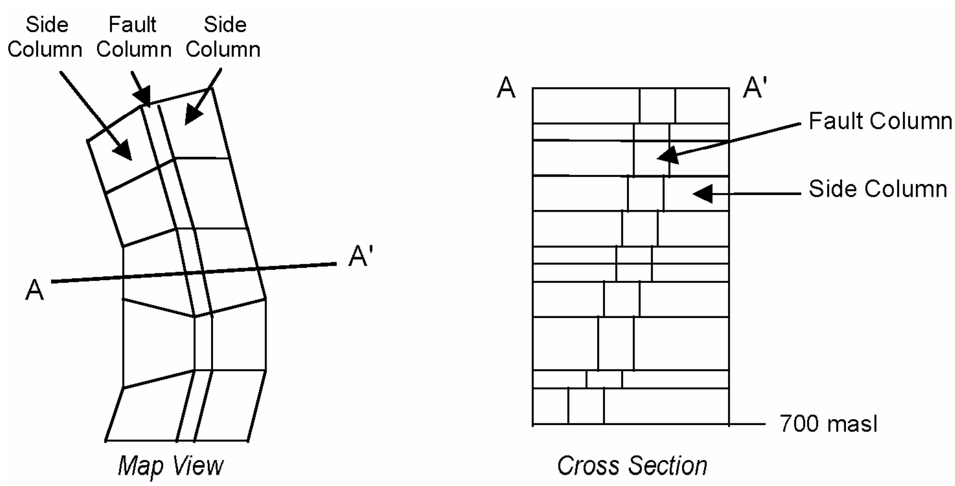


Figure 2. Schematic Illustration of Fault-Related Gridblocks in Map View and in Cross Section

The three fault-related columns (the fault column and its two side columns) are processed together to generate 3-D gridblocks representing the fault and layer offset. From the bedrock surface to the water table, the x, y location of fault gridblocks may shift according to the elevation and dip of the fault. Similarly, the volumes and the center (nodal point) location of the corresponding side cells are adjusted accordingly. As a result, the inclination of the fault is described by a series of connected gridblocks whose x, y locations vary with elevation. The fault-related gridblocks are connected vertically, if they belong to the same column, regardless of the fault angle. Columns of side cells are connected in a similar fashion regardless of the horizontal shifting of position and change in volume. To look at it from another perspective, each set of three fault-related columns (i.e., the fault column plus its two side columns) can be viewed collectively as one vertical column that is subdivided into three nonvertical columns to capture the angle of inclination along a fault. One limitation of this method is that intersecting faults cannot be represented.

This method of representing the three-dimensionality of faults requires that all fault gridblocks have the same elevation and thickness as the laterally adjacent gridblock to facilitate vertical displacement of geologic layers. Because Yucca Mountain is comprised of hydrogeologic layers with variable thickness, simply reassigning material properties from one row of gridblocks to another to establish offset along faults is insufficient for representing the true layer configurations. This approach removes certain layers from columns adjacent to fault columns and often misrepresents layer thicknesses. To avoid such error, additional vertical resolution is added to fault-related gridblocks based on the elevation of hydrogeologic layer contacts on both sides of the fault. Therefore, vertical grid discretization in each set of three fault-related columns is identical, and all interfaces between hydrogeologic units in both side columns correspond to the interfaces between gridblocks. The layer and rock properties of fault gridblocks are then assigned according to the stratigraphy of the fault column.

The assignment of lateral connections that involve fault-related gridblocks is different from the way lateral connections are assigned to normal (non-fault-related) gridblocks. Fault-related lateral connections are of two types, fault-fault gridblock connections and fault-side cell connections. In these two cases, lateral connections occur between gridblocks that share the same interface. The interface area is precisely determined by the contact area between the two gridblocks.

As mentioned in Section 6.3, some simplification of the GFM2000 faults was made in creating the UZ Model grids, including the representation of the Solitario Canyon and Solitario Canyon (west) faults as a single fault. During the evaluation of the 3-D grid described in Attachment III, it was discovered that some matrix columns adjacent to fault columns exhibited fault-related stratigraphic offset with their neighboring columns. To ensure proper flow behavior in the grid, these columns were classified as "faults” while building the 3-D grid so that lateral connections between gridblocks in these columns and those in the adjacent columns were made with the closest lateral neighbor, and not with the same stratigraphic interval. A total of 18 columns, all adjacent to faults, were treated in this manner.

6.6.2 Repository

For numerical gridding purposes, the proposed repository is defined as a 3-D object that is subdivided into a regular mesh of gridblocks. The repository design used in the constuction of the numerical grids (BSC 2002 [159527]) calls for two sets of waste emplacement drifts to be constructed, with the primary proposed repository area located west and/or north of the ESF Main Drift, and the lower elevation block located east of the primary block (Assumption 8). Note that the lower elevation block has been removed from the most recent revision of the proposed repository layout (BSC 2003 [161726]; BSC 2003 [161727]). All repository columns are aligned along the direction of the emplacement drifts, as currently designed, and each column of gridblocks (except those corresponding to borehole locations) has four sides to facilitate the representation of a drift with a series of connected 3-D gridblocks.

Local refinement is added vertically at the proposed repository horizon in the UZ Model grids for PA. For each repository column, a repository thickness of 25 m is assigned at the appropriate elevation. This thickness is then divided vertically into five layers, each 5 m thick. For the interfaces between repository gridblocks, lateral connections are established if two adjacent gridblocks belong to the same layer within the five-layer grid structure of the proposed repository horizon. For interfaces between a repository gridblock and a nonrepository gridblock, the connection is built based on their hydrogeologic-layer similarity. The assignment of rock properties to repository gridblocks is determined by the elevation of the gridblock and the corresponding hydrogeologic layer present at that elevation.

6.6.3 Vitric/Zeolitic Boundaries

The ISM3.1 Rock Properties Model (Assumptions 4 and 5) is used together with measured rock-property measurements from boreholes and corroborative data from the RPM2000 and Mineralogical Model 3.1 (MM3.1) to add resolution to UZ Model grids within the lowermost Topopah Spring tuffs (TSw) and Calico Hills nonwelded unit (CHn). Of great importance to UZ flow and transport modeling is the distribution of low-permeability zeolites, because of their potential to significantly alter flowpaths and travel times and to retard radionuclides migrating from the proposed repository horizon to the water table.

At high matrix saturations, groundwater flow within the TSw and CHn should be diverted around zeolitic volumes of rock and preferentially flow through the less-altered, higher-permeability vitric matrix. Consequently, only a low percentage of the total percolation flux is expected to travel through significantly zeolitized tuffs. This suggests that sorption within the slightly altered (mostly vitric) tuffs is of far greater importance. As such, high- and low-permeability regions are defined within certain UZ Model layers corresponding to the tuffs of the lowermost TSw and upper CHn (above lithostratigraphic unit Tcpuv).

Lateral boundaries between high- and low-permeability tuffs within the lowermost TSw and upper CHn were determined using results from the geostatistical RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]), as well as information found in RPM2000 (DTN: SN0112T0501399.004 [159524]) and MM3.1 (DTN: MO9910MWDISMMM.003 [119199]). The details and results of this exercise and a comparison between RPM3.1, RPM2000, and MM3.1 are provided below. The net result is the subdivision of the lithostratigraphic unit Tac (see Table 11) vertically into four grid layers (ch2, ch3, ch4, ch5), and laterally into vitric and zeolitic regions for which separate hydrogeologic and sorptive properties are assigned. The UZ Model layers tsw 39 (corresponding to the Tptpv2), ch1 (corresponding to the combined lithostratigraphic units Tptpv1 and Tpbt1), and ch6 (corresponding to the Tacbt) are also laterally subdivided into vitric and zeolitic regions. Note that the horizontal and vertical resolution of the UZ Model grids is too coarse to capture meter-scale heterogeneity within the CHn. Small-scale heterogeneity is, however, observed within the CHn and may have an impact on flow and transport calculations.

Data from the Rock Properties Models 3.1 (DTN: MO9910MWDISMRP.002 [145731]) and 2000 (DTN: SN0112T0501399.004 [159524]) and Mineralogic Models 3.1 (DTN: MO9910MWDISMMM.003 [119199]) are analyzed in EARTHVISION V5.1 (Dynamic Graphics 1998 [152614]) by generating map-view figures of percent-zeolite distribution (from MM3.1), interpreted saturated hydraulic conductivity (Ksat) data (from RPM3.1), and a contoured region with <0.5 hydrous-phase alteration (from RPM2000). Results from the RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) were used as the primary means to define vitric and zeolitic boundaries. Because RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) does not include more recent rock-property data from SD-6, saturation, porosity, and hydraulic conductivity data from this borehole (DTNs: GS980908312242.038 [107154] and GS980808312242.014 [106748]) are used to modify zeolitic and vitric boundaries where appropriate. In general, vitric material is characterized by relatively low saturation (<~90%), relatively high Ksat (>~10^{-10} m/s), and oven-dried porosity that is less than 5% higher than relative-humidity porosity. The MM3.1 (DTN: MO9910MWDISMMM.003 [119199]) and RPM2000 (DTN: SN0112T0501399.004 [159524]) data are used as corroborative evidence for the presence of vitric and zeolitic tuffs.

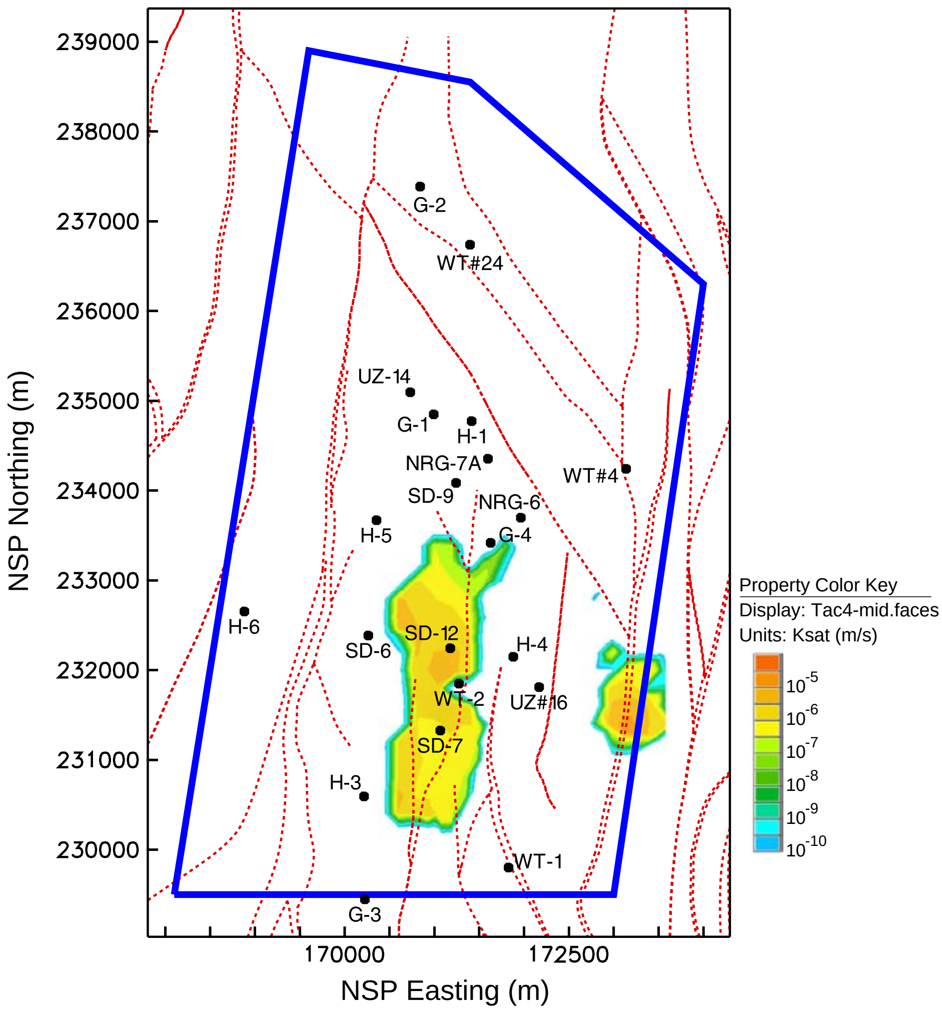
Major faults are assumed to represent appropriate lateral boundaries for unaltered areas (Assumption 6). It is reasonable to assume that vitric portions of the CHn may be laterally continuous within fault blocks that have a higher structural position above the water table compared to adjacent structural blocks. For example, the Solitario Canyon fault system offsets the CHn by more than 300 m in the southern part of the UZ Model domain. CHn layers west of the Solitario Canyon fault lie near or below the water table in this area; consequently they are most likely altered to zeolites. In contrast, CHn layers east of the Solitario Canyon fault may be up to 300 m above the water table and are less likely to have undergone alteration because of limited rock/water interaction. The vertical offset along the Dune Wash fault suggests that this is another possible boundary for vitric and zeolitic subunits within the CHn. As a result, major faults are considered as potential boundaries between vitric and zeolitic areas when interpreting data from RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) and corroborative evidence from RPM2000 (DTN: SN0112T0501399.004 [159524]) and MM3.1 (DTN: MO9910MWDISMMM.003 [119199]).

RPM3.1 uses porosity (data that are relatively abundant at Yucca Mountain) as a surrogate to predict Ksat values. The limitations of this correlation are discussed in Rautman and McKenna (1997 [100643], pp. 13–14). In the RPM3.1 (DTN: MO9910MWDISMRP.002 [145371]), the CHn consists of the volume of rock lying between the upper Tptpv1 contact and the lower Tacbt contact (in other words, geologic layers Tptpv1, Tpbt1, Tac, and Tacbt, shown in Table 11, equivalent to the UZ Model HGUs ch1–ch6). Ksat distributions within the CHn (represented by 24 grid layers in the Rock Properties Model) are plotted in EARTHVISION V5.1 by contouring (2-D minimum tension gridding) the regularly spaced (200 × 200 m) Ksat data for each of the 24 rock-property grid layers. The 24 rock-property grid layers are not stratabound; rather, they are equally thick at any given x, y coordinate. An equivalent GFM2000 isochore file was created by combining the thicknesses of the layers mentioned above. Using the midpoint surface positions for each of the UZ Model layers, Ksat isosurfaces were then back-interpolated from the RPM3.1 file "ChnZksStrat.3grd" (see Attachment I, ISM 3.1 files). The plots show Ksat data that range from approximately 10^{-5} to 10^{-12} m/s; note that Ksat values >10^{-10} m/s are assumed to represent vitric tuffs (Assumption 4). Figure 3 shows an example of one of these Ksat plots for the upper Tac (UZ Model layer ch2) lithostratigraphic unit. Details explaining the extraction of relevant ISM3.1 rock-property data used to define vitric boundaries within UZ Model grid layers are documented in the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, p. 24).

A similar approach was used to evaluate vitric and altered tuffs using data from RPM2000 (DTN: SN0112T0501399.004 [159524]). This version of the RPM contains data from boreholes not included in RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]), but is not qualified, and thus can be used only for corroborative purposes. The RPM2000 file "CHn_hmap_etype.out" (see Attachment I, RPM2000 files) is an "E-type" model of hydrous-phase mineral alteration in the form of a probability distribution, with values close to 1 indicating a strong probability of mineral alteration to phases such as zeolites and clays. For more discussion on E-type models, see *Rock Properties Model Analysis Model Report* (BSC 2002 [159530], Sections 6.1 and 6.4.8.3). Using the mid-point elevation of UZ Model layers ch1, ch2, ch3, ch4, ch5, and ch6, faces files were created for each unit, where the 0.5 probability contour is interpreted to represent the vitric-zeolitic boundary, and where altered (zeolitic) tuffs lie on the >0.5 probability side of the contour line. Figure 4 shows an example of one of these alteration-probability contour plots for the upper Tac (UZ Model layer ch2) lithostratigraphic unit. Details explaining the extraction of RPM2000 rock-property data used to define vitric boundaries within UZ Model grid layers are documented in the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, pp. 24–25).

Percent-zeolite plots were also made from MM3.1 data (DTN: MO9910MWDISMMM.003 [119199]) in EARTHVISION V5.1 by contouring (2-D minimum tension gridding) the regularly spaced (61 × 61 m) percent-zeolite data for the CHn contained in the ISM3.1 file "mineralsM.pdat" (see Attachment I, ISM 3.1 files). The plots essentially represent the exact results of the Mineralogic Model. The plots show a general trend of increased zeolitic alteration to the north and east across the model area. Figure 5 is an example of one of these plots for the upper one-fourth of the Tac lithostratigraphic unit. This representation of zeolite distribution is not appropriate as the primary means of defining vitric-zeolitic boundaries in the numerical grids discussed in this Scientific Analysis report because of the lack of mineralogic sample data and the interpolation technique used in the development of the Mineralogic Model. However, these data can be used for corroborative purposes.

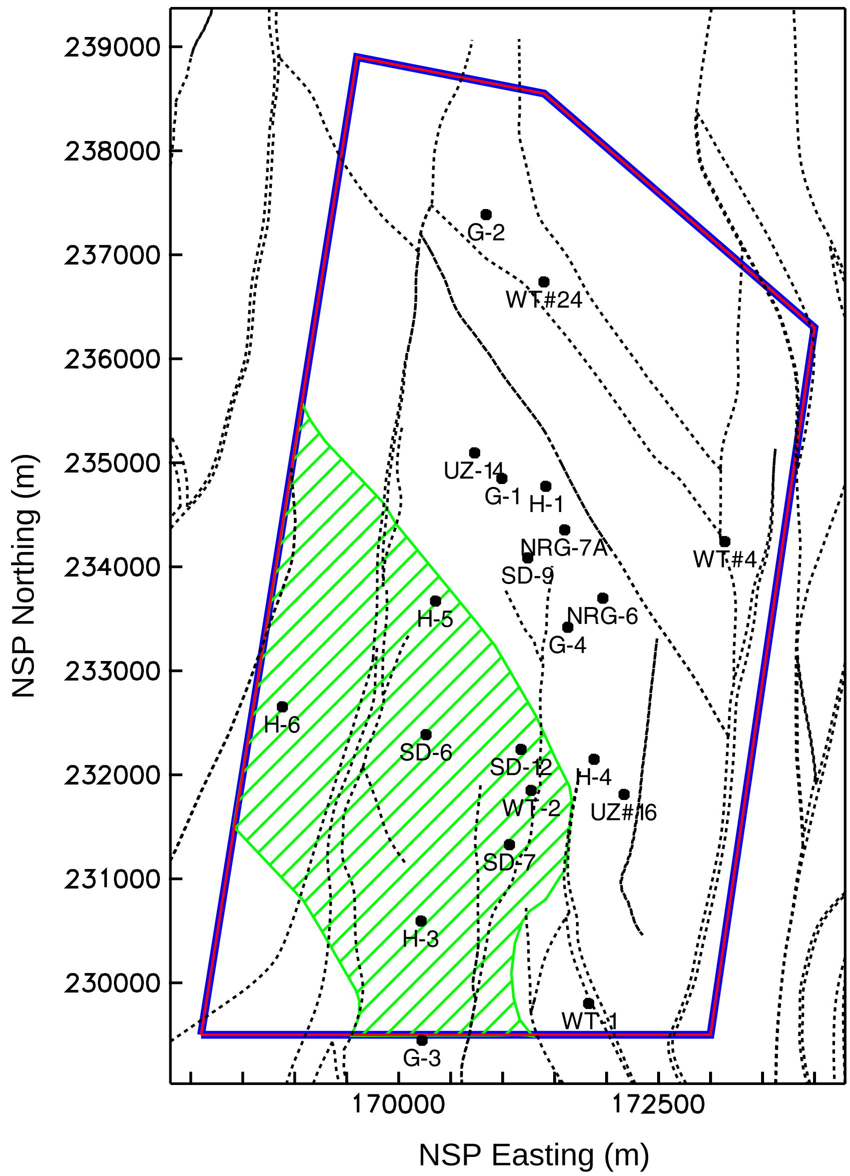
The interpreted extent of the vitric-zeolitic boundaries from the above analysis are shown in Figures 6a and 6b. These boundaries are used in WINGRIDDER V2.0 to assign material names to gridblocks (i.e., "vitric" or "zeolitic," for which associated rock properties will be assigned) within UZ Model layers tsw39, ch1, ch2, ch3, ch4, ch5, and ch6. These boundaries were selected using the results of the RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) Ksat plots (Assumption 4), measured rock-property data for boreholes within the UZ Model area (Assumption 5), and the location of faults with significant vertical offset (Assumption 6). A summary of how vitric/zeolitic boundaries were defined for each UZ Model layer is presented below; additional details can be found in the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, pp. 25–34, 63–66; 2003 [162380], SN-LBNL-SCI-V1, p. 67).



DTN: MO9910MWDISMRP.002 (Rock Properties Model 3.1) [145731]

NOTE: Values less than 10^{-10} m/s given by white.

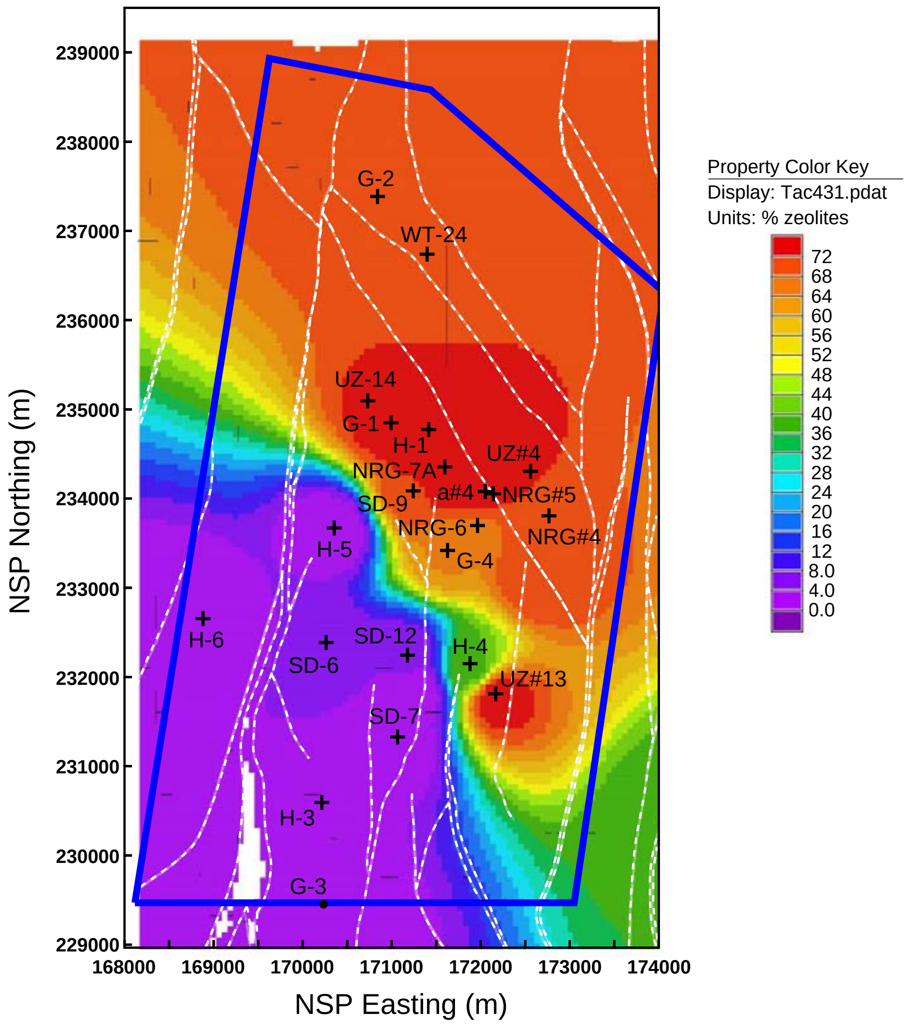
Figure 3. Distribution of Ksat from ISM3.1 Rock Properties Model, Upper 1/4 of Layer Tac (UZ Model layer “ch2”). Ksat Contour Units are m/s.



DTN: SN0112T0501399.004 (Rock Properties Model 2000 (Non-Q)) [159524]

NOTE: Hachured area within UZ Model boundary indicates vitric tuff

Figure 4. Alteration Probability Contour (0.5) Plot from RPM2000, Upper 1/4 of Layer Tac (UZ Model layer “ch2”)



DTN: MO9910MWDISMMM.003 (Mineralogic Model 3.1) [119199]

NOTE: Vitric region denoted by purple

Figure 5. Percent Zeolite Distribution from ISM3.1 Mineralogic Model, Upper 1/4 of Layer Tac (UZ Model layer "ch2")

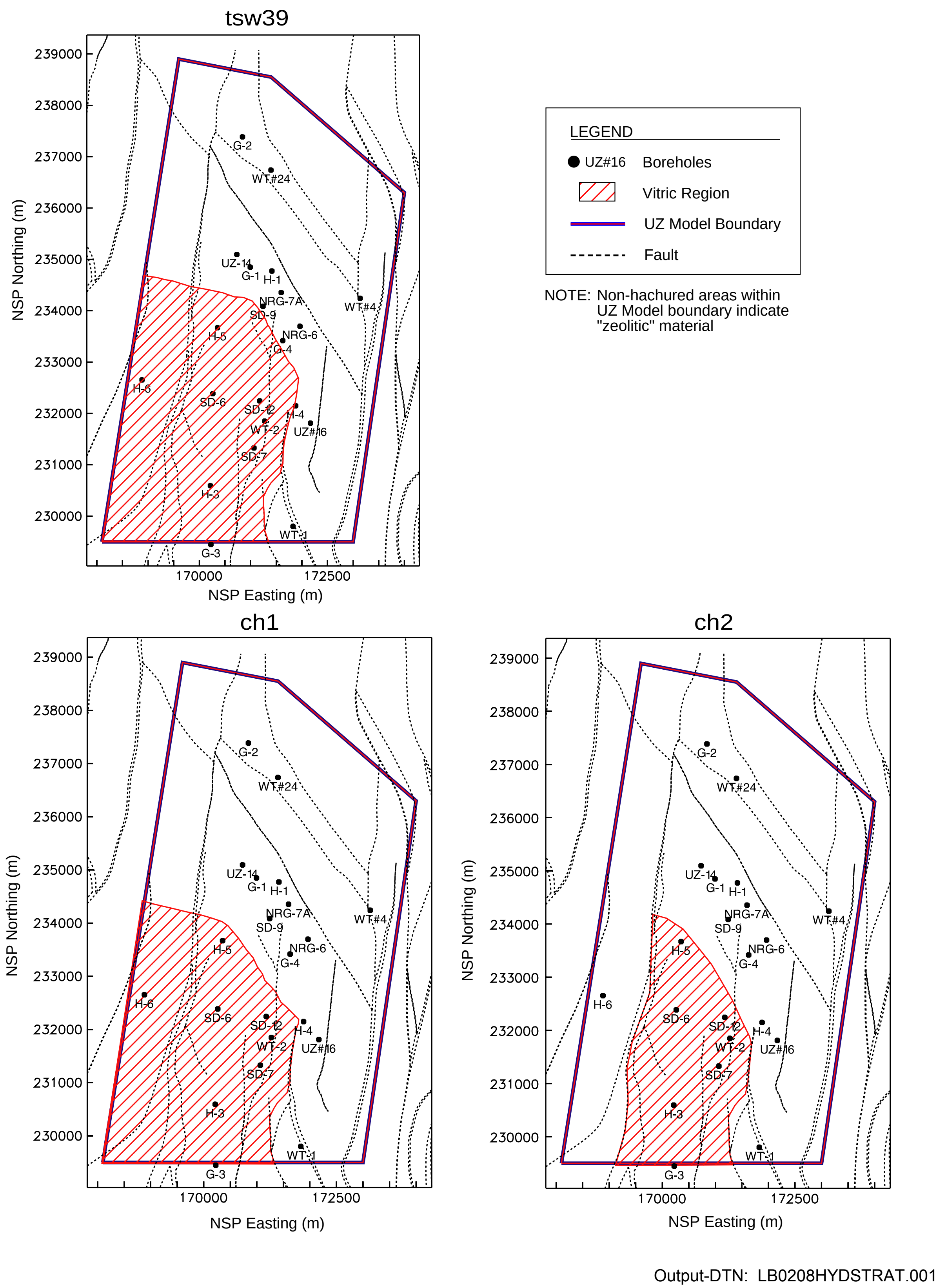
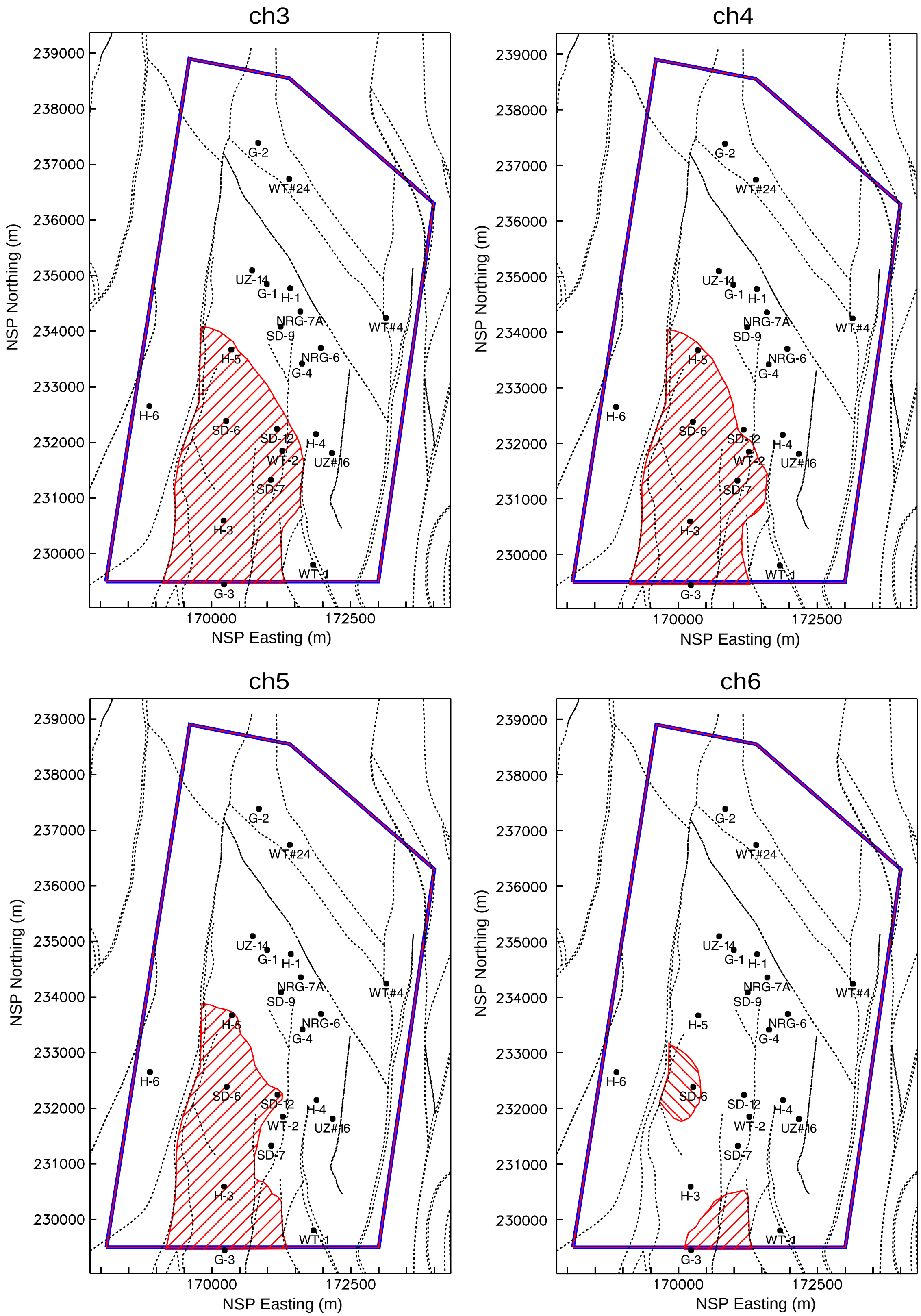


Figure 6a. Extent of Vitric Region in FY02 UZ Model Layers tsw39, ch1 and ch2



Output-DTN: LB0208HYDSTRAT.001

Figure 6b. Extent of Vitric Region in FY02 UZ Model Layers ch3, ch4, ch5 and ch6

Tsw39 (Tptpv2)

Because RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) cannot be easily used to evaluate Ksat values for the unit Tptpv2, rock-property data from boreholes SD-6, SD-7, SD-9, SD-12, UZ-14, UZ-16, NRG-7a, and WT-24 (DTN: LB0207REVUZPRP.002 [159672]; see Wang 2002 [159673], SN-LBNL-SCI-213-V1, pp. 63–66, 93 for details) were the primary input used to define the vitric and zeolitic regions for layer tsw39. Tuffs were characterized as vitric when the following properties were observed: relatively low saturation (<~90%), relatively high Ksat (>~10^{-10} m/s), and a difference between oven-dried and relative-humidity porosities of less than 5% (Assumptions 4 and 5). An evaluation of these rock properties within this unit for the boreholes listed above suggests that the boreholes SD-6, SD-7, SD-9 and SD-12 contain vitric tuffs, UZ-14, UZ-16, and WT-24 contain zeolitic tuffs, and that NRG-7a has samples with both vitric and zeolitic properties. However, to reconcile the presence of perched water above this unit in boreholes SD-9 and NRG-7a (Rousseau et al. 1999 [102097], pp. 170–171), these boreholes were assigned to lie near the boundary, but within the zeolitic region. In general, the vitric-zeolitic boundary for this unit is similar in shape to that determined for the underlying ch1 unit. The Dune Wash fault system was used to bound a portion of the eastern margin of the vitric zone.

Ch1 (Tptpv1 + Tpbt1)

The vitric region is initially defined by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) Ksat data and data from boreholes SD-6, SD-7, SD-12, G-3, H-3, H-5, H-6, and WT-2. Rock-property data for SD-6 (DTN: GS980808312242.014 [106748]) within this unit (corresponding to a depth interval of 463.3–475.8 m) report low saturations (29–51%), and differences in oven-dried and relative-humidity porosities less than 5%, indicating that the ch1 interval in this borehole is vitric. Two of the three hydraulic conductivity values reported for this borehole (DTN: GS98090831224.038 [107154]) are greater than 10^{-10} m/s, consistent with the vitric interpretation. The Dune Wash fault system was used to bound a portion of the eastern margin of the vitric zone.

Ch2 (upper ¼ of Tac)

The vitric region is initially defined by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) Ksat data and data from boreholes SD-6, SD-7, SD-12, G-3, H-3, H-5, H-6, and WT-2. Rock-property data for SD-6 (DTN: GS980808312242.014 [106748]) within this unit (corresponding to a depth interval of 475.8–483.6 m) report low saturations (<70%, avg. 35%), and differences in oven-dried and relative-humidity porosities less than 5%, indicating that the ch2 interval in this borehole is vitric. The three hydraulic conductivity values reported for this borehole (DTN: GS98090831224.038 [107154]) are greater than 10^{-10} m/s, consistent with the vitric interpretation. The Dune Wash fault system was used to bound a portion of the eastern margin of the vitric zone, and the Solitario Canyon fault, which downdrops the region to the west by over 200 m (Figure III-4), was assumed to form the western boundary of the vitric zone for this unit, thus resulting in assigning the H-6 borehole as zeolitic (consistent with the results of RPM3.1 (DTN: MO9910MWDISMRP.002 [145731])).

Ch3 (mid-upper ¼ of Tac)

The vitric region is initially defined by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) Ksat data and data from boreholes SD-6, SD-7, SD-12, G-3, H-3, H-5, H-6, and WT-2. Rock-property data for SD-6 (DTN: GS980808312242.014 [106748]) within this unit (corresponding to a depth interval of 483.6–491.5 m) report low saturations (25–30%), and differences in oven-dried and relative-humidity porosities of less than 5%, indicating that the ch3 interval in this borehole is vitric. The Dune Wash fault system was used to bound a portion of the eastern margin of the vitric zone, and the Solitario Canyon fault, which downdrops the region to the west by over 200 m (Figure III-4), was assumed to form the western boundary of the vitric zone for this unit, thus resulting in assigning the H-6 borehole as zeolitic (consistent with the results of RPM3.1 (DTN: MO9910MWDISMRP.002 [145731])).

Ch4 (mid-lower ¼ of Tac)

The vitric region is initially defined by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) Ksat data and data from boreholes SD-6, SD-7, G-3, H-3, H-5, H-6, and WT-2. Rock-property data for SD-6 (DTN: GS980808312242.014 [106748]) within this unit (corresponding to a depth interval of 491.5–499.3 m) report low saturations (25–43%), and differences in oven-dried and relative-humidity porosities less than 5%, indicating that the ch4 interval in this borehole is vitric. The hydraulic conductivity value (2.31×10^{-5} m/s) reported for this borehole (DTN: GS98090831224.038 [107154]) is greater than 10^{-10} m/s, consistent with the vitric interpretation. While SD-12 lies within the vitric region as defined by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]), rock-property data (DTN: GS960808312231.004 [108985]) for samples from this borehole within the ch4 interval (depths of 458.9–473.2 m) indicate elevated saturation values (92–100%), suggesting that this borehole lies within the zeolitic zone. The Dune Wash fault system was used to bound a portion of the eastern margin of the vitric zone, and the Solitario Canyon fault, which downdrops the region to the west by over 200 m (Figure III-4), was assumed to form the western boundary of the vitric zone for this unit, thus resulting in assigning the H-6 borehole as zeolitic (consistent with the results of RPM3.1 (DTN: MO9910MWDISMRP.002 [145731])).

Ch5 (lower ¼ of Tac)

The vitric region is initially defined by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) Ksat data and data from boreholes SD-6, SD-12, G-3, H-3, and H-5. No rock-property data are available for SD-6 (DTN: GS980808312242.014 [106748]) within this unit (corresponding to a depth interval of 499.3–507.2 m). While SD-7 lies within the vitric region as defined by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]), rock-property data (DTN: GS951108312231.009 [108984]) for samples from this borehole within the ch5 interval (depths of 465.4–477.7 m) indicate elevated saturation values (87–100%, avg. 97%) and differences in oven-dried and relative-humidity porosities typically greater than 5%, suggesting that this borehole lies within the zeolitic zone. The Dune Wash fault system was used to bound a portion of the eastern margin of the vitric zone, and the Solitario Canyon fault was assumed to form the western boundary of the vitric zone for this unit.

Ch6 (Tacbt)

The vitric region is defined by data from boreholes SD-6 and G-3 (no vitric region is indicated by RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]). Rock-property data for SD-6 (DTN: GS980808312242.014 [106748]) within this unit show low saturations (54–67%), and differences in oven-dried and relative-humidity porosities less than 5% in one of two samples, indicating that the ch6 interval in this borehole is vitric. The hydraulic conductivity value (1.2×10^{-9} m/s) reported for this borehole (DTN: GS98090831224.038 [107154]) is greater than 10^{-10} m/s, consistent with the vitric interpretation. The Solitario Canyon fault was assumed to form the western boundary of the vitric zone for this unit.

6.7 DUAL-PERMEABILITY GRID GENERATION

The software program 2kgrid8.for V1.0 (LBNL 2002 [154787]) generates dual-k numerical grids for heterogeneous, fractured rocks. The 2kgrid8.for V1.0 generates a dual-k grid using (a) a primary single-continuum mesh (ECM grid) with 8-character element names, and (b) fracture properties for multiple hydrogeological units. The program is adapted from the software macro DKMgenerator V1.0 (LBNL 1999 [140702]). The 2kgrid8.for V1.0 software is designed to handle three types of fractured media:

1. A set of parallel, infinite fractures (Type #1, 1-D fracture continuum) with uniform spacing within each hydrogeological unit

2. Two sets of parallel, infinite, orthogonal fractures (Type #2, 2-D fracture continuum) with the same spacing within each hydrogeological unit

3. Three sets of parallel, infinite, orthogonal fractures (Type #3, 3-D fracture continuum) with the same spacing within each hydrogeological unit.

Volumes of fracture and matrix elements are computed with 2kgrid8.for V1.0 using the following formulas:

$$V_f = \Phi_f V_n \quad \text{(Eq. 2)}$$

and

$$V_m = (1 - \Phi_f) V_n \quad \text{(Eq. 3)}$$

where V_f and V_m are volumes of fracture and matrix elements, respectively, for the dual-k grid, V_n is the volume of element n of the primary mesh from which a dual-k grid is being generated, and ϕ_f is the fracture porosity or fractional volume of fractures within the bulk rock.

The connection information in the dual-permeability grid is determined as follows:

- Global fracture-fracture and matrix-matrix connection data are kept the same as the connections in the primary mesh for the corresponding gridblocks. This implies that permeabilities used for both fracture and matrix systems are the "continuum" values for both, relative to the bulk-connecting areas.

- Inner-connection distances between fractures and matrix within a primary gridblock are calculated as:

$$D_f = 0 \quad \text{(Eq. 4)}$$

$$D_m = \frac{D}{6} \quad \text{for Type \#1 fractures} \quad \text{(Eq. 5)}$$

$$D_m = \frac{D}{8} \quad \text{for Type \#2 fractures} \quad \text{(Eq. 6)}$$

$$D_m = \frac{D}{10} \quad \text{for Type \#3 fractures} \quad \text{(Eq. 7)}$$

and

$$D = \frac{1}{F} \quad \text{(Eq. 8)}$$

where D_f is the distance from the fracture center to the surface of a matrix block; D_m is the calculated distance for flow crossing fracture/matrix interfaces, based on the quasi-steady state assumption (Warren and Root 1963 [100611], p. 247; Pruess 1983 [100605], Table 1); D is the fracture spacing; and F is the fracture frequency within the unit.

The interface area (A) between fractures and matrix blocks is estimated by:

$$A = A_{fm} V_n \quad \text{(Eq. 9)}$$

where A_{fm} is a volume-area factor, which represents the total fracture-matrix interface area per unit volume of rock, determined from site fracture characterization studies. Fracture properties incorporated in the UZ Model are listed in Table 4. Only Type #1 fractures were used in the generation of dual-k numerical grids.

The program 2kgrid8.for V1.0 must first be compiled using a FORTRAN compiler to create the executable file for the operating platform. Three input files are required to run 2kgrid8.for V1.0. These files are called "2kgrid.dat," "connec.dat," and "framtr.dat," and contain the following information:

1. The "2kgrid.dat" file contains the two parts of ELEME and CONNE data blocks from the primary single-continuum mesh using the same formats.

2. The "connec.dat" file contains connection indexes from the primary single-continuum mesh using the same formats.

3. The "framtr.dat" file contains fracture properties (DTN: LB0205REVUZPRP.001 [159525] and DTN: LB0207REVUZPRP.001 [159526]) with the following format and data:

   Format (A5,5X,4(E10.3))
   urock(i), volf(i), xxx, dspac(i), afm_v(i)

   urock(i) rock type name as rock(n)

   volf(i) porosity or volume fraction of fractures within bulk rock

   xxx aperture, not used

   dspac(i) fracture frequency

   afm_v(i) a volume-area factor, representing the total fracture-matrix area per unit volume rock, as determined from site fracture characterization studies.

Execution of "2kgridv1" creates three output files:

1. The "2kgrid.out" file contains information from the primary mesh and new dual-k meshes for grid verification purposes.

2. The "eleme.dat" file contains "ELEME" data blocks for the new dual-k grid.

3. The "conne.dat" contains "CONNE" data blocks for the new dual-k grid.

6.8 GRID VERIFICATION

The Scientific Analysis report presents the grids to represent the geological framework model, refined from borehole data for the unique representation of Yucca Mountain. Since there are no alternative geologic models developed (Section 4.1), no alternative grids are presented in this report. The grids are intended for use by the UZ Model for site-scale flow and transport processes. Numerical grids are fixed objects, or frameworks, that alone do not capture physical processes or phenomena occurring at Yucca Mountain. As such, the process of "model validation," in the usual sense, does not apply. However, the process of grid "verification"—an evaluation of how accurately the numerical grid represents the geologic and hydrogeologic input—does apply, and is discussed in this section.

The parameters generated for each numerical grid include gridblock material names, gridblock volumes and locations, connection lengths and interface areas between gridblocks, and direction of absolute permeability for each connection. Because of the number and size of the numerical grids developed for UZ Model activities, it is not practical to verify each parameter for each gridblock generated. Consequently, a subset of gridblocks from each mesh is taken, and the associated parameters are verified to ensure the accuracy and representativeness of the mesh. The criteria by which the numerical grids are evaluated are not as rigorous as, for example, those specified for engineering design. This is because of the simplified approximation and large uncertainty inherent in modeling studies, where variations in modeling results up to an order of magnitude may be considered acceptable.

For the 1-D numerical grids (Output-DTN: LB02081DKMGRID.001), which consist of columns of gridblocks at borehole locations only, gridblock material names and elevations are verified through comparison with stratigraphic information from GFM2000 (see Attachment II for details). For the 2-D cross-sectional grids through borehole UZ-7a (Output-DTN: LB02081DKMGRID.001), gridblock material names and elevations are verified through visual comparison with stratigraphic and structural information from GFM2000 exported surface horizons (see Attachment III for details). For the 3-D UZ Model grids (Output-DTN: LB03023DKMGRID.001) for calibration and calculation of flow fields, gridblock material names and elevations are verified through comparisons at borehole locations with the GFM2000 file “contacts00el.dat” (see Attachment I, GFM2000 files) and through visual comparison with stratigraphic and structural information from GFM2000 exported surface horizons (see Attachment III for details).

A spot check involving hand calculation of gridblock volumes, connection lengths, and interface areas between gridblocks showed consistency with calculated results for all UZ Model grids generated. A spot check of the direction of connectivity confirmed vertical connections for all connections within gridblock columns (except for columns associated with nonvertical faults, where the x-y locations of grid nodes can vary with depth). These spot checks are documented in the scientific notebook by Wang (2002 [159673], SN-LBNL-SCI-213-V1, p. 93).

An additional test of the 3-D grid was performed through the use of a TOUGH2 V1.4 (LBNL 2000 [146496]) simulation. For this fully saturated isothermal (25°C) simulation, all gridblocks were assigned the same rock properties and an initial fluid pressure of 500 bars. Several large volume gridblocks at the base of the grid were assigned constant pressures, and the remainder of the grid was allowed to attain equilibrium pressure conditions over time. Thus, for an ideally configured grid, there should be a linear relation between gridblock elevations and steady-state pressures. Small deviations from this relation were observed for the gridblocks in inclined fault columns, where vertical connections between gridblocks deviate from 90 degrees. The shift in pressure for a given elevation for these gridblocks is a function of the relative deviation from vertical for the fault columns, with more inclined faults exhibiting a greater deviation from the predicted pressure. A more detailed discussion of this simulation is presented in Attachment III.

Corroborative Studies

Sensitivity studies that examine the effect of grid resolution (i.e., gridblock size) on flow and transport simulation results were documented in FY97 (Haukwa and Wu 1997 [107934]; Haukwa et al. 1997 [101243]) and FY98 (Zhang 2000 [159531], pp. 52–56, 66–72) UZ Models, and are summarized below as corroborative material for this Scientific Analysis report.

FY97 UZ Model Sensitivity Study—Both coarse and refined 2-D, cross-sectional grids of the UZ at Yucca Mountain were developed by Haukwa and Wu (1997 [107934], pp. 4-12–4-13) to address concerns over the use of appropriate numerical grid resolution in UZ moisture flow modeling. The cross sections were developed along a north-south (N-S) transect through the proposed repository area, extending from borehole G-2 in the north to borehole G-3 in the south. The coarse grid used an average horizontal spacing of 50 m within the proposed repository area and 100 m outside the proposed repository area. The fine grid used a horizontal spacing as small as 6 m within the proposed repository area and as high as 50 m outside the proposed repository area. The coarse grid was comprised of 23 vertical layers; the refined grid had 61 layers (Haukwa et al. 1997 [101243], pp. 12-2–12-3). Identical layer-averaged rock properties were used in both grids. From comparison of flow simulation results using the coarse and refined grids, it was concluded by Haukwa et al. (1997 [101243], p. 12-16) that the 100 m lateral grid resolution within the proposed repository area, used in the 3-D UZ Model, was sufficient for ambient site-scale flow modeling purposes.

Results indicated that moisture flow is predominantly vertical (Haukwa et al. 1997 [101243], p. 12-4), except where zeolites are present, suggesting that modeling results are less sensitive to lateral gridblock dimensions than to vertical changes in grid resolution, unless a sudden change in rock hydrogeologic properties occurs at a layer contact, resulting in significant lateral diversion. Below the proposed repository horizon, lateral diversion is most likely to occur above zeolites in the CHn. Calculated saturation and percolation flux distribution could be adequately resolved by adding a few grid layers at the PTn-TSw interface and at the vitric-zeolitic interfaces within the CHn, since these are transitional areas where rock properties change rapidly over short distances.

The current (FY02) 3-D UZ Model is vertically resolved with about 57 layers in the proposed repository footprint; about 26 of these layers are above the proposed repository horizon, 5 layers are within the proposed repository horizon, and about 26 layers lie between the proposed repository horizon and the water table). The transitional areas at the PTn-TSw and vitric-zeolitic interfaces are generally captured by several thin layers.

FY98 UZ Model Sensitivity Study—In this study, the influence of gridblock size on flow and transport simulation results was examined along an east-west (E-W) cross section through borehole SD-9. Four meshes, each with a different nominal gridblock size, were developed along the E-W transect (for details, refer to Zhang 2000 ([159531], pp. 52–56, 66–72)). Three simulation scenarios were considered in this study. In the first simulation scenario (Scenario #1), no modifications are made to the calibrated FY98 hydrogeologic property sets to represent perched water. In the second simulation scenario (Scenario #2), FY98 calibrated perched-water hydrogeologic properties are used. In the third simulation scenario (Scenario #3), perched-water properties are used, but fracture flow is ignored in zeolitic units (except in fault zones). Both conservative and reactive tracers are considered in the transport simulations for each of the three scenarios.

Under the conditions prescribed in Scenario #1 (no perched water), the effect of gridblock size is minimal. Results from the coarsest of the four cross-sectional grids (which has a nominal horizontal spacing of 112 m and a maximum layer thickness of 60 m) compared with the results from the finest of the four cross-sectional grids (which has a nominal horizontal spacing of 28 m and a maximum layer thickness of 15 m) show an approximate 20% difference in the time at which half of the tracer mass (both conservative and reactive) reaches the water table.

Under the conditions prescribed in Scenario #2 (perched water), model results for the coarsest mesh and finest mesh show differences of about 10% in the time at which half of the tracer mass reaches the water table for conservative tracers. For reactive tracers, results for the coarsest mesh differ from those for the finest mesh by a factor of two.

Under the conditions prescribed in Scenario #3 (perched water, no fractures in zeolitic units), the effect of gridblock size is once again minimal. Results from the coarsest of the four cross-sectional grids compared with the results from the finest of the four cross-sectional grids show an approximate 20% difference in the time at which half of the conservative tracer mass reaches the water table, as well as an approximate 15% difference in the time at which half of the reactive tracer mass reaches the water table.

The results of this FY98 modeling study suggest that the numerical grid resolution used in the FY02 site-scale UZ Model grids, at least within the proposed repository area, is appropriate for capturing important flow and transport phenomena.

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7. CONCLUSIONS

Data from the GFM2000 geological model (DTN: MO0012MWDGFM02.002 [153777]) were integrated with hydrogeologic units defined by Flint (1998 [100033]) and adjusted using rock-property data contained in ISM3.1 to create integral finite-difference numerical grids for the UZ at Yucca Mountain. The layer subdivision and assignment of material properties resulted in numerical grids that are appropriate for UZ flow and transport modeling.

These grids were verified for accuracy by inspection of gridblock material names, volumes, location, interface areas, and connection length and direction. The grids were also verified against known stratigraphy in reference boreholes and the GFM2000 (DTN: MO0012MWDGFM02.002 [153777]). The results show that the resulting 1-D, 2-D, and 3-D grids accurately reflect the stratigraphy and structural features of GFM2000, with contact elevations and unit thicknesses usually within 5 m of those of GFM2000. Larger deviations may occur in the vicinity of faults with large vertical offsets or with nonvertical fault slopes.

Corroborative sensitivity studies show that the grids developed are valid and appropriate for UZ flow and transport modeling. The FY02 UZ Model grids incorporate closer spacing of layers (maximum of 5 m) for the PTn units (where lateral flow may occur), the proposed repository, and the unit ch1, thus allowing for adequate resolution of flow and transport phenomena within the UZ.

Results from the development of numerical grids to simulate the UZ at Yucca Mountain include:

- One primary mesh and one dual-k mesh consisting of 1-D columns at borehole locations (Output-DTN: LB02081DKMGRID.001) used for developing calibrated hydrogeologic property sets for the UZ at Yucca Mountain.

- One primary mesh and one dual-k mesh comprising a 2-D cross section through borehole UZ-7a (Output-DTN: LB02081DKMGRID.001) used to calibrate fault hydrogeologic properties in the UZ at Yucca Mountain.

- One primary mesh and one dual-k mesh (Output-DTN: LB03023DKMGRID.001) used for 3-D UZ Model calibration and to generate 3-D UZ flow fields for Performance Assessment.

7.1 LIMITATIONS AND UNCERTAINTIES

The numerical grids developed in this report are intended for use in mountain-scale flow and transport modeling of the Yucca Mountain UZ system. A model of a complex system such as Yucca Mountain must be used with recognition of its limitations. For the site-scale UZ Model, a key limitation is imposed by numerical grid resolution. Since computational time rapidly increases with grid size (i.e., number of gridblocks and connections), the use of large refined grids is currently limited by both simulation time and CPU requirements. Refining an entire 3-D model with gridblocks having dimensions roughly equivalent to the expected drift spacing in the proposed repository and using comparably refined vertical resolution would increase current grid sizes by more than an order of magnitude. Thus, it is not feasible at the mountain scale to characterize flow behavior on horizontal scales less than a few tens of meters. Current lateral resolution (up to 300 m in areas outside the proposed repository boundary) can sometimes lead to high aspect ratios within very thin layers. This may lead to inaccuracies when trying to calculate lateral flow components; however, fracture spacing and orientation data suggest that groundwater flow is primarily downward, except within the altered tuffs.

Previous modeling studies at Yucca Mountain have established that sufficient vertical grid resolution is critical to capturing important flow and transport processes, such as lateral flow (Wu et al. 2002 [161058]; BSC 2001 [155950], Sections 3.3.3.4.2 and 3.3.4.8.1). Wu et al. (2002 [161058]) evaluated the effect of grid refinement on percolation fluxes and noted that simulations using a vertical grid spacing of 10 m within the PTn were unable to resolve the effects of lateral flow. In contrast, the use of a more refined grid with a maximum vertical spacing of 2 m within the PTn could capture the capillary barrier effects of ptn21 and ptn23, resulting in significant lateral flow. The results of this sensitivity study were used to design the current numerical grids by employing a variable maximum vertical grid spacing with enhanced grid resolution within the PTn (See Section 6.6 for details).

The impact of utilizing nonorthogonal grids on TH modeling at Yucca Mountain was evaluated by Haukwa et al. (2003 [161647]). With a nonorthogonal grid, cross-term contributions in the numerical discretization are neglected because of vertical separation of laterally connected nodes. A comparison of simulations conducted using orthogonal and nonorthogonal grids for the Yucca Mountain UZ system (where represented layers typically have dips less than 10 degrees; see Section 6.6) indicated little impact on both steady-state and transient solutions, because the cross-term connections contribute less than 6% to the total flux. As mentioned in Section 6.8 and Attachment III, the use of non-vertical columns for inclined faults does lead to some deviations in the flow behavior for the affected grid blocks.

The accuracy of UZ Model grids depends largely on the accuracy of the GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) and RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]) input data. Both of these models, which are assumed to provide a representative picture of subsurface geology and rock properties, are constructed with limited data resources. GFM2000 includes assumptions about the lateral continuity and thickness trends of layers at Yucca Mountain based on limited borehole data. The UZ Model numerical grids attempt to match this layered approach as closely as possible to constrain UZ flow and transport processes. While the degree of lateral continuity of layers represented in GFM2000 is a valid interpretation, the impact of more lateral discontinuity resulting from the inclusion of small faults on flow could be significant, especially in areas where little or no information has been collected. However, these areas typically lie too far from the proposed repository area to have any significant impact on repository performance.

The GFM2000 bedrock surface ("s00bedrockRWC.2grd"; listed in GFM2000 files in Attachment I) was used to define the upper boundary of the UZ Model grids (see Section 6.4.2). The use of the bedrock surface thus results in the exclusion of alluvial cover from the model. In the area of the proposed repository, bedrock is typically exposed at the surface, with alluvium confined to washes and other topographic lows (BSC 2002 [159124]), Figure 13). Because alluvial cover is mostly absent above the proposed repository, any insulating effects of this material are likely to be minimal. Sensitivity studies to test the effect of alluvial cover on thermal modeling are not within the scope of this Scientific Analysis report.

Within RPM3.1 (DTN: MO9910MWDISMRP.002 [145731]), the interpretation of saturated hydraulic conductivity (Ksat) distribution and mineral alteration at Yucca Mountain is also based on limited data and assumed correlations (e.g., using porosity as a surrogate for predicting Ksat). The spatial heterogeneity of low-permeability alteration products such as zeolites has a profound impact on UZ flow and transport modeling, yet the nature of their distribution is not fully understood. Though currently represented per hydrogeologic layer (i.e., UZ Model layers tsw39, ch1, ch2, ch3, ch4, ch5, and ch6), true mineral alteration and rock-property variation may not strictly follow a layered model. While a variety of geologic and rock property data were used to define vitric-zeolitic boundaries (see Sections 5.2 and 6.6.3), the location of vitric to zeolitic transitions are not consisely resolved.

Grid verification exercises show that UZ Model layer thicknesses and elevations are reasonable representations of the hydrogeologic input data. Using visual cross-sectional comparisons with GFM2000 (DTN: MO0012MWDGFM02.002 [153777]), UZ Model layer contact elevations are shown to have some large (up to 50 m) differences in areas immediately adjacent to inclined fault zones, reflecting the coarse lateral grid resolution used as well as certain limitations of the gridding software. Given the large uncertainties associated with fault zone hydrogeologic characteristics, the effect of these differences along faults on modeling results has yet to be determined, but is likely limited in extent to the area immediately surrounding the fault zones. Additional hydrogeologic property data and analyses within fault zones would reduce uncertainty in this area.

There are some limitations relating to the modeling of faults in the UZ Model grids. As noted earlier (Section 6.6.1), faults cannot be modeled as intersecting features. To simplify the model, subsidiary faults related to the Solitario Canyon fault ("Splay N," "Splay G," "Splay S," and the Solitario [west] faults) were omitted from the UZ Model grids because of their proximity to the dipping Solitario Canyon fault (making them difficult to incorporate as separate features to the model). Faults observed within the ESF and ECRB that are not part of the GFM2000 (owing to either insufficient length or offset) are also not incorporated in the UZ Model grid.

As mentioned in Section 5.2, the proposed repository design used for the UZ Model numerical grid generation (BSC 2002 [159527]) was the most recent representation of the repository layout at the time the grids were generated. It is recognized that the proposed repository layout may be subject to future design modifications, and that the most recent revision of the proposed repository layout (BSC 2003 [161726]; BSC 2003 [161727]) does not include the lower block area (See Section 4.1.1). If additional design changes are made, the numerical grids should be evaluated to ensure that sufficient grid resolution in the area of the proposed repository exists, and if this is no longer the case, new numerical grids should be generated utilizing the revised repository design.

7.1.1 Water Table Uncertainty

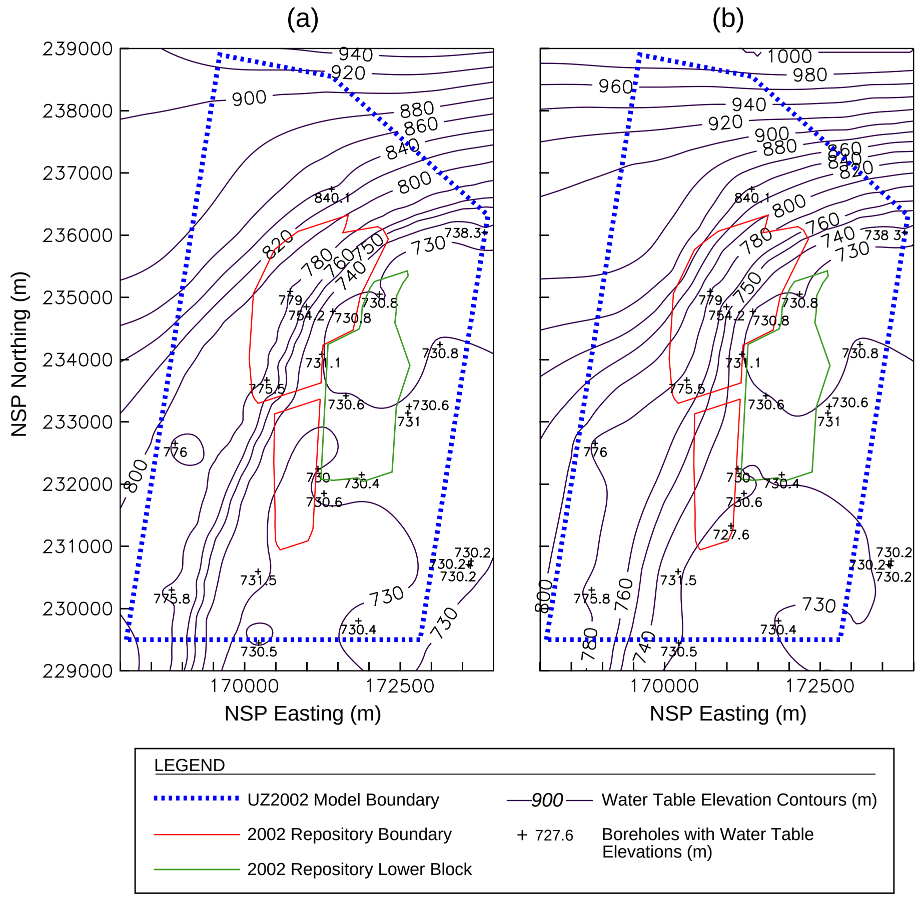
The water table by definition forms the base of the UZ (Assumption 1). The potentiometric-surface map as defined by USGS (2001 [157611], Figure 6-1) was constrained by borehole water levels in the Yucca Mountain area (USGS 2001 [157611], Table I-2). Contours for this map were hand-drawn to conform to the borehole water levels, assuming that the measured water level in WT-24 represents the regional water table, whereas the water levels in boreholes G-2 and WT-6 represent perched conditions. The water table is well constrained in the area near the ESF where abundant borehole data exist, but is poorly constrained to the north and west, where there are very few control points and the potentiometric surface has a higher gradient. Thus, any definition of the water table elevations will inevitably include some uncertainty, especially in the areas where few borehole constraints are available.

The water table is defined in the qualified DTN: GS010608312332.001 [155307] through the use of borehole locations and their associated water table elevations and potentiometric map contours. The DTN: GS010608312332.001 [155307] from USGS 2001 [157611] contains the ARCINFO files ("pot_contours.e00" and "wells.e00"). The layer "GWL_SSPAC" in the Vulcan GFM2000 Representation database (DTN: MO0110MWDGFM26.002 [160565]) was derived by digitizing the contours depicted on the potentiometric surface map included in *FY 01 Supplemental Science and Performance Analyses, Volume 1: Scientific Bases and Analyses* (BSC 2001 [155950], Figure 12.3.1.2-2), which appears to be identical to that presented in USGS (2001 [157611], Figure 6-1). The data defining this layer (contours and borehole coordinates) were then extracted and the resulting data set (gwl_sspac2.asc) was submitted to the TDMS as DTN: MO0212GWLSSPAX.000 [161271] (see Attachment IV for details). This representation of the water table was qualified using the procedure AP-SIII.2Q, *Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data* and the Data Qualification Plan found in the *Technical Work Plan for: Performance Assessment Unsaturated Zone* (BSC 2002 [160819], Attachment III). The data qualification reviews for DTN: MO0212GWLSSPAX.000 [161271] are presented in Attachment IV.

The file gwl_sspac2.asc was used as input for the generation of the UZ water table reference horizon (see Section 6.4.2 for details). Data files in DTNs: GS010608312332.001 [155307] and MO0212GWLSSPAX.000 [161271] both contain water table contours, but these contours do not uniquely define a surface from which regularly spaced water table data could be obtained. Thus, the digitized potentiometric contour data and borehole water-level data must be used to create a numerical surface to facilitate production of a regularly spaced set of water table elevations.

The x, y data contained in the ARCINFO files (DTN: GS010608312332.001 [155307]) are given in Universal Transverse Mercator (UTM) coordinates, whereas those from the gwl_sspac2.asc file (DTN: MO0212GWLSSPAX.000 [161271]) are in Nevada State Plane (NSP) meters. The ARCINFO file "pot_contours.e00" was modified using a text editor so that it could be read as a ".dat" file in EARTHVISION V5.1 (Dynamic Graphics 1998 [152614]). The coordinate transformation utility of EARTHVISION V5.1 was used to convert the UTM coordinates to NSP coordinates. Elevation values were then assigned to each point on the basis of visual comparison to the potentiometric map in the report, *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (USGS 2001 [157611], Figure 6-1). The contour line locations were then compared with those extracted from the Vulcan data base, and significant deviations in water table elevations between the data sets were observed in areas north (up to 60 m) and northwest (up to 30 m) of the ESF within the UZ Model grid area. These variations may result from errors associated with the digitization of the contour lines.

The data from these two sources were imported into EARTHVISION V5.1 to construct gridded surfaces to permit more rigorous comparison of the data (Wang 2003 [162380], SN-LBNL-SCI-213-V1, pp. 110–115). Borehole water table data included in the input file converted from Vulcan were appended to the modified ARCINFO file (which contained only water table contour data), with the only modification being that SD-7 was removed from the input data set, as it was considered to be unreliable in the report, *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (USGS 2001 ([157611], Table I-2). Using the 2-D minimum tension gridding utility in EARTHVISION V5.1, the data were coarsely gridded and then finely gridded, using the same steps as outlined in Section 6.4.2 that were employed to create the water table utilized for numerical grid generation. The contoured water table surfaces created in EARTHVISION V5.1 using the two data sets are displayed in Figure 7.



DTNs: (a) GS010608312332.001 [155307]
(b) MO0212GWLSSPAX.000 [161271]

NOTE: 2002 Repository Lower Block will not be used in any LA calculations.

Figure 7. Comparison of EARTHVISION V5.1 Gridded Potentiometric Surfaces

Because neither data set uniquely defines a water table that could be used to extract a set of regularly spaced data needed for creating the numerical grids, it was necessary to create a numerically defined surface in EARTHVISION V5.1 through gridding of the borehole water table elevations and potentiometric surface contour lines. The two-step process used to create the fine-spaced grid (see Section 6.4.2) does result in small changes in the appearance of the contoured surface, such as the creation of a small ridge in the potentiometric surface where the water table is around 730 m elevation. Such features are artifacts of the irregularly spaced input data and the use of 2-D minimum tension gridding, and result in minor shifts in the water table. As mentioned in Section 6.4.2, the resulting regularly spaced data set was edited to have a minimum water table elevation of 730 m, and thus the final numerical grids generated by WINGRIDDER V2.0 (LBNL 2002 [154785]) have a lower boundary no lower than 730 m. Both contoured surfaces are consistent with the measured borehole water table elevations; however, significant differences exist between the locations of the contour lines used to define the potentiometric surface. These differences translate into significant deviations (up to 60 m) in the water table elevations in the areas to the north and west, where there is a pronounced gradient to the water table and few borehole constraints. In general, the water table elevations as indicated by DTN: MO0212GWLSSPAX.000 [161271] are higher than the corresponding elevations from DTN: GS010608312332.001 [155307], resulting in a shorter distance for radionuclide transport through the UZ. It is recommended that for future revisions of this document, a single water table be generated using the best available data and conceptual models. Such a surface could be applied to the full range (e.g., UZ modeling, SZ modeling, and repository design) of Yucca Mountain studies, and would reduce potential inconsistencies and differences between these products.

7.2 RESTRICTIONS FOR SUBSEQUENT USE

The UZ Model numerical grids developed herein shall be used only for development of UZ hydrogeologic property sets, for UZ Model calibration, and for development of UZ flow fields for Performance Assessment. These activities will involve the use of software from the TOUGH2 family of codes.

7.3 TECHNICAL PRODUCT OUTPUT

The technical product output files for this Scientific Analysis report have been submitted to the TDMS and are included in the following Output-DTNs:

LB02081DKMGRID.001

LB0208HYDSTRAT.001

LB02092DGRDVER.001

LB03023DKMGRID.001

8. INPUTS AND REFERENCES

The following is a list of the references cited in this document. Column 1 represents the unique six digit numerical identifier (the Document Input Reference System [DIRS] number), which is placed in the text following the reference callout (e.g., BSC 2002 [155950]). The purpose of these numbers is to assist the reader in locating a specific reference. Within the reference list, multiple sources by the same author (e.g., BSC 2002) are sorted alphabetically by title.

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LB02092DGRDVER.001. Files for 2D Grid Verification. Submittal date: 09/30/2002.

9. ATTACHMENTS

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ATTACHMENT I

ELECTRONIC GFM2000, ISM3.1, RPM2000, AND ROCK- AND FRACTURE-PROPERTY DATA FILES USED TO DEVELOP UZ MODEL NUMERICAL GRIDS

GFM2000 Files: (DTN: MO0012MWDGFM02.002 [153777])

Isochores:
ia00cLDRWC.2grd
ia00cpv3RWC.2grd
ia00cpv2RWC.2grd
ia00cpv1RWC.2grd
ia00bt4RWC.2grd
ia00tpyRWC.2grd
ia00bt3RWC.2grd
ia00tppRWC.2grd
ia00bt2RWC.2grd
ia00trv3RWC.2grd
ia00trv2RWC.2grd
ia00trv1RWC.2grd
ia00trnRWC.2grd
ia00trltfRWC.2grd
ia00tpulRWC.2grd
ia00tpmnRWC.2grd
ia00tpllRWC.2grd
ia00tplnRWC.2grd
ia00tpv3RWC.2grd
ia00tpv2RWC.2grd
ia00tpv1RWC.2grd
ia00bt1RWC.2grd
ia00tacRWC.2grd
ia00tacbtRWC.2grd
ia00prowuvRWC.2grd
ia00prowucRWC.2grd
ia00prowmdRWC.2grd
ia00prowlcRWC.2grd
ia00prowlvRWC.2grd
ia00prowbtRWC.2grd
ia00bulluvRWC.2grd
ia00bullucRWC.2grd
ia00bullmdRWC.2grd
ia00bulllcRWC.2grd
ia00bulllvRWC.2grd
ia00bullbtRWC.2grd
ia00tramuvRWC.2grd
ia00tramucRWC.2grd
ia00trammdRWC.2grd
ia00tramlcRWC.2grd
ia00tramlvRWC.2grd
ia00trambtRWC.2grd

Faults:
f00bowex.dat
f00solEX.dat
f00solwestEX.dat
f00soljfatEX.dat
f00splaygEX.dat
f00splaynEX.dat
f00splaysEX.dat
f00sundanceEX.dat
f00toeex.dat
f00severEX.dat
f00paganyEX.dat
f00drillEX.dat
f00ghostEX.dat
f00ghostwEX.dat
f00duneEX.dat
f00dunexEX.dat
f00dunew1EX.dat
f00imbex.dat
f00exileEX.dat

Surface Horizons:
s00bedrockRWC.2grd
s00TpcpEXuncut.2grd
s00Tptpv3EXuncut.2grd

Other:
boreholepaths.dat contacts00el.dat

ISM3.1 Files:	mineralsM.pdat*	(DTN: MO9910MWDISMMM.003 [119199])
	CHnKsatEtype.out	(DTN: MO9910MWDISMRP.002 [145731])
	CHnZksStrat.3grd	(DTN: MO9910MWDISMRP.002 [145731])
	ISM31.seq	(DTN: MO9910MWDISMRP.002 [145731])

*Data considered for corroborative purposes.

RPM2000 Files: CHn-hmap_etype.out* (DTN: SN0112T0501399.004 [159524])

Rock and Fracture Property Data

General borehole rock property data (DTN: LB0207REVUZPRP.002 [159672])

Rock fracture property data (DTN: LB0205REVUZPRP.001 [159525])

Fault fracture property data (DTN: LB0207REVUZPRP.001 [159526])

Specific Borehole Rock Property Data

Borehole	DTN and Q-status	Description
SD-6	GS980808312242.014 [106748] qualified	saturation, porosity
SD-6	GS980908312242.038 [107154] qualified	hydraulic conductivity
SD-7	GS951108312231.009 [108984] qualified	saturation, porosity
SD-12	GS960808312231.004 [108985] qualified	saturation, porosity

ATTACHMENT II

DEVELOPMENT OF NUMERICAL GRIDS FOR 1-D HYDROGEOLOGIC-PROPERTY-SET INVERSIONS

UZ Model numerical grids developed for the FY02 1-D hydrogeologic-property-set inversions are comprised of numerous 1-D columns centered at borehole coordinates, or in the case of boreholes closer than 80 m to each other, the midpoint location between the two boreholes (Wang 2003 [162380], SN-LBNL-SCI-213-V1, p. 71). Layer subdivision within these 1-D columns is based on a combination of borehole stratigraphic picks identified in the GFM2000 file "contacts00el.dat" (DTN: MO0012MWDGFM02.002 [153777]) and HGU boundaries defined by Flint (1998 [100033]).

The mesh files identified by Output-DTN: LB02081DKMGRID.001 and created for use in 1-D hydrogeologic property set inversions and calibration for the UZ Model include:

- The primary effective-continuum model (ECM) mesh, "Boreholes.mesh"
- The ECM mesh "Boreholes_NF.mesh" with rock (rather than fault) matrix properties used for fault grid nodes, in turn used for generation of the dual-k mesh
- The dual-k mesh "mesh_1d.dkm" for transient (pneumatic) and steady-state simulations based on the "Boreholes_NF.mesh" file and the fracture values given in Table 4.

The detailed steps describing the generation of these files are documented in scientific notebooks (Wang 2002 [159673], SN-LBNL-SCI-103-V1, pp. 134–140, 145–151; SN-LBNL-SCI-199-V1, pp. 85–91; Wang 2003 [162380], SN-LBNL-SCI-103-V1, p. 139; SN-LBNL-SCI-199-V1, pp. 86, 88–89).

Table II-1 summarizes the layer contact elevation input to the 1-D inversion grids based on the GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) file "contacts00el.dat." Note that the GFM2000 borehole elevations, which have been converted from feet to meters, are also adjusted in the same manner as described in Section 6.4.1 of this Scientific Analysis report to correspond with Flint's (1998 [100033]) HGUs. The corresponding elevations for each of these HGU contacts as determined from the UZ Model grid file "Boreholes.mck", is also given to provide a means of verifying the accuracy of the UZ Model results (Wang 2002 [159673], SN-LBNL-SCI-213-V1, pp. 67–69; Wang 2003 [162380], SN-LBNL-SCI-103-V1, p. 67).

A total of 45 borehole locations were cross-checked. Note that in most cases, the differences in contact elevations are less than 5 m. There are several cases where deviations exceed this amount. A number of boreholes (e.g., UZ-7a, H-6, NRG#7, UZ#4/5) had greater than 5 m discrepancies for the elevation of the uppermost unit present. These differences (primarily at the bedrock surface) arise from channel erosion that produces surfaces with large local variations in slope and elevation. Although the nearest GFM2000 data point may be only meters to a few tens of meters away, the highly variable surface elevations may result in the observed mismatches in the upper contact surfaces. These differences are restricted to the upper unit only, and thus should not have a significant impact on UZ Model flow and transport modeling results.

Two boreholes (b#1 and N11) exhibit poor matches for most of the contact elevations, with an abrupt shift in elevations occurring below a given unit contact. Both of these boreholes are near faults, and differences in how faults were modeled in GFM2000 and the UZ Model grids may explain these discrepancies. In the case of N11, where there is a difference of over 50 m in most of the contact elevations, the borehole lies on the west side of the Solitario Canyon fault in the GFM2000 representation, but is situated on the east side of this fault in the UZ Model grid. The difference in contact elevations is similar to the observed vertical offset on the fault. The N11 borehole is located ~2 km north of the proposed repository footprint (Figure 1b), and thus this discrepancy should have little impact on UZ flow and transport models for the proposed repository area. Because of the observed differences between GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) and UZ Model grid contact elevations, the b#1 and N11 boreholes were not used for 1-D rock property calibration calculations.

Table II-1. Comparison of Borehole Layer Contact Elevations from GFM2000 and UZ Model Grid

UZ Model	GFM2000	HGU	UE25#b1/a#1		USW G-1		USW G-2		USW G-4		USW H-1	
Unit	Unit		GFM2000[1]	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid
tcw11	Tpcr	CCR, CUC					1553.87	1553.712				
tcw12	Tpcp	CUL, CW	1,153.4	1,156.1			1512.6	1512.659	1260.958	1262.655	1293.632	1293.934
tcw13	Tpcpv3,2	CMW	1,146.0	absent			1485.29	absent	1234.135	1234.133	1284.732	1284.968
ptn21	Tpcpv1	CNW	1,145.4	1134.212			1484.376	1483.961	1230.478	1230.418	1281.989	1282.185
ptn22	Tpbt4+upper Tpy	BT4	1,143.3	absent	1309.2	1309.45	1482.242	1481.804	1227.125	1227.101	1275.893	1276.083
ptn23	mid Tpy	TPY	absent	absent	1304.299	1303.468	1469.39	1468.958	absent	absent	1267.663	1267.865
ptn24	lower Tpy+Tpbt3	BT3	1,142.4	1131.843	1301.299	1300.468	1459.586	1459.17	1224.747	1224.72	1260.958	1261.173
ptn25	Tpp	TPP	1,138.7	1127.739	1286.34	1285.567	1403.238	1402.876	1218.834	1218.847	1245.413	1245.609
ptn26	Tpbt2+Tptrv3,2	BT2	1,126.8	1114.494	1255.86	1255.032	1331.123	1330.732	1209.477	1209.484	1218.286	1218.412
tsw31	Tptrv1	TC	1,117.1	absent	1245.192	1244.388	1320.15	1319.759	1197.254	1197.259	1202.741	1202.952
tsw32	Tptrn	TR	1,115.1	1102.955	1243.192	1242.388	1318.15	1317.759	1195.254	1195.259	1200.741	1200.952
tsw33	Tptrl+Tpul	TUL	1,075.0	1061.772	1193.986	1193.215	1276.777	1276.417	1148.06	1148.069	1149.401	1149.597
tsw34	Tptpmn	TMN	993.5	981.825	1110.044	1109.192	1174.09	1174.063	1064.666	1064.668	1063.142	1065.354
tsw35	Tptpll	TLL	967.7	955.920	1079.137	1078.217	1163.726	1163.586	1034.186	1034.197	1029.919	1030.21
tsw36	upper Tptpln	TM2	856.5	844.713	961.9718	961.1646	1064.971	1064.956	926.3177	926.425	899.7696	900.3949
tsw37	lower Tptpln	TM1	825.4	816.428	944.1309	943.1175	1058.916	1058.846	887.9942	888.0687	882.2944	882.9135
tsw38	Tptpv3	PV3	809.9	802.286	935.2104	934.094	1055.888	1055.791	868.8324	868.8906	873.5568	874.1729
tsw39	Tptpv2	PV2	793.7	785.864	918.3245	917.0564	1044.854	1044.759	860.0237	860.0588	855.4212	856.0834
ch1	Tptpv1+Tpbt1	BT1, BT1a	788.8	780.979	912.8076	911.5274	1040.435	1040.345	857.5243	857.5441	850.331	850.9791
ch2	upper 1/4 Tac	CH	778.8	771.669	892.9956	892.0233	1018.337	1018.324	840.5165	840.5243	844.6008	845.1284
ch3	mid 1/4 Tac	CH	743.7	735.789	869.305	868.4537	955.8757	955.8505	817.9613	817.9547	821.9694	822.432
ch4	mid 1/4 Tac	CH			845.6144	844.8841			795.4061	795.3852	799.338	799.7356
ch5	lower 1/4 Tac	CH			821.9239	821.3145			772.8509	772.8157	776.7066	777.0392
ch6	Tacbt	BT			798.2333	797.7448			750.2957	750.2462	754.0752	754.3427
pp4	Prowuv	PP4			779.1528	778.724			732.8306	732.8007	736.092	736.3386
pp3	Prowuc	PP3			759.798	759.4007						
pp2	Prowmd+Prow	PP2										
pp1	Prowlv+Prowbt+Bulluv	PP1										
bf3	Bulluc+Bullmd+Bulllc	BF3										
bf2	Bulllv+Bullbt+Tramuv	BF2										

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]; Output-DTN: LB02081DKMGRID.001

NOTE: [1] GFM2000 data for b#1. A subset of these boreholes was used in 1-D Property Set Inversions. Depths given in meters.

Table II-1. Comparison of Borehole Layer Contact Elevations from GFM2000 and UZ Model Grid (cont.)

UZ Model	GFM2000	HGU	USW H-3		USW H-4		USW H-5		USW H-6		UE#25 NRG#4	
Unit	Unit		GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid
tcw11	Tpcr	CCR, CUC	1483.467	1482.424			1478.89	1477.951	1292.962	1303.709	1249.988	1249.887
tcw12	Tpcp	CUL, CW	1466.207	1465.925	1248.766	1248.831	1445.3	1444.681	1244.194	1244.537	1246.108	1245.239
tcw13	Tpcpv3,2	CMW	1370.747	1371.286	1195.761	1196.322	1355.75	1355.991	1241.146	1241.459	1153.058	1152.775
ptn21	Tpcpv1	CNW	1365.199	1365.668	1192.378	1192.874	1350.874	1351.079	1222.858	1223.221	1151.534	1151.223
ptn22	Tpbt4+upper Tpy	BT4	1361.542	1361.983	1189.939	1190.416	1345.54	1345.763	absent	absent	1146.962	1146.662
ptn23	mid Tpy	TPY	absent	absent	absent	absent	absent	absent	1218.286	absent	absent	absent
ptn24	lower Tpy+Tpbt3	BT3	1360.353	1360.77	1188.415	1188.841	1342.492	1340.3	1217.371	1217.639	1142.086	1141.823
ptn25	Tpp	TPP	1356.36	absent	1182.929	1183.442	1335.329	1335.52	1213.714	1214.006	1135.685	1135.431
ptn26	Tpbt2+Tptrv3,2	BT2	1356.36	1356.737	1180.49	1181.028	1323.442	1323.615	1201.522	1201.762	1110.386	1110.143
tsw31	Tptrv1	TC	1347.826	1348.126	1172.261	1172.831	1307.592	1307.783	1199.522	1199.762	1102.157	1101.87
tsw32	Tptrn	TR	1345.826	1346.126	1170.261	1170.831	1305.592	1305.783	1177.442	1177.645	1100.157	1099.87
tsw33	Tptrl+Tpul	TUL	1322.862	1323.116	1134.161	1134.673	1265.53	1265.736	1103.071	1103.359	1048.664	1048.393
tsw34	Tptpmn	TMN	1276.167	1276.471	1073.201	1073.696	1177.747	1178.021	1059.79	1060.018		
tsw35	Tptpll	TLL	1224.961	1225.293	1034.491	1035.049	1147.267	1147.494	967.74	968.0029		
tsw36	upper Tptpln	TM2	1163.452	1163.756	947.928	948.4726	1036.93	1037.192	944.1688	944.4087		
tsw37	lower Tptpln	TM1	1134.171	1134.473	907.6944	908.251	1010.107	1010.321	932.3832	932.6117		
tsw38	Tptpv3	PV3	1119.53	1119.832	887.5776	888.1402	996.696	996.8859	902.8176	903.0982		
tsw39	Tptpv2	PV2	1084.783	1085.145	880.2624	880.734	973.2264	973.4256	899.16	899.4235		
ch1	Tptpv1+Tpbt1	BT1, BT1a	1074.725	1075.087	868.68	869.2362	969.264	969.4739	888.7968	889.0499		
ch2	upper 1/4 Tac	CH	1056.742	1057.069	847.344	848.0614	959.2056	959.3875	881.0244	881.2959		
ch3	mid 1/4 Tac	CH	1053.922	1054.238	827.913	828.6188	945.8782	946.072	873.252	873.542		
ch4	mid 1/4 Tac	CH	1051.103	1051.407	808.482	809.1762	932.5508	932.7565	865.4796	865.788		
ch5	lower 1/4 Tac	CH	1048.283	1048.575	789.051	789.7336	919.2235	919.441	857.7072	858.0341		
ch6	Tacbt	BT	1045.464	1045.744	769.62	770.2909	905.8961	906.1255	842.4672	842.7937		
pp4	Prowuv	PP4	1027.786	1028.084	752.8865	753.6395	886.0841	886.3395	828.1416	828.495		
pp3	Prowuc	PP3	1020.775	1021.054	742.188	743.0525	879.348	879.5576	813.816	814.126		
pp2	Prowmd+Prow	PP2	983.5896	983.8958			843.3816	843.6558	788.5176	788.8992		
pp1	Prowlv+Prowbt+Bulluv	PP1	964.692	964.9361			829.6656	829.9347				
bf3	Bulluc+Bullmd+Bulllc	BF3	897.636	897.8414								
bf2	Bulllv+Bullbt+Tramuv	BF2	752.856	753.1556								

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]; Output-DTN: LB02081DKMGRID.001

NOTE: A subset of these boreholes was used in 1-D Property Set Inversions. Depths given in meters.

Table II-1. Comparison of Borehole Layer Contact Elevations from GFM2000 and UZ Model Grid (cont.)

UZ Model	GFM2000	HGU	UE#25 NRG#5		UE#25 NRG-6		UE#25 NRG-7a		USW SD-6		USW SD-7	
Unit	Unit		GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid
tcw11	Tpcr	CCR, CUC							1495.349	1495.412		
tcw12	Tpcp	CUL, CW	1241.007	1239.184	1277.722	1283.19	1277.569	1291.754	1472.299	1472.224	1363.98	1362.601
tcw13	Tpcpv3,2	CMW	1206.307	1206.628	1261.659	1261.554	1239.347	1234.845	1368.979	1369.086	1271.016	1271.179
ptn21	Tpcpv1	CNW	1201.278	1201.715	1258.763	1258.603	1233.221	1229.901	1364.59	1364.668	1267.663	1267.791
ptn22	Tpbt4+upper Tpy	BT4	1199.205	1199.598	1251.814	1251.722	1229.045	1225.738	1360.505	1360.602	1264.676	1264.795
ptn23	mid Tpy	TPY	absent	absent	1245.433	1244.768	absent	absent	absent	absent	absent	absent
ptn24	lower Tpy+Tpbt3	BT3	1197.925	1198.265	1240.394	1240.869	1227.247	1224.024	1356.451	1356.551	1263.213	1263.303
ptn25	Tpp	TPP	1194.237	1194.494	1230.478	1230.335	1223.802	absent	1349.045	1349.14	1259.434	1259.514
ptn26	Tpbt2+Tptrv3,2	BT2	1180.247	1180.591	1204.021	1203.916	1222.675	1220.493	1346.363	1346.453	1255.471	1255.592
tsw31	Tptrv1	TC	1168.359	1168.713	1192.621	1192.461	1213.531	absent	1335.115	1335.18	1246.236	1246.327
tsw32	Tptrn	TR	1166.359	1166.713	1190.621	1190.461	1211.531	1209.552	1333.115	1333.18	1244.236	1244.327
tsw33	Tptrl+Tpul	TUL	1116.787	1117.237	1137.148	1136.969	1174.151	1172.198	1302.715	1302.787	1217.676	1217.75
tsw34	Tptpmn	TMN	1030.224	1030.781	1057.351	1057.121			1235.354	1235.444	1155.954	1156.091
tsw35	Tptpll	TLL	1000.658	1002.85	1015.411	1015.292			1192.073	1192.177	1119.134	1119.219
tsw36	upper Tptpln	TM2			904.0368	903.9169			1097.585	1097.692	1053.084	1053.035
tsw37	lower Tptpln	TM1			869.127	869.2099			1066.902	1067.005	1020.166	1020.158
tsw38	Tptpv3	PV3			851.6722	851.8564			1051.56	1051.661	1003.706	1003.719
tsw39	Tptpv2	PV2			838.8096	838.919			1037.234	1037.334	972.312	972.4217
ch1	Tptpv1+Tpbt1	BT1, BT1a			833.4451	833.5818			1032.053	1032.144	965.3016	965.3709
ch2	upper 1/4 Tac	CH			826.3128	826.387			1019.556	1019.646	935.5531	935.7576
ch3	mid 1/4 Tac	CH							1011.707	1011.792	923.2392	923.4592
ch4	mid 1/4 Tac	CH							1003.859	1003.938	910.9253	911.1608
ch5	lower 1/4 Tac	CH							996.0102	996.0834	898.6114	898.8624
ch6	Tacbt	BT							988.1616	988.2292	886.2974	886.564
pp4	Prowuv	PP4							972.6168	972.6871	869.7468	869.9841
pp3	Prowuc	PP3							965.0273	965.0948	862.1268	862.45
pp2	Prowmd+Prow	PP2							924.7632	924.841	826.008	826.324
pp1	Prowlv+Prowbt+Bulluv	PP1							913.7904	913.8426	793.3944	793.756
bf3	Bulluc+Bullmd+Bulllc	BF3							848.4413	848.5061		
bf2	Bulllv+Bullbt+Tramuv	BF2										

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]; Output-DTN: LB02081DKMGRID.001

NOTE: A subset of these boreholes was used in 1-D Property Set Inversions. Depths given in meters.

Table II-1. Comparison of Borehole Layer Contact Elevations from GFM2000 and UZ Model Grid (cont.)

UZ Model	GFM2000	HGU	USW SD-9		USW SD-12		UE#25 UZ#4/5		UE#25 UZ-6		USW UZ-1/14	
Unit	Unit		GFM2000	UZGrid	GFM2000	UZGrid	GFM2000[2]	UZGrid	GFM2000	UZGrid	GFM2000[3]	UZGrid
tcw11	Tpcr	CCR, CUC							1501.446	1500.024		
tcw12	Tpcp	CUL, CW	1303.02	1301.601	1323.746	1319.003	1189.33	1194.513	1480.806	1480.864		
tcw13	Tpcpv3,2	CMW	1285.585	1285.393	1250.747	1250.691	1179.454	1178.984	1384.706	1382.479		
ptn21	Tpcpv1	CNW	1279.703	1279.489	1245.718	1245.633	1177.442	1176.162	1372.819	1372.966		
ptn22	Tpbt4+upper Tpy	BT4	1275.131	1274.913	1243.371	absent	1171.042	1170.298	1369.619	1369.766	1339.6	1338.763
ptn23	mid Tpy	TPY	1268.447	1268.24	absent	absent	1163.474	1163.726	absent	absent	1334.733	1332.634
ptn24	lower Tpy+Tpbt3	BT3	1265.447	1265.24	1242.67	1242.548	1160.474	1160.726	1368.186	1368.322	1332.733	1330.592
ptn25	Tpp	TPP	1255.624	1255.428	1238.921	1238.791	1148.212	1148.619	1364.254	1364.416	1320.58	1317.966
ptn26	Tpbt2+Tptrv3,2	BT2	1233.952	1233.767	1234.989	1234.878	1108.253	1108.838	1362.608	1362.807	1278.427	1276.032
tsw31	Tptrv1	TC	1221.181	1221	1224.839	1224.731	1096.061	1096.891	1352.398	1352.604	1265.595	1263.237
tsw32	Tptrn	TR	1219.181	1219	1222.839	1222.731	1094.061	1094.891	1350.398	1350.604	1263.595	1261.237
tsw33	Tptrl+Tpul	TUL	1165.86	1165.689	1190.732	1190.622			1326.185	1326.38	1220.637	1217.538
tsw34	Tptpmn	TMN	1080.516	1080.378	1121.451	1121.398			1264.31	1264.554	1133.769	1131.36
tsw35	Tptpll	TLL	1045.22	1045.081	1083.899	1083.817			1221.943	1222.135	1099.326	1096.919
tsw36	upper Tptpln	TM2	942.7464	942.5479	998.982	998.8207			1138.733	1139.025	1004.838	1001.555
tsw37	lower Tptpln	TM1	906.9832	906.7829	955.7817	955.6774			1109.675	1109.94	976.1666	973.3775
tsw38	Tptpv3	PV3	889.1016	888.9004	934.1815	934.1058			1095.146	1095.398	961.8309	959.2885
tsw39	Tptpv2	PV2	870.6917	870.5053	925.068	925.0046			1081.126	1081.264	937.7822	935.5172
ch1	Tptpv1+Tpbt1	BT1, BT1a	868.4666	868.2757	916.0764	915.9899			1068.019	1068.212	930.1622	927.9533
ch2	upper 1/4 Tac	CH	851.9465	851.7716	893.5212	893.4719			1056.437	1056.566	918.8236	916.2651
ch3	mid 1/4 Tac	CH	830.2676	830.1	879.1956	879.1375			1049.792	1049.948	897.96	895.2167
ch4	mid 1/4 Tac	CH	808.5887	808.4284	864.87	864.8032			1043.148	1043.329	877.0965	874.1683
ch5	lower 1/4 Tac	CH	786.9098	786.7568	850.5444	850.4688			1036.503	1036.711	856.2329	853.1199
ch6	Tacbt	BT	765.2309	765.0852	836.2188	836.1344			1029.858	1030.093	835.3694	832.0715
pp4	Prowuv	PP4	748.0706	747.9223	821.3141	821.1733			1016.203	1016.409	818.2396	814.8519
pp3	Prowuc	PP3	733.4402	733.2986	812.5968	812.5241			1009.498	1009.693	798.4581	795.0506
pp2	Prowmd+Prow	PP2			779.0688	778.9805			968.0448	968.2735	787.8206	784.2032
pp1	Prowlv+Prowbt+Bulluv	PP1			755.2944	755.2224			943.9656	944.2452		
bf3	Bulluc+Bullmd+Bulllc	BF3										
bf2	Bulllv+Bullbt+Tramuv	BF2										

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]; Output-DTN: LB02081DKMGRID.001

NOTE: A subset of these boreholes was used in 1-D Property Set Inversions. Depths given in meters
[2] GFM2000 data for UZ#4
[3] GFM2000 data for UZ-14

Table II-1. Comparison of Borehole Layer Contact Elevations from GFM2000 and UZ Model Grid (cont.)

UZ Model	GFM2000	HGU	UE-25 UZ#16		USW UZ-N11		USW UZ-N31/32		USW UZ-N33		USW UZ-N37	
Unit	Unit		GFM2000	UZGrid	GFM2000	UZGrid	GFM2000[4]	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid
tcw11	Tpcr	CCR, CUC			1591.754	1590.4						
tcw12	Tpcp	CUL, CW	1207.709	1206.519	1589.294	1590.4	1267.358	1268.672	1316.096	1317.546	1245.931	1249.623
tcw13	Tpcpv3,2	CMW	1176.894	1176.393	1584.594	1527.931	1238.098	1238.968	1316.096	1315.646	1223.65	1224.214
ptn21	Tpcpv1	CNW	1173.175	1172.661	1583.223	1526.528	1234.592	1234.821	1313.2	1312.708	1220.084	1220.49
ptn22	Tpbt4+upper Tpy	BT4	1170.828	1170.255	1578.132	1524.853	1232.886	1233.371	1306.617	1306.123	1218.072	1218.335
ptn23	mid Tpy	TPY	absent	absent	1573.804	1510.692	absent	absent	1305.672	1299.612		
ptn24	lower Tpy+Tpbt3	BT3	1166.957	1166.424			1231.392	1231.866				
ptn25	Tpp	TPP	absent	absent			1227.734	1228.838				
ptn26	Tpbt2+Tptrv3,2	BT2	1162.263	1161.761			1219.048	1220.769				
tsw31	Tptrv1	TC	1149.888	1149.557			1206.581	1209.008				
tsw32	Tptrn	TR	1147.888	1147.557			1205.667	1207.008				
tsw33	Tptrl+Tpul	TUL	1110.752	1110.504								
tsw34	Tptpmn	TMN	1053.694	1053.462								
tsw35	Tptpll	TLL	1015.898	1015.648								
tsw36	upper Tptpln	TM2	934.8216	934.4863								
tsw37	lower Tptpln	TM1	899.7696	899.3915								
tsw38	Tptpv3	PV3	882.2436	881.8441								
tsw39	Tptpv2	PV2	864.6566	864.3239								
ch1	Tptpv1+Tpbt1	BT1, BT1a	860.7552	860.3443								
ch2	upper 1/4 Tac	CH	854.964	854.3603								
ch3	mid 1/4 Tac	CH	835.2739	834.6529								
ch4	mid 1/4 Tac	CH	815.5838	814.9455								
ch5	lower 1/4 Tac	CH	795.8938	795.2381								
ch6	Tacbt	BT	776.2037	775.5308								
pp4	Prowuv	PP4	767.1816	766.3932								
pp3	Prowuc	PP3	763.3106	762.4906								
pp2	Prowmd+Prow	PP2	740.9688	740.0902								
pp1	Prowlv+Prowbt+Bulluv	PP1										
bf3	Bulluc+Bullmd+Bulllc	BF3										
bf2	Bulllv+Bullbt+Tramuv	BF2										

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]; Output-DTN: LB02081DKMGRID.001

NOTE: A subset of these boreholes was used in 1-D Property Set Inversions. Depths given in meters
[4] GFM2000 data for N32

Table II-1. Comparison of Borehole Layer Contact Elevations from GFM2000 and UZ Model Grid (cont.)

UZ Model	GFM2000	HGU	USW UZ-N53/54		USW UZ-N55		USW WT-1		USW WT-2		USW WT-7	
Unit	Unit		GFM2000[5]	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid	GFM2000	UZGrid
tcw11	Tpcr	CCR, CUC										
tcw12	Tpcp	CUL, CW	1227.43	1229.417	1241.45	1240.629	1192.073	1181.052	1282.903	1297.756	1184.758	1195.65
tcw13	Tpcpv3,2	CMW	1188.872	1189.809	1187.501	1188.169	1080.821	1081.838	1242.365	1242.33	1092.098	1096.113
ptn21	Tpcpv1	CNW	1184.819	1186.203	1183.538	1184.155	1074.115	1075.147	1235.659	1235.841	1088.746	1092.733
ptn22	Tpbt4+upper Tpy	BT4	1182.106	1183.028	1179.302	1180.216	1069.848	1070.891	1232.002	1232.137	1084.326	1088.3
ptn23	mid Tpy	TPY	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
ptn24	lower Tpy+Tpbt3	BT3	1179.728	1180.797	1176.254	1177.255	1068.629	1069.64	1231.087	1231.072	1082.802	1086.783
ptn25	Tpp	TPP	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
ptn26	Tpbt2+Tptrv3,2	BT2	1174.882	1175.823	1173.907	1174.418	1065.276	1066.249	1225.906	1226.111	1077.773	1081.723
tsw31	Tptrv1	TC	1162.324	1163.564	1167.079	1166.659	1053.694	1054.672	1215.847	1216.156	1065.276	1069.231
tsw32	Tptrn	TR			1166.287	1164.659	1051.694	1052.672	1213.847	1214.156	1063.276	1067.231
tsw33	Tptrl+Tpul	TUL					1025.957	1026.927	1185.367	1184.726	1039.978	1043.926
tsw34	Tptpmn	TMN					977.7984	978.7964	1121.359	1120.757	981.7608	985.726
tsw35	Tptpll	TLL					930.5544	931.6222	1079.602	1079.452	904.6464	908.6525
tsw36	upper Tptpln	TM2					839.4192	840.6009	992.124	992.2496	864.4128	868.3616
tsw37	lower Tptpln	TM1					816.6608	817.8055	958.596	958.5879	824.5856	828.5462
tsw38	Tptpv3	PV3					805.2816	806.4078	941.832	941.7571	804.672	808.6385
tsw39	Tptpv2	PV2					793.6992	794.7491	928.4208	928.2658	785.1648	789.0901
ch1	Tptpv1+Tpbt1	BT1, BT1a					784.2504	785.3049	915.924	915.8546	782.4216	786.3244
ch2	upper 1/4 Tac	CH					779.3736	780.3893	899.16	898.901		
ch3	mid 1/4 Tac	CH					765.6576	766.6763	883.7676	883.5388		
ch4	mid 1/4 Tac	CH					751.9416	752.9632	868.3752	868.1765		
ch5	lower 1/4 Tac	CH					738.2256	739.2502	852.9828	852.8143		
ch6	Tacbt	BT							837.5904	837.452		
pp4	Prowuv	PP4							absent	absent		
pp3	Prowuc	PP3							815.34	815.3688		
pp2	Prowmd+Prow	PP2							781.2024	781.2358		
pp1	Prowlv+Prowbt+Bulluv	PP1							754.38	754.3675		
bf3	Bulluc+Bullmd+Bulllc	BF3										
bf2	Bulllv+Bullbt+Tramuv	BF2										

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]; Output-DTN: LB02081DKMGRID.001

NOTE: A subset of these boreholes was used in 1-D Property Set Inversions. Depths given in meters
[5] GFM2000 data for N54

Table II-1. Comparison of Borehole Layer Contact Elevations from GFM2000 and UZ Model Grid (cont.)

UZ Model	GFM2000	HGU	UE-25 WT#18		USW WT-24	
Unit	Unit		GFM2000	UZGrid	GFM2000	UZGrid
tcw11	Tpcr	CCR, CUC	1336.246	1335.836	1493.518	1492.268
tcw12	Tpcp	CUL, CW	1310.106	1309.962	1469.098	1468.345
tcw13	Tpcpv3,2	CMW	1240.536	1240.952	1427.988	1428.093
ptn21	Tpcpv1	CNW	1235.05	1235.45	1415.796	1415.992
ptn22	Tpbt4+upper Tpy	BT4	1232.611	1232.983	1408.603	1408.822
ptn23	mid Tpy	TPY	1221.537	1221.926	1399.184	1399.395
ptn24	lower Tpy+Tpbt3	BT3	1214.425	1214.821	1390.802	1391.022
ptn25	Tpp	TPP	1184.758	1185.218	1349.045	1349.198
ptn26	Tpbt2+Tptrv3,2	BT2	1137.818	1138.332	1292.565	1292.599
tsw31	Tptrv1	TC	1122.578	1123.119	1281.074	1281.107
tsw32	Tptrn	TR	1120.578	1121.119	1279.074	1279.107
tsw33	Tptrl+Tpul	TUL	1068.324	1068.839	1231.087	1231.096
tsw34	Tptpmn	TMN	1007.669	1007.687	1142.482	1142.494
tsw35	Tptpll	TLL	979.6272	980.1595	1108.954	1109.128
tsw36	upper Tptpln	TM2	absent	absent	998.22	998.5361
tsw37	lower Tptpln	TM1	absent	absent	987.044	987.4208
tsw38	Tptpv3	PV3	878.7384	879.184	981.456	981.8631
tsw39	Tptpv2	PV2	859.536	859.9577	969.0202	969.4164
ch1	Tptpv1+Tpbt1	BT1, BT1a	851.0016	851.4074	966.155	966.5284
ch2	upper 1/4 Tac	CH	842.4672	842.8865	954.3898	954.7154
ch3	mid 1/4 Tac	CH				
ch4	mid 1/4 Tac	CH				
ch5	lower 1/4 Tac	CH				
ch6	Tacbt	BT				
pp4	Prowuv	PP4				
pp3	Prowuc	PP3				
pp2	Prowmd+Prow	PP2				
pp1	Prowlv+Prowbt+Bulluv	PP1				
bf3	Bulluc+Bullmd+Bulllc	BF3				
bf2	Bulllv+Bullbt+Tramuv	BF2				

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]; Output-DTN: LB02081DKMGRID.001

NOTE: A subset of these boreholes was used in 1-D Property Set Inversions. Depths given in meters

ATTACHMENT III — GRID VERIFICATION

This attachment describes the verification activities associated with the 1-D, 2-D, and 3-D UZ Model Grids.

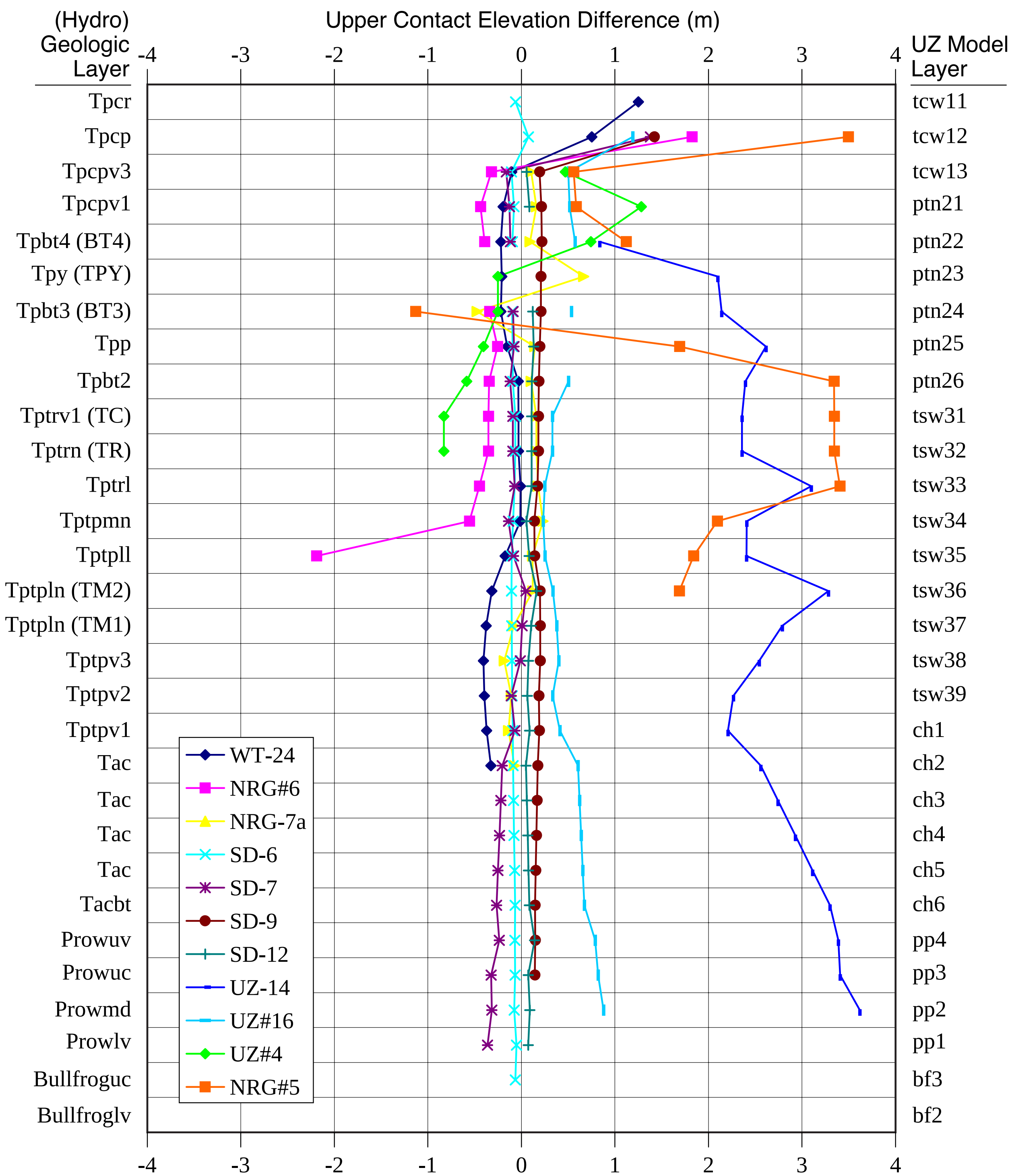
III.1 GRIDBLOCK ATTRIBUTE VERIFICATION

Because the total number of gridblocks within the 3-D UZ Model grids is quite large, a subset of gridblocks from the model is evaluated to ensure the accuracy of the calculated gridblock volumes, connection lengths, and interface areas. These verification activities are described in scientific notebooks by Wang (2002 [159673], SN-LBNL-SCI-213-V1, p. 93).

Spot checks of the 1-D and 2-D mesh files were conducted to verify that the proper gridblock connections were created in mesh generation. For all 1-D and 2-D grid columns examined, gridblocks had the correct gridblock volumes and vertical connections with the adjoining gridblocks within the column (BETAX = -1). The lateral connections between gridblocks in adjoining columns for the 2-D mesh file were also spot-checked. These checks revealed that the examined gridblocks were laterally connected to neighboring blocks (in adjoining columns) and had the same assigned rock properties, with two exceptions. These exceptions were: (1) the neighboring column, or the column under investigation, was a fault block (fault blocks have different properties assigned to them), and (2) the rock type might be absent in the adjacent column, in which case the lateral connection was made with the stratigraphically closest rock type. Note that connections between gridblocks within columns associated with nonvertical (inclined) faults may be nonvertical, because the x, y locations of grid nodes within these columns can vary with depth.

III.2 CONTACT ELEVATION VERIFICATION

Model layer contact elevations for 45 grid columns were compared against the observed stratigraphic contact elevations contained in the GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) file "contacts00el.dat." Given an estimated maximum error in layer contact elevations at column centers of about 5 m (see first paragraph of Section 6.6), a grid validation criterion of plus-or-minus 5 m for layer contact elevations in grid columns corresponding to borehole locations was established. Differences in layer contact elevations (values from UZ Model calibration grid subtracted from values from "contacts00el.dat") are plotted in Figures III-1 and III-2. Line discontinuities indicate missing, or pinched out, layers for that particular location.

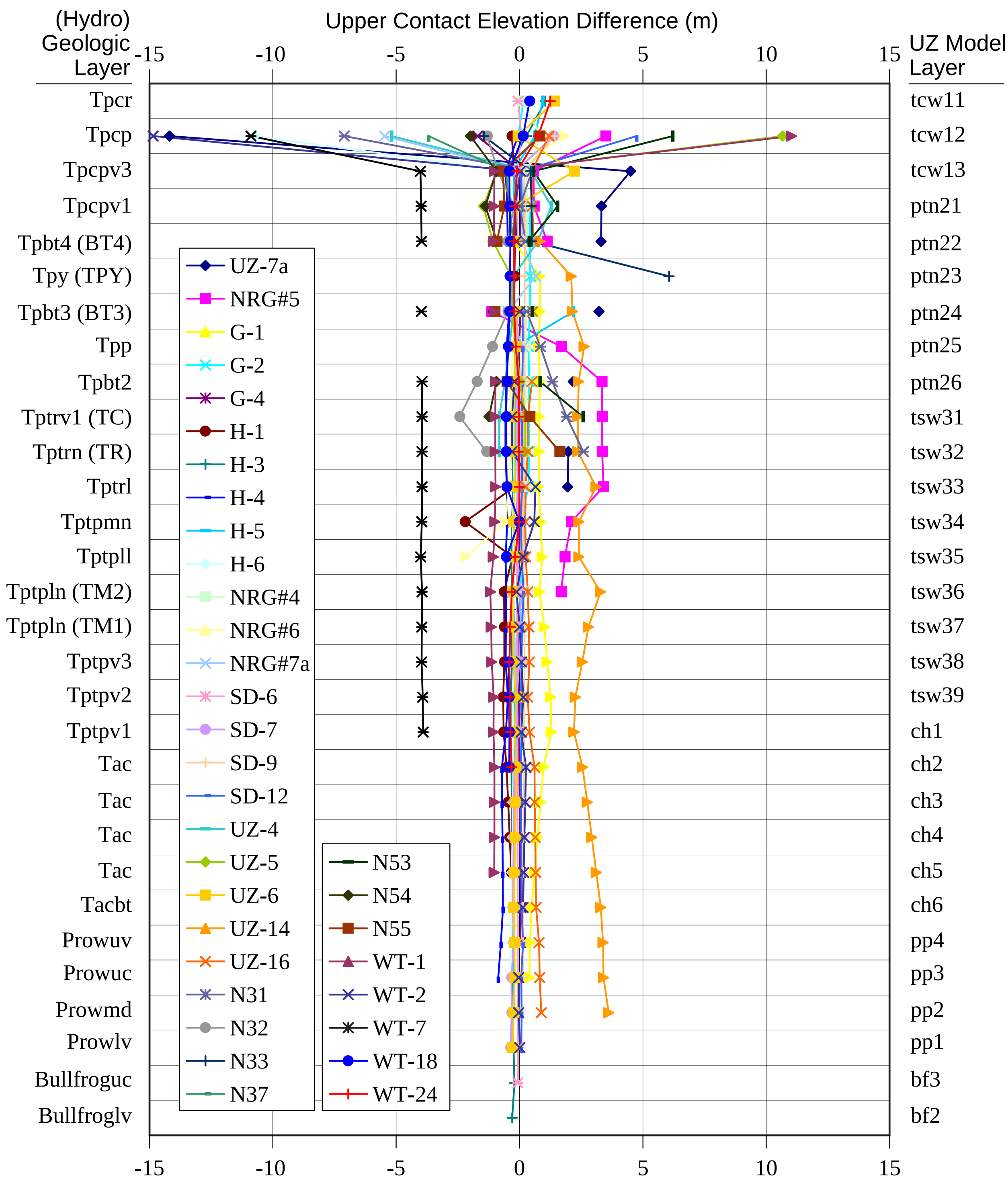


Output-DTN: LB02081DKMGRID.001

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]

NOTE: A negative value means the UZ Model layer contact elevation is higher than the stratigraphic pick.

Figure III-1. Upper Contact Elevation Differences at Select Borehole Locations (GFM2000 file "contacts00el.dat" Minus UZ Model Grid)



Output-DTN: LB02081DKMGRID.001

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]

NOTE: A negative value means the UZ Model layer contact elevation is higher than the stratigraphic pick.

Figure III-2. Upper Contact Elevation Differences at All Borehole Locations (GFM2000 file "contacts00el.dat" Minus UZ Model Grid)

Note that in most cases, the differences in contact elevations are less than 5 m. There are several cases where deviations exceed this amount. A number of boreholes (e.g., UZ-7a, H-6, NRG#7, UZ#4/5) had greater than 5 m discrepancies for the elevation of the uppermost unit present. These differences (primarily at the bedrock surface) arise from channel erosion that produces surfaces with large local variations in slope and elevation. Although the nearest GFM2000 data point may be only meters to a few tens of meters away, the highly variable surface elevations may result in the observed mismatches in the upper contact surfaces. These differences are restricted to the upper unit only, and thus should not have a significant impact on UZ Model flow and transport modeling results.

Two boreholes (b#1 and N11) exhibit poor matches for most of the contact elevations, with an abrupt shift in elevations occurring below a given unit contact. Both of these boreholes are near faults, and differences in how faults were modeled in GFM2000 and the UZ Model grids may explain these discrepancies. In the case of N11, where there is a difference of over 50 m in most of the contact elevations, the borehole lies on the west side of the Solitario Canyon fault in the GFM2000 representation, but is situated on the east side of this fault in the UZ Model grid. The difference in contact elevations is similar to the observed vertical offset on the fault. The N11 borehole is located ~2 km north of the proposed repository footprint (Figure 1b), and thus this discrepancy should have little impact on UZ flow and transport models for the proposed repository area. Because of the observed differences between GFM2000 (DTN: MO0012MWDGFM02.002 [153777]) and UZ Model grid contact elevations, the b#1 and N11 boreholes were not used for 1-D rock property calibration calculations.

III.3 2-D CROSS SECTION VERIFICATION

To verify the accuracy of the 2-D E-W cross section (Figures III-3 and III-4), ten selected adjacent pairs of grid columns were compared to a series of GFM2000 cross sections constructed using the location of each pair of grid column nodes as ends of the cross sections (Wang 2002 [159673], SN-LBNL-SCI-213-V1, pp. 94–99). The apparent vertical offset between adjacent columns as seen in Figure III-3 is an artifact of the visualization generated by WINGRIDDER V2.0 (LBNL 2002 [154785]), and does not reflect how the layers are connected in the numerical grids (see Section 6.6 for more details). Cross sections constructed using EARTHVISION V5.1 (Dynamic Graphics 1998 [152614]) and the following GFM surfaces (see Table III-1) were compared with the correlative UZ Model grid columns (Figures III-5 to III-7).

Table III-1. UZ Model Layers and GFM2000 Surfaces

File Name	Corresponding UZ Model Layers
REF00bedrock.m.2grd	tcw11
REF00tpcp.m.2grd	tcw12, tcw13
s00Tpcpv1EX.m.2grd	ptn21, ptn22, ptn23, ptn24
s00PahEX.m.2grd	ptn25, ptn26
s00Tptrv1EX.m.2grd	tsw31, tsw32
s00TptrlEX.m.2grd	tsw33
s00TptpmnEX.m.2grd	tsw34

Table III-1. UZ Model Layers and GFM2000 Surfaces (continued)

File Name	Corresponding UZ Model Layers
s00TptpllEX.m.2grd	tsw35
s00TptplnEX.m.2grd	tsw36, tsw37
s00Tptpv3EX.m.2grd	tsw38
s00Tptpv2EX.m.2grd	tsw39, ch1
s00CalicoEX.m.2grd	ch2, ch3, ch4, ch5, ch6
s00ProwuvEX.m.2grd	pp4, pp3, pp2
s00ProwlvEX.m.2grd	pp1
s00BullfrogucEX.m.2grd	bf3
s00BullfroglvEX.m.2grd	bf2
s00TramucEX.m.2grd	tr3
gwl_sspac_60.96.2grd	base of UZ

The corresponding pairs of column coordinates used for each of the traverses are listed in Table III-2.

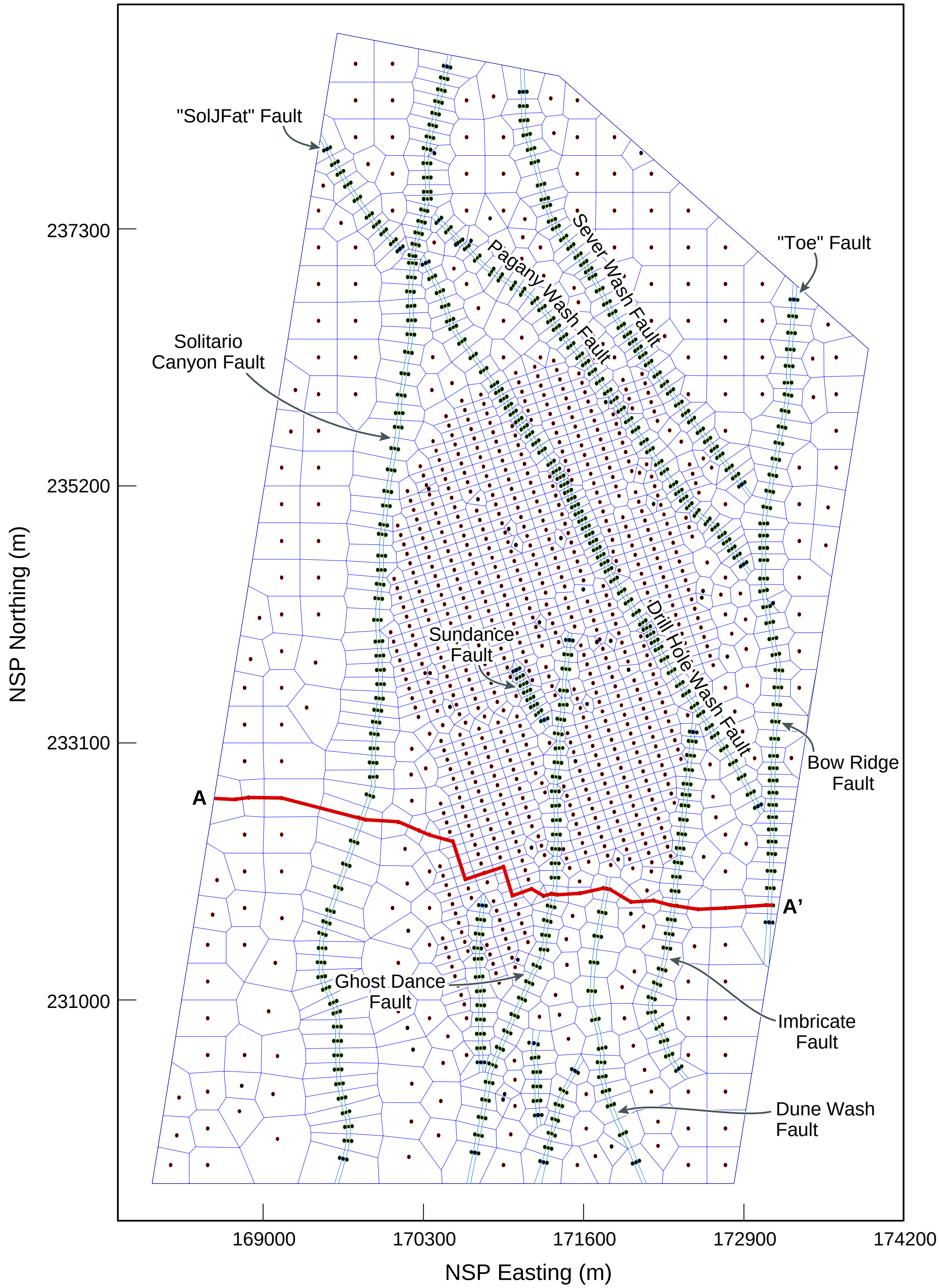
Table III-2. Cross Section Traverse Columns

Traverse #	ID of W Column	W Column Easting	W Column Northing	ID of E Column	E Column Easting	E Column Northing
1	q40	168882.0938	232653.5	a63	169150	232650
2	e64	170094.6094	232454.7344	q44	170263.7031	232385.9062
3	i24	170539.8438	232295.8125	i29	170564.875	232218.7812
4	i40	170614.9375	232064.7031	i41	170769.0156	232114.7656
5	i47	170948.1094	232087.7812	i52	170973.1406	232010.75
6	i60	171023.2031	231856.6875	i61	171177.2812	231906.7344
7[1]	p 3	171338.0469	231868.3125	p 2	171388.5781	231860.8594
8	q62	171982.7969	231801.2969	q51	172168.4062	231811.0938
9[2]	o 2	172299.2812	231776.0312	o 1	172358.8906	231769.2031
10[3]	a48	172750	231750	q19	173079.3906	231774.7656

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]; Output-DTN: LB02081DKMGRID.001

NOTE: [1]- Columns separated by Ghost Dance Fault
[2]- Columns separated by Imbricate Fault
[3]- Column q19 adjacent to Toe Fault

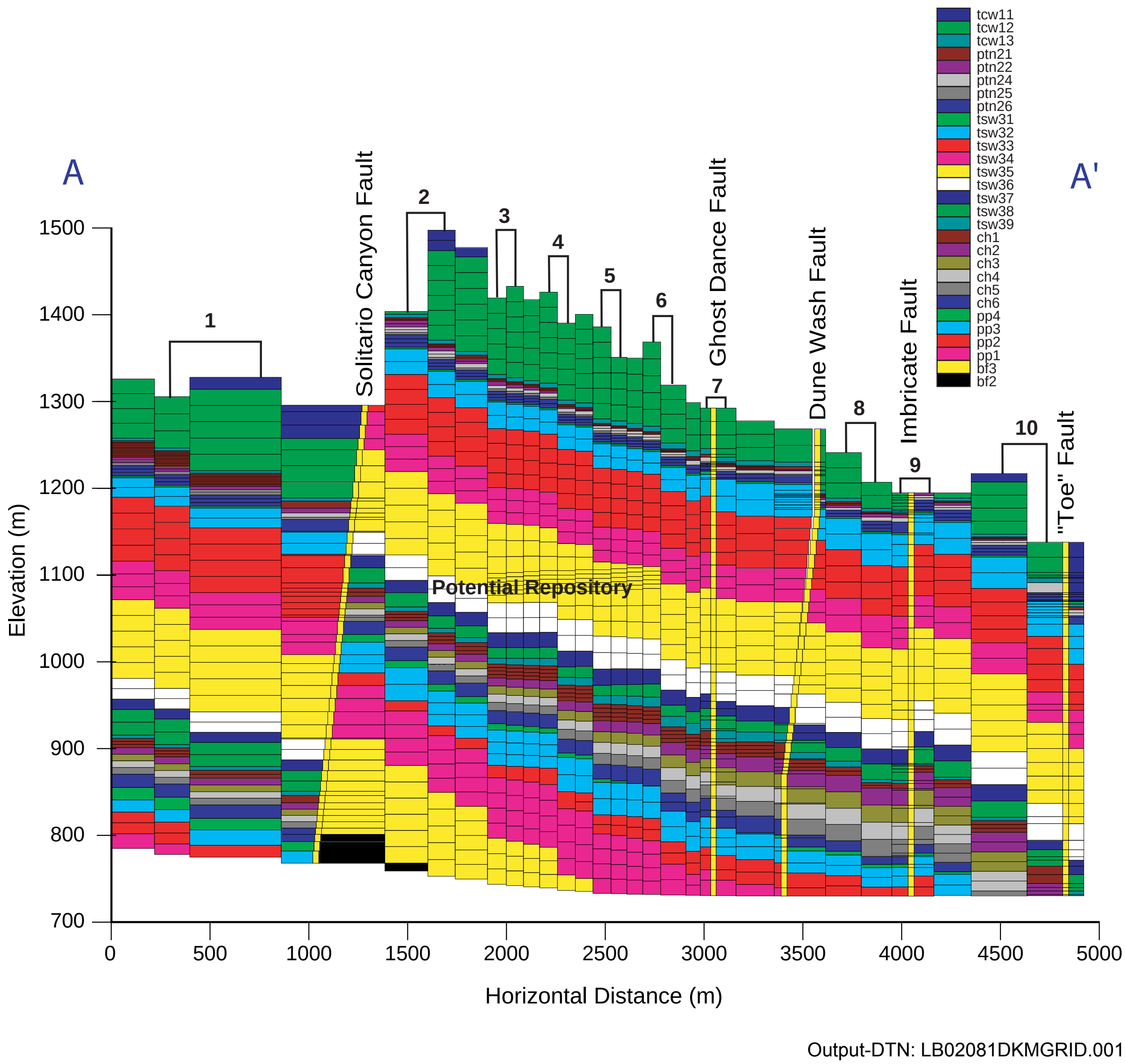
Using these traverse endpoints and the stacked GFM2000 surfaces listed in Table III-2, ten 2-D cross sections were created. The results of this comparison are shown below. Figures III-3 and III-4 depict the 2-D plan-view grid design and an East-West cross section from the UZ Model grid (file "EWUZ7a_profile.eps" from Output-DTN: LB02081DKMGRID.001) and illustrate the location of each of the column pairs used to construct the 10 traverses. Figures III-5 to III-7 depict each of the GFM2000 traverse cross sections, sandwiched between the corresponding UZ Model columns.



Output-DTN: LB02081DKMGRID.001

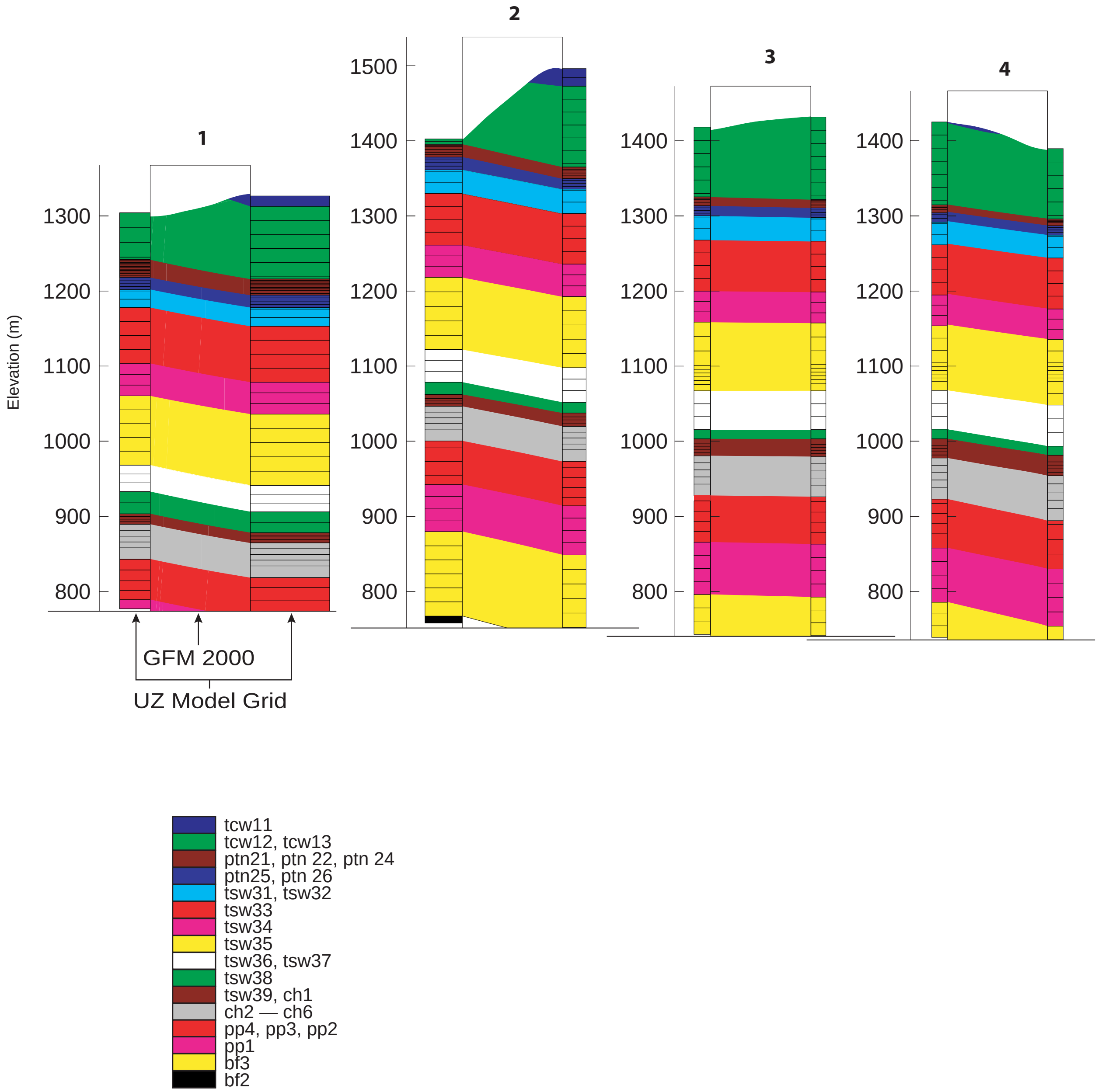
NOTE: Line A-A' indicates location of cross section shown in Figure III-4.

Figure III-3. 2-D (plan-view) UZ Model Grid Design



NOTE: UZ Model layer ptn23 does not occur within this traverse. Numbered column pairs were used to construct the comparison plots between the UZ Model grid and GFM2000.

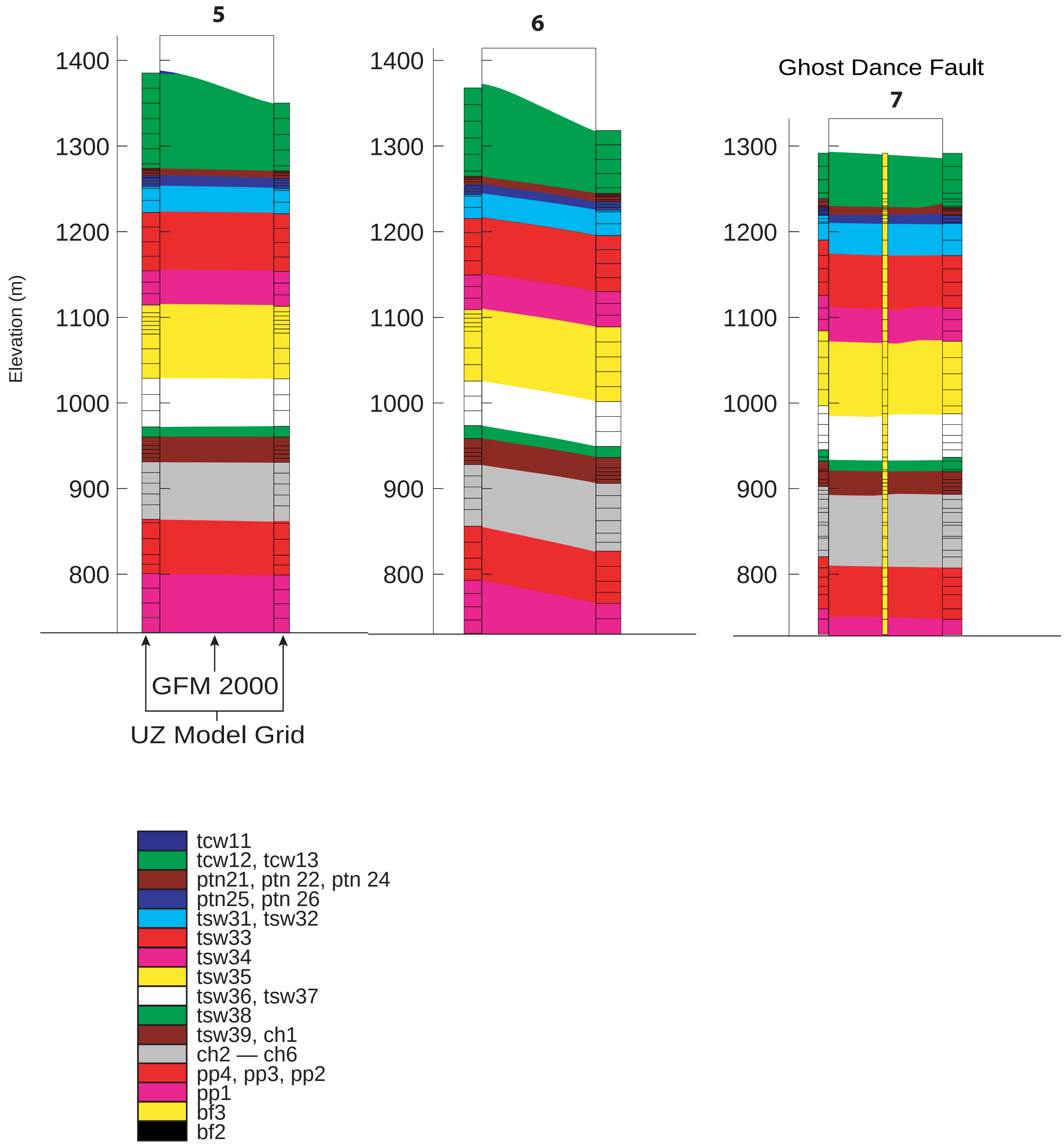
Figure III-4. Two-dimensional Cross Section from the UZ Model Grid



Output-DTN: LB02081DKMGRID.001

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]

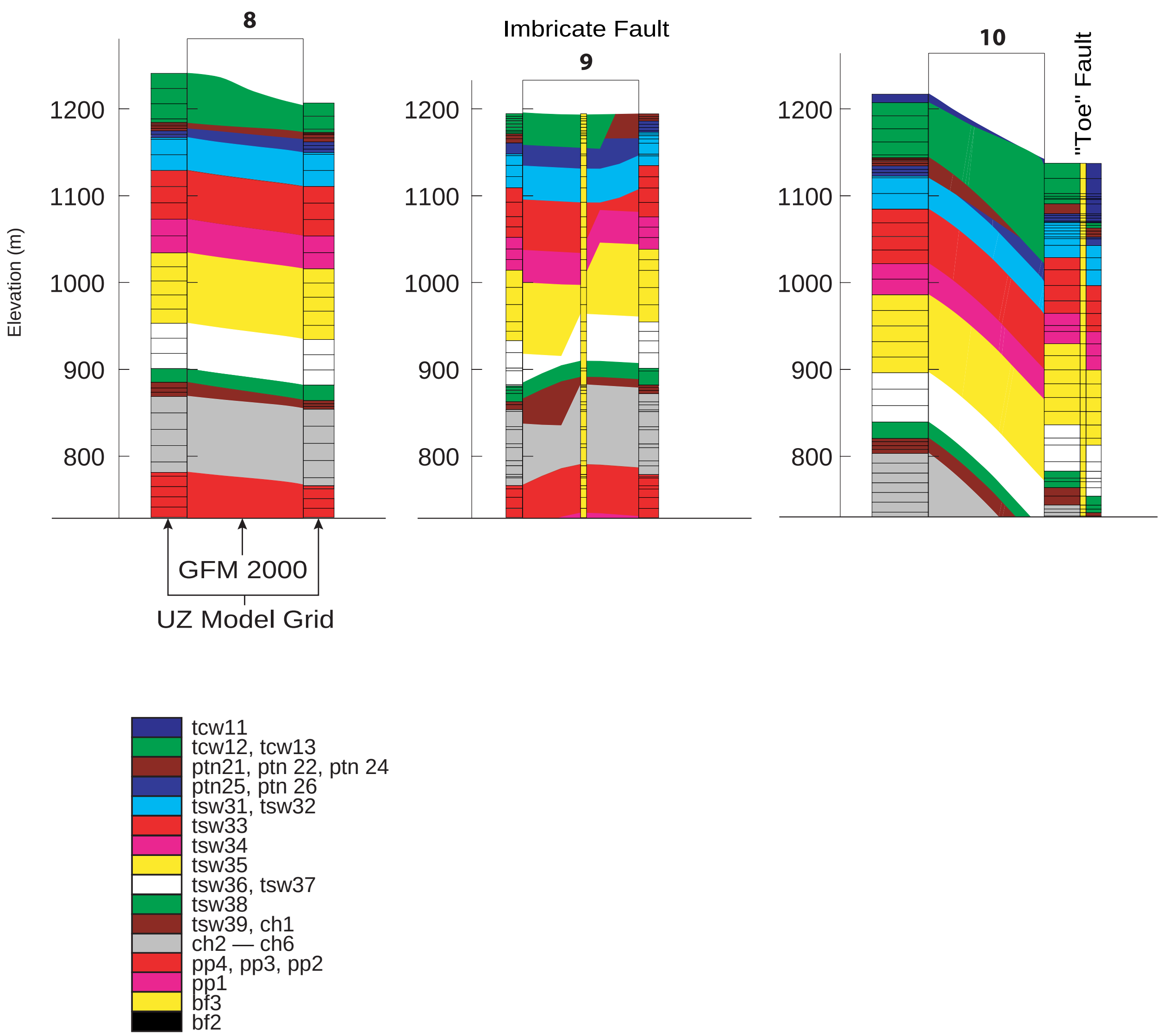
Figure III-5. Traverses 1–4 of 2-D Cross Section, Comparing Results of UZ Model and GFM2000 Grids



Output-DTN: LB02081DKMGRID.001

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]

Figure III-6. Traverses 5–7 of 2-D Cross Section, Comparing Results of UZ Model and GFM2000 Grids



Output-DTN: LB02081DKMGRID.001

Source DTN: MO0012MWDGFM02.002 (GFM2000) [153777]

Figure III-7. Traverses 8–10 of 2-D Cross Section, Comparing Results of UZ Model and GFM2000 Grids

For Traverses 1–6 and 8, the matches between the unit contacts for the GFM2000 cross sections and the UZ Model columns are extremely good, with minimal offset of units observed. These intervals are not intersected by faults, and thus a good match is expected.

Discrepancies between unit contacts are observed for traverses (7, 9, 10) that cross or are immediately adjacent to faults. Most of the GFM2000 unit thicknesses in Traverse 7 (where the Ghost Dance fault passes) correlate with their counterparts for the two UZ Model columns; however, there are some differences in the location of the contact elevations. More significant differences are observed in Traverses 9 and 10. Substantial (~50 m) vertical offset is observed along the Imbricate fault, which cuts through Traverse 9, and discrepancies of up to 10–20 m are observed between the UZ model column and GFM2000 contacts. Even larger discrepancies are observed between the GFM2000 cross section in Traverse 10 and the eastern UZ Model column.

This difference may result from the nearby presence of the Toe fault, which is modeled as a vertical feature by the UZ model, but as a dipping fault in GFM2000 (DTN: MO0012MWDGFM02.002 [153777]).

The comparisons made using column centers around faults in the UZ Model are affected by the closely spaced nature of the column nodes (50–60 m), similar to the data resolution (61 × 61 m) of the GFM2000 grid (BSC 2002 [159124], Section 6.4.2). The localization of contact elevation discrepancies between the GFM2000 and UZ Model grids near faults results in part from the differences in the way that faults are represented in the two systems. The simplification of faults as required by the use of vertical columns in the UZ Model grids (Assumption 7) results in localized discrepancies between the two grids. However, as demonstrated by good matches observed in Traverses 1–6 and 8, the UZ Model grids accurately portray the stratigraphic representation of geologic units within structural blocks.

III.4 3-D MESH VERIFICATION

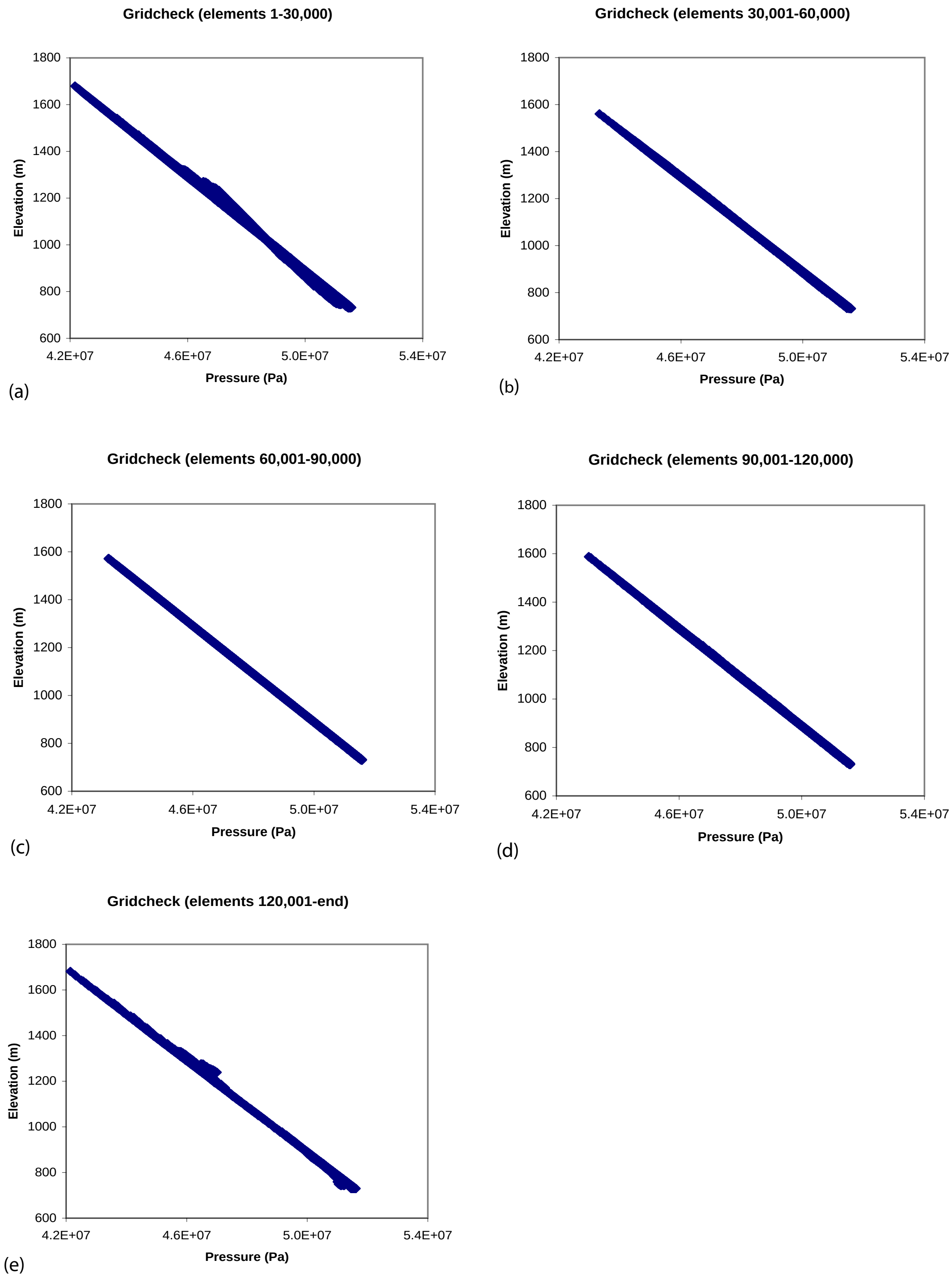
To verify the accuracy of the 3-D mesh and its connections, test simulations using isothermal, saturated conditions were conducted on the ECM mesh using TOUGH2 V1.4 (LBNL 2000 [146496]). The goal of these simulations was to look for improperly connected gridblocks that would be identified by anomalous points on a pressure-elevation plot. Under steady-state conditions, the observed fluid pressures should vary linearly as a function of gridblock elevation. A description of the simulations and their results are given in Wang 2003 ([162380], SN-LBNL-SCI-213-V1, pp. 125–131; SN-LBNL-SCI-103-V2, pp. 17–28; SN-LBNL-SCI-199-V1, pp. 237–238).

Initial conditions of 25°C, 500 bars water pressure, and a single suite of rock properties were assigned to all of the gridblocks. Large volume gridblocks located at the base of the grid served as a constant pressure boundary and the remaining gridblocks in the mesh were allowed to come to pressure equilibrium with this boundary condition. The simulations were run for 0.316×10^{18} s to ensure that a steady-state solution would be obtained (Wang 2003 ([162380], SN-LBNL-SCI-199-V1, p. 238).

Several modifications to some of the lateral connections in the 3-D mesh were made as a result of the simulation results. First, improper lateral connections between adjoining fault and repository columns were corrected (Wang 2003 [162380], SN-LBNL-SCI-103-V2, pp. 17–23). During further evaluation of the 3-D grid, it was discovered that anomalous pressures were associated with some matrix columns adjacent to fault columns (Wang 2003 [162380], SN-LBNL-SCI-213-V1, pp. 125–131; SN-LBNL-SCI-103-V2, pp. 23–26). As mentioned in Section 6.3, some simplification of the GFM2000 faults was made in creating the UZ Model grids, including the representation of the Solitario Canyon and Solitario Canyon (west) faults as a single fault. The gridblocks with the anomalous pressure-elevation relations exhibited fault-related stratigraphic offset with their neighboring columns. To ensure proper flow behavior in the grid, the columns with apparent fault-related offset were classified as "faults" while reconstructing the 3-D grid so that lateral connections between gridblocks in these columns and those in the adjacent columns were made with the closest lateral neighbor, and not with the same stratigraphic interval. A total of 18 columns, all adjacent to faults, were adjusted in this manner.

The pressure-elevation relation results from the test simulation conducted using the final 3-D mesh exhibited very little deviation from linearity (Figure III-8).

A few small deviations were observed in this simulation were attributed to the presence of non-vertical connections associated with inclined fault columns. Larger pressure shifts were observed for gridblocks associated with faults with dips that had the largest deviation from vertical. This feature is a result of the non-orthogonal configuration of the 3-D grid (Wang 2003 [162380], SN-LBNL-SCI-213-V1, pp. 130–131). The changes in the 3-D mesh resulting from these test simulations were captured in the output DTN: LB03023DKMGRID.001. This DTN supersedes DTN: LB02083DKMGRID.001. These changes do not impact the 1-and 2-D grids of DTN: LB02081DKMGRID.001.



Output-DTN: LB03023DKMGRID.001

Figure III-8. Pressure-Evaluation Relations of 3-D Mesh (124,795 elements) after TOUGH2 Test Simulation

ATTACHMENT IV – QUALIFICATION OF WATER TABLE CONTOUR DATA

IV.1 INTRODUCTION

During the development of this Scientific Analysis Report, it was discovered that the data set originally used to define the water table (DTN: MO0110MWDGFM26.002 [160565]) was not qualified. A Data Qualification Plan was developed in the *Technical Work Plan for: Performance Assessment Unsaturated Zone* (BSC 2002 [160819], Attachment III) in accordance with AP-SIII.2Q, *Qualification of Unqualified Data and Documentation of Rationale for Accepted Data*.

The first step of the data qualification process was to have a subset of the original data set that contained only the needed water table data extracted from the Vulcan GFM2000 Representation (DTN: MO0110MWDGFM26.002 [160565]) and submitted to the TDMS. An ASCII file with water table contour and borehole water level data was obtained from the Vulcan layer file "GWL_SSPAC" by Tim Vogt, and this file was then submitted to the TDMS as DTN: MO0212GWLSSPAX.000 [161271]. The data qualification reports listed below relate to the qualification of DTN: MO0212GWLSSPAX.000 [161271]. The qualified water table data developed by the USGS (DTN: GS010608312332.001 [155307]) are used to determine if the new data set (DTN: MO0212GWLSSPAX.000 [161271]) meets the qualification criteria specified in the TWP (BSC 2002 [160819], Attachment III)

A data qualification team was selected by the Responsible Manager, Joe Wang. The team consisted of a chairperson (Patrick Dobson, the Scientific Analysis report originator) and two technically qualified team members (Tim Vogt and Daniel Gillies). The team members were assigned the task of conducting independent data reviews following the procedure AP-SIII.2Q and using the qualification criteria specified in the Data Qualification Plan.

Tim Vogt facilitated the submission of DTN: MO0212GWLSSPAX.000 [161271], and is listed as the originator of this DTN within the TDMS. Section 5.1.2 of AP-SIII.2Q specifies that "Team members selected should be independent of the data sets to be qualified (i.e., team members did not participate in the acquisition or development of the data sets to be qualified). If independence cannot be achieved, provide the rationale for choosing the teammates and provide the method(s) for mitigating any conflict of interest." Tim was not involved in the acquisition or development of the original source data (the originator of DTN: MO0110MWDGFM26.002 [160565] is Robert Elayer, who also prepared the extracted water table data file for DTN: MO0212GWLSSPAX.000 [161271]), and thus there is no conflict of interest that would preclude Tim's participation in the data qualification team.

The results of the two independent data reviews are presented in the following sections. Both of these reviews concluded that the new water table data met the acceptance criteria as described in the Data Qualification Plan of the TWP (BSC 2002 [160819], Attachment III). Additional discussion relating to the differences between the USGS (DTN: GS010608312332.001 [155307]) and Vulcan (DTN: MO0212GWLSSPAX.000 [161271]) representations of the water table can be found in Section 7.1.1 of this Scientific Analysis Report.

IV.2 DATA QUALIFICATION REPORT (T. VOGT)

Data Qualification Report for DTN: MO0212GWLSSPAX.000
"ASCII FILE, EXTRACTED FROM DTN: MO0110MWDGFM26.002, WHICH INCLUDES 1) CONTOURS DIGITIZED FROM DTN: GS010608312332.001 AND 2) WATER LEVELS FROM DTNs: MO0106RIB00038.001 and GS010608312332.001"

Introduction

This report was prepared in accordance with Procedure AP-SIII.2Q under the direction of Pat Dobson, Qualification Chairperson. The numbered sections in this report correspond to the headings found in Section 5.3.1 a) of that procedure.

The third bullet of Section 5.1.2 b) 3) of the procedure indicates that "Team members selected should be independent of the data sets to be qualified... If independence cannot be achieved, provide the rationale for choosing the teammates and provide the method(s) for mitigating any conflict of interest." The TDIF for DTN: MO0212GWLSSPAX.000 [161271] lists me as the Data Originator/Preparer. All data preparation was completed by Robert Elayer. I did facilitate the submission of the data for this DTN by forwarding the file prepared by Robert to the TDMS. Inasmuch as I was not involved in the actual data preparation, there is no conflict of interest.

1. Data Set(s) for Qualification

The data set submitted for qualification is the data found in DTN: MO0212GWLSSPAX.000 [161271]. The data set consists of an ASCII file, extracted from the unqualified DTN: MO0110MWDGFM26.002 [160565] by Robert Elayer, and includes: 1) contours digitized from DTN: GS010608312332.001 [155307] and 2) water levels from DTNs: MO0106RIB00038.001 [155631] and GS010608312332.001 [155307].

Several DTNs are referenced throughout this Data Qualification Report. Table 1 is a tabulation of these DTNs and a brief explanation of the source of data or documentation.

Table 1. Commonly referenced DTNs.

DTN	Source/Documentation	Interpretation	Q-status
GS000508312332.001 [149947]	Documented in: ANL-NBS-HS-000034 REV00 ICN 01 (USGS 2001 [154625])	Regional potentiometric surface; No perched water; Used as input to SZ flow and transport model.	Q
GS010608312332.001 [155307]	Documented in: ANL-NBS-HS-000034 REV01 (USGS 2001 [157611])	Regional potentiometric surface; Perched water interpretation.	Q
MO0110MWDGFM26.002 [160565]	Contours derived from: GS010608312332.001 [155307]	Perched water interpretation.	Non-Q
MO0212GWLSSPAX.000 [161271] (subject of this qualification report)	All data derived from: MO0110MWDGFM26.002 [160565]	Perched water; Used as input to UZ flow and transport model.	Non-Q

2. Method(s) of Qualification Selected and Rationale

The method of qualification is Technical Assessment (method 5) as found in Attachment 2 of OCRWM Procedure AP-SIII.2Q. This method is appropriate because the data have not been previously reviewed (eliminating methods 1–3) and the conditions needed for method 4 are not present. The following are conditions for a Technical Assessment approach: a) the correctness of the data is in question as a result of an absence of procedures or inadequate procedures, and b) there is a lack of adequate documentation of data acquisition or procedural compliance.

The procedure defines the action to be taken for a Technical Assessment:

"Action to be taken: Evaluate data acquisition and/or development records to determine the adequacy of the procedural compliance documentation. If the evaluation indicates there is inadequate procedural compliance documentation, initiate a technical review of the data with appropriate compliance documentation as defined in this procedure. If possible, confirm that the data have been used in similar applications to enhance the confidence in the technical assessment process."

Examination of the description of the origin of this data set (Wang 2003 [162380], SN-LBNL-SCI-213-V1, pp. 108–109) leads to the conclusion that both of the conditions for a Technical Assessment are present and a technical review was initiated. This examination and conversations with Robert Elayer suggest that the original DTN (MO0110MWDGFM26.002 [160565]) included water level information that is in part the result of poor digitization of a printed contour map and/or poor coordinate transformation. This occurred when the water level information was initially incorporated into DTN: MO0110MWDGFM26.002 [160565] (the source for the DTN that is the subject of this report). The existing documentation describing the digitization and coordinate transformation is not complete enough to determine the details of the process (Wang 2003 [162380], SN-LBNL-SCI-213-V1, pp. 108–109).

The approach and scope of the technical review has been defined in *"Data Qualification Plan for U0000, Development of Numerical Grids for UZ Flow and Transport Modeling (DI: ANL-NBS-HS-000015 REV 01)*" which is Attachment III of *the "Technical Work Plan for: Performance Assessment Unsaturated Zone*" (BSC 2002 [160819]) as:

"*Two different ASCII files containing x, y, z coordinates (geographic location and elevation) that represent digitized water table elevation contours and measured borehole water levels will be derived from existing DTNs in the TDMS. The two ASCII files will therefore be subsets of two DTNs in the TDMS. The first ASCII file will be derived from the VULCAN layer file 'GWL-SSPAC' from the unqualified DTN: MO0110MWDGFM26.002. It will be submitted to the TDMS as a new unqualified DTN, to be used as input to U0000, and qualified under this Data Qualification Plan. The second ASCII file will be derived from the ARCINFO file 'pot_contours_e00'(sic) from the DTN: GS010608312332.001, which is qualified."*

"The ASCII files will be derived from the original DTNs using standard commercial spreadsheet or word-processing software (Microsoft Excel and Microsoft Word) and VULCAN V.3.5NT software listed in Table II-2. EARTHVISION V.5.1, listed in Table II-2, will then be used to create contour maps suitable for visual comparison of the data."

"The unqualified data set will be qualified through visual inspection and corroboration with a qualified data set and associated potentiometric map."

The new unqualified DTN described above (DTN: MO0212GWLSSPAX.000 [161271]) has been created and is the subject of this Data Qualification Report. This unqualified data set (DTN: MO0212GWLSSPAX.000 [161271]) will be evaluated by comparison with the qualified data set derived from DTN: GS010608312332.001 [155307]. Each of these data sets represents a water table contour map.

3. Evaluation Criteria

The evaluation criteria have been defined in "*Data Qualification Plan for U0000, Development of Numerical Grids for UZ Flow and Transport Modeling* (DI: ANL-NBS-HS-000015 REV 01)" which is Attachment III of the *Technical Work Plan for: Performance Assessment Unsaturated Zone* (BSC 2002 [160819]) as:

"*The data evaluation will consist of visual examination to compare the two water table contour maps. The criterion for qualifying the unqualified data set is that the elevation difference between the unqualified and qualified data sets be within plus/minus 10 % of the total UZ Grid vertical extent of 600 m (i.e., the criterion is plus/minus 60 m) within the current repository footprint as defined in Repository Design, Repository/PA IED Subsurface Facilities Plan Sht. 1 of 5, Sht. 2 of 5, Sht. 3 of 5, Sht. 4 of 5, and Sht 5 of 5. DWG-MGR-MD-000003 REV A. (BSC 2002 [159527]), and less than plus/minus 15 % of the total UZ Grid vertical extent (i.e., plus/minus 90 m) for other areas outside the repository footprint but still within the UZ Model Grid area."* (sic)

Note: In the time between the preparation of the Technical Work Plan (BSC 2002 [160819]) and preparation of this report the IED cited above (BSC 2002 [159527]) was superseded by *Repository Design, Repository/PA IED Subsurface Facilities* 800-IED-EBS0-00401-000-00B (BSC 2003 [161726]), *Repository Design Repository/PA IED Subsurface Facilities,* 800-IED-EBS0-00402-000-00B (BSC 2003 [161727]), and *Repository Design Repository/PA IED Subsurface Facilities,* 800-IED-EBSO-00403-000-00B (BSC 2003 [161731]). The change in repository footprint has no impact on this Data Qualification Report because the area affected by the repository change is in the area of very good agreement between data sets.

4. Recommendation Criteria

The recommendation criteria have been defined in "Data Qualification Plan for U0000, Development of Numerical Grids for UZ Flow and Transport Modeling (DI: ANL-NBS-HS-000015 REV 01)", which is Attachment III of the *Technical Work Plan for: Performance Assessment Unsaturated Zone* (BSC 2002 [160819]) as:

"*The qualification status of the original DTNs will not change. If the data evaluation meets the criteria described above, the Data Qualification Team will recommend that the qualification status of the new DTN will change from unqualified to qualified. The Data Qualification Report data submittals will list any restrictions or limitations associated with the use of these data."*

The new DTN referred to here is DTN: MO0212GWLSSPAX.000 [161271], the subject of this qualification report; it is also referred to as the "unqualified data set".

5. Data Generated by the Evaluation, if Applicable:

No new data were generated by this evaluation. However, the data were formatted for comparison using qualified software. The data handling process used in this evaluation is described here.

Description of process for used:

a). For the new unqualified data set (DTN: MO0212GWLSSPAX.000 [161271]):

Electronic file gwl_sspac2.asc (State Plane, Nevada Central Zone, meters) was downloaded from DTN: MO0212GWLSSPAX.000 [161271]. This file was edited to produce EARTHVISION-compatible file: gwl_sspac2.dat. The file: gwl_sspac2.dat was then converted to UTM (Zone 11) coordinates with the EARTHVISION coordinate transformation utility (EARTHVISION V5.1 (Dynamic Graphics 1998 [152614])), resulting in file gwl_sspac2_utm.dat. The file: gwl_sspac2_utm.dat was divided into two files for display purposes: gwl_sspac2_utm_lines.dat and gwl_sspac2_utm_points.dat.

b). For the qualified data set (DTN: GS010608312332.001 [155307]):

Electronic files: pot_contours.e00 and wells.e00 from DTN: GS010608312332.001 [155307] were translated into files: pot_contours.dxf and wells.csv using ARCINFO V7.2.1 (CRWMS M&O 2000 [157019]). The dxf file was converted and then sorted and edited for display to create file: pot_contours_e00_dxf_bydgi_Q_sorted.dat. The csv file was edited to create file: wells_csv_utm.dat. These data were already in UTM coordinates so no coordinate transformation was required.

c). For the definition of the UZ model area:

Electronic file: uz_border.dat was created from Table 9 of this Scientific Analysis Report. This file: uz_border.dat was converted to UTM (Zone 11) coordinates with the EARTHVISION coordinate transformation utility (EARTHVISION V5.1) yielding file: uz_border_utm.dat.

d). For the definition of the repository footprint:

The repository layout derived from DWG-MGR-MD-000003 REV A (BSC 2002 [159527]) was converted to EARTHVISION format and converted to UTM using the EARTHVISION coordinate transformation utility (EARTHVISION V5.1) resulting in the file: lalayout_fromdxfbydgi_utm.dat.

All of the above resulting files were combined to yield Figure IV.2-1. The solid blue lines, points, and labels represent the qualified data set and the black dashed lines, points, and labels represent the unqualified data set. The five-sided border near the center top of Figure IV.2-1 is the UZ model area and the patterned area near the center of the UZ model area represents the repository footprint. Figure IV.2-2 is a close up of the area of interest and Figure IV.2-3 shows additional detail.

The qualified data set derived from DTN: GS010608312332.001 [155307] is described in *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* (USGS 2001 [157611]). That report discusses the interpretation of several boreholes as representing perched water. Specifically the two northernmost boreholes on Figure IV.2-3 were interpreted to represent perched water and were not used to constrain the contour lines. Previous interpretation of the water table did not include perched water (USGS 2001 [154625]).

The resulting ASCII files are included as part of this qualification report: gwl_sspac2_utm_lines.dat, gwl_sspac2_utm_points.dat, uz_border_utm.dat, pot_contours_e00_dxf_bydgi_Q_sorted.dat, and wells_csv_utm.dat.

6. Evaluation Results:

Observations:

The following observations are based on a visual examination of the two data sets as shown in Figures IV.2-1 through IV.2-3. No additional processing was used to produce grids or digital surfaces.

a). The unqualified data set covers a much smaller area than the qualified data set.

b). Control points (boreholes that intercept the permanent water table) are very limited in the northern and northwestern portion of the UZ model area.

c). The greatest differences between the qualified and unqualified data sets occur in the northern and northwestern portion of the UZ model area outside the repository footprint. There is a difference in excess of 50 meters in the area where the unqualified 900-meter elevation contour is north of the qualified-950 meter contour. The largest difference is approximately 55 meters in the extreme northern portion of the UZ model area.

d). The greatest difference between the qualified and unqualified data sets within the repository footprint is approximately 40 meters. This occurs along the northwestern edge of the footprint where the 800-meter elevation contour of the qualified data set is in close proximity to the 850-meter contour of the unqualified data set.

e). The unqualified 775-meter contour appears on the wrong side of the data point labeled 775.5, located along the western edge of the repository footprint (See Figure IV.2-3). The lateral distance between the data point and the contour line is on the order of 20 meters. Given the gradient defined by the contour lines, it is likely that the vertical difference is less than 5 meters.

f). The unqualified data set presents a steeper gradient in the northwestern portion of the UZ model area than does the qualified data set.

g). In areas of good control (greater borehole data density) there is little or no difference between the qualified and unqualified data sets as depicted by the two sets of contour lines. This area of good control generally coincides with an area of very flat water table and constitutes the southeastern two thirds of the repository area as shown.

h). The 729.4 and 729-meter contours in the unqualified data set, located just outside of the UZ model area to the southeast, do not exist in the qualified data set.

i). The locations of the boreholes as represented in the two data sets do not exactly coincide. For example, see the duplicated 775.8 and 731.5 values in the southeastern portion of the UZ model area.

Discussion:

The representation of a surface constructed from scattered data points is an inexact process. Many factors may be considered in addition to the simple spatial relationship of the scattered observational data, particularly where those data are sparse. As an example, examination of the qualified data set suggests that topography was a factor in the placement of the contour lines in the northern part of the contoured area. In some cases, particularly where data are sparse, there may be several interpretations of the same data that result in different spacing and trending of contour lines.

Each interpretation of the placement of the contour lines must, however, accurately represent the data upon which it is based. In the case of observation "e)." above, the 775-meter contour line of the unqualified data set does not honor the data point with an elevation of 775.5 meters. This may be construed to be a technical error in the development of the unqualified data set.

With regard to observation "i)." above, the unqualified data set and the qualified data set were compared to the information contained in DTN: MO0106RIB00038.001 [155631]. When evaluating this comparison it is important to remember that both the DTN: MO0106RIB00038.001 [155631] and the qualified data set were originally presented in UTM coordinates. The unqualified data set was converted from State Plane Coordinates (Central Zone) into UTM coordinates using qualified software (EARTHVISION V 5.1 [152614]). The results of that comparison are listed here:

a). One borehole (USW WT-24) listed in both the unqualified data set and the qualified data set is not listed in the DTN: MO0106RIB00038.001 [155631].

b). The x value (easting) for one borehole (USW SD-9) is different in DTN: MO0106RIB00038.001 [155631] than in both the unqualified and the qualified data sets. Examination of the source for DTN: MO0106RIB00038.001 [155631] indicates that the easting is in error in that DTN and correct in the qualified data set.

c). Borehole locations given in the unqualified data set differ from 0 to 72 meters when compared to the DTN: MO0106RIB00038.001 [155631] (after correcting the easting for USW SD-9) with an average difference of 16.9 meters. The differences do not appear to be systematic as might be caused by a coordinate conversion process. Borehole locations given in the qualified data are identical to the locations given in DTN: MO0106RIB00038.001 [155631].

The results of this comparison reinforce the conclusion reached in the second paragraph of section 2: “that both of the conditions for a Technical Assessment are present: a) the correctness of the data is in question as a result of an absence of procedures or inadequate procedures, and b) there is a lack of adequate documentation of data acquisition or procedural compliance.”

The unqualified data set is not the result of an alternative interpretation. It is the result of poor digitization of a printed contour map and/or poor coordinate transformation. The fact that a contour line is on the wrong side of a data point in the circumstances of this unqualified data set is purely coincidence. Although the unqualified data set is not the result of an alternative interpretation it represents a plausible interpretation of the sparse scattered data (except in the case of the observation “e)”. above) because it honors the available water level data upon which the contours are based.

Application of Evaluation Criteria:

Within the footprint of the proposed repository layout the vertical difference does not exceed 60 meters. Therefore the first evaluation criteria listen in Section 3 is met.

Within the UZ model area boundary the vertical difference does not exceed 90 meters. Therefore the second evaluation criteria listen in Section 3 is met.

7. Recommendation for/against Changing the Qualification Status of the Data:

The unqualified data set (MO0212GWLSSPAX.000 [161271]), when compared in a visual examination with the qualified data set (GS010608312332.001 [155307]), meets the evaluation criteria, listed in section 3 above. In accordance with the qualification criteria listed in section 4 above, it is recommended that the qualification status of DTN: MO0212GWLSSPAX.000 [161271] be changed from unqualified to qualified. The following information must be included with the data set found in DTN: MO0212GWLSSPAX.000 [161271]. These following five items should be associated with the DTN in the TDMS.

a). This data set (DTN: MO0212GWLSSPAX.000 [161271]) is in part the result of poor digitization of a printed contour map and/or poor coordinate transformation when the source DTN (DTN: MO0110MWDGFM26.002 [160565]) was created. The existing documentation describing the digitization and coordinate transformation is not sufficiently complete to determine the details of the process (Wang 2003 [162380], SN-LBNL-SCI-213-V1, pp. 108–109).

b). A technical error in the form of one data point which is not honored by the developed contour lines is present in this data set (DTN: MO0212GWLSSPAX.000 [161271]).

c) This data set (DTN: MO0212GWLSSPAX.000 [161271]) includes contours that are a plausible representation of the scattered data (except where the 775 meter contour lies on the wrong side of the 775.5 data point),

d) This data set (DTN: MO0212GWLSSPAX.000 [161271]) must not be interpreted or presented as a representation of the qualified data set (DTN: GS010608312332.001 [155307]).

e) Although this data set (DTN: MO0212GWLSSPAX.000 [161271]) represents a plausible interpretation of the scattered data (except where the 775 meter contour lies on the wrong side of the 775.5 data point), the impacts of the differences between DTN: MO0212GWLSSPAX.000 [161271] and DTN: GS010608312332.001 [155307] on the processes that build on these data set have not been determined. Such processes might include gradient, flow paths, or spatial locations.

8. Rationale for Abandoning any of the Qualification Methods:

The technical assessment qualification method is satisfactory for this evaluation.

9. Identification of any Supporting Information used in the Qualification Effort by the Appropriate Reference Identifier (Data Tracking Number [DTN], accession number, Technical Information Center [TIC] catalog number, etc.)

(Note: These references have been incorporated into Section 8, but are included here to comply with the requirements of AP-SIII.2Q.)

DOCUMENTS CITED

BSC (Bechtel SAIC Company) 2002 [160819]. *Technical Work Plan for: Performance Assessment Unsaturated Zone.* TWP-NBS-HS-000003 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030102.0108

BSC 2002 [159527], "*Repository Design, Repository/PA IED Subsurface Facilities Plan Sht. 1 of 5, Sht. 2 of 5, Sht. 3 of 5, Sht. 4 of 5, and Sht 5 of 5", DWG-MGR-MD-000003 REV A.*

BSC 2003 [161726], Repository Design Repository/PA IED Subsurface Facilities 800-IED-EBSO-00401-000 Revision 00B, ACC: MOL20030109.0145.

BSC 2003 [161727], Repository Design Repository/PA IED Subsurface Facilities 800-IED-EBSO-00402-000 Revision 00B, ACC: MOL20030109.0146.

BSC 2003 [161731], Repository Design Repository/PA IED Subsurface Facilities 800-IED-EBSO-00403-000 Revision 00B, ACC: MOL20030109.0147.

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Wang, J.S. 2003 [162380]. "Scientific Notebooks Referenced in Scientific Analysis Report U0000, Development of Numerical Grids for UZ Flow and Transport Modeling, ANL-NBS-HS-000015 REV01." Memorandum from J.S. Wang (BSC) to File, March 04, 2003 with attachments. ACC: MOL.20030306.0526.

SOFTWARE CITED

CRWMS M&O 2000. *Software Code: ARCINFO.* V7.2.1. SGI Irix. 10033-7.2.1-00 [157019].

Dynamic Graphics. 1998. *Software Code: EARTHVISION.* 5.1. Silicon Graphics Indigo R4000. 10174-5.1-00 [152614].

Codes, Standards, Regulations, and Procedures:

AP-SIII.2Q, Rev. 1, ICN 0. *Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20021105.0164.

SOURCE DATA. LISTED BY DATA TRACKING NUMBER

DTN: GS000508312332.001 [149947] Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model. Submittal date: 06/01/2000.

DTN: GS010608312332.001. [155307] Potentiometric-Surface Map, Assuming Perched Conditions North of Yucca Mountain, in the Saturated Site-Scale Model. Submittal date: 06/19/2001.

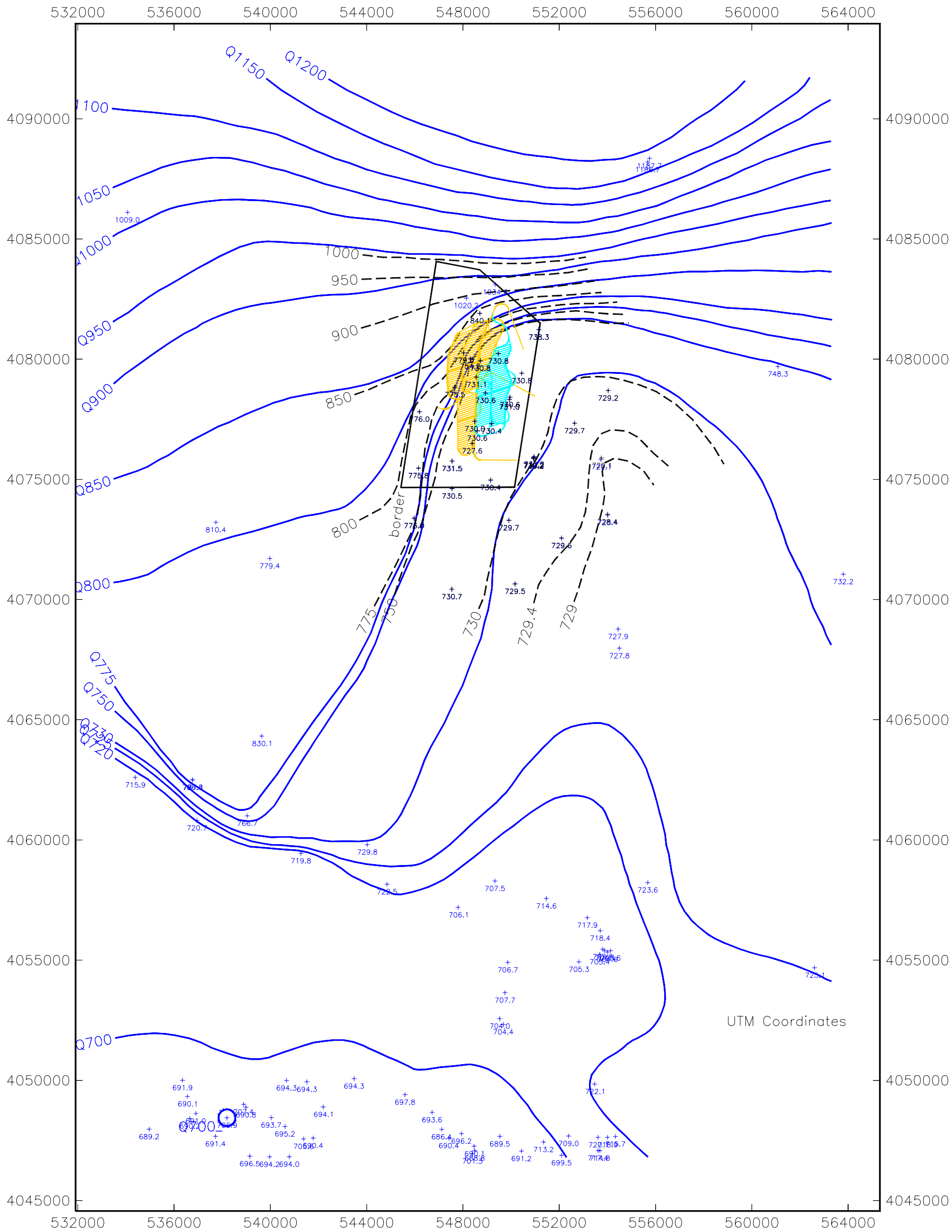
DTN: MO0106RIB00038.001 [155631] Water-Level Data and the Potentiometric Surface. Submittal date: 06/22/2001.

DTN: MO0110MWDGFM26.002 [160565] Vulcan GFM2000 Representation. Submittal date: 10/18/2001.

DTN: MO0212GWLSSPAX.000 [161271] ASCII File, Extracted from DTN: MO0110MWDGFM26.002 [160565], Which Includes 1) Contours Digitized from DTN: GS010608312332.001 and 2) Water Levels from DTN: MO0106RIB00038.001. Submittal date: 12/23/2002.

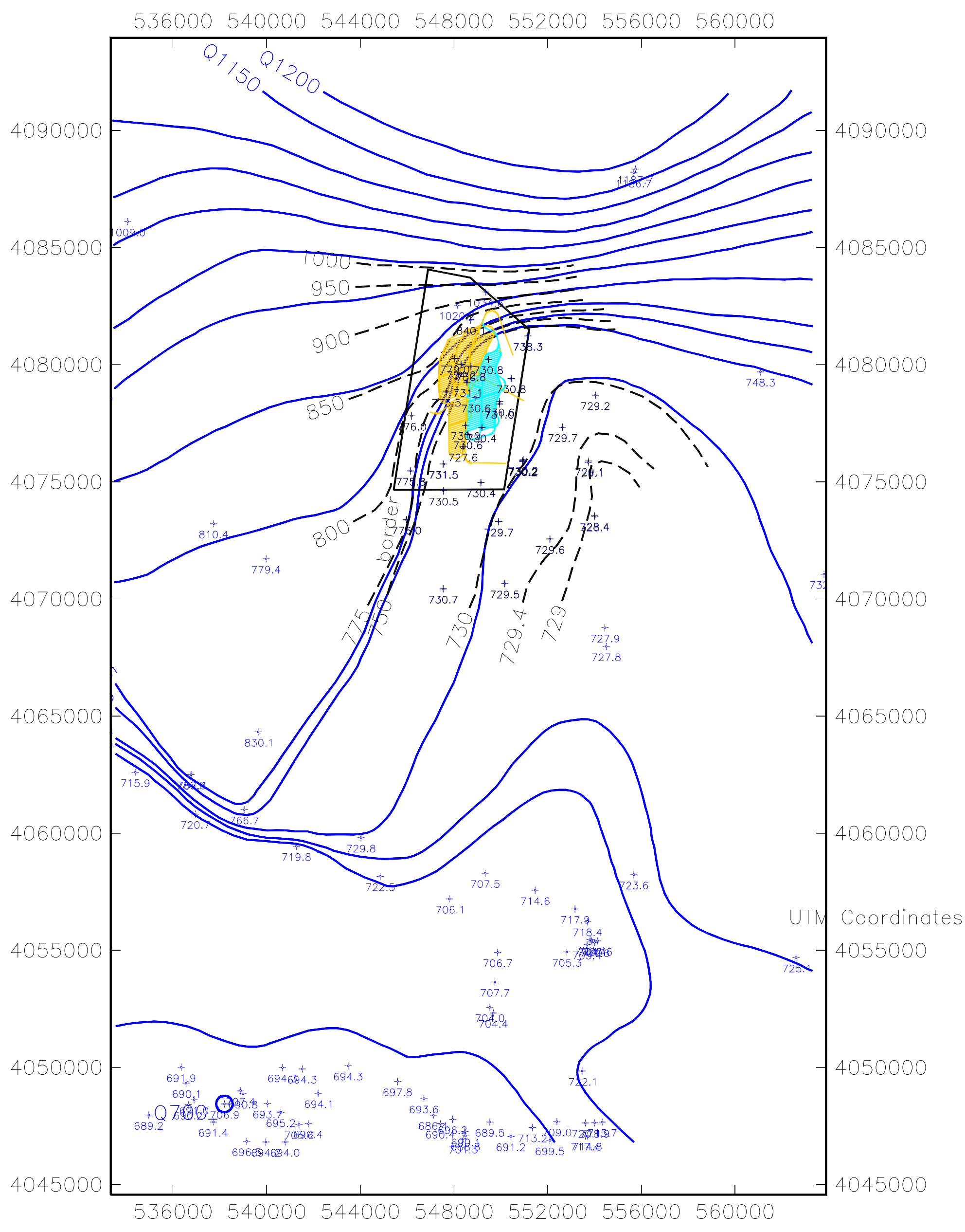
Reference to the Technical Work Plan or Data Qualification Plan

Data Qualification Plan for U0000, *Development of Numerical Grids for UZ Flow and Transport Modeling* (DI: ANL-NBS-HS-000015 REV 01)", which is Attachment III of (BSC 2002 [160819]), *Technical Work Plan for: Performance Assessment Unsaturated Zone*, TWP-NBS-HS-000003 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030102.0108



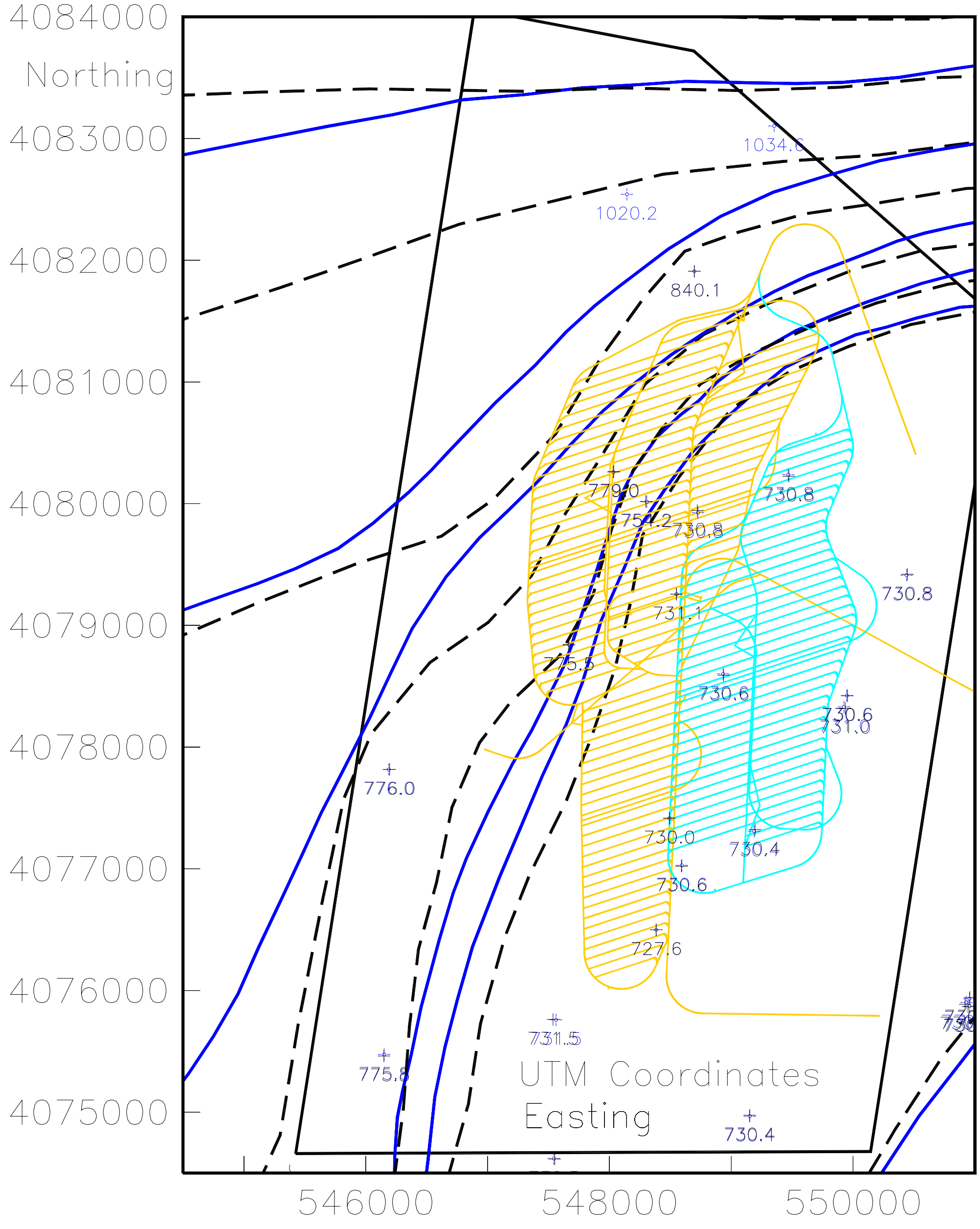
NOTE: 2002 Repository Lower Block (shown in turquoise) will not be used in any LA calculations.

Figure IV.2-1. Overview of contour lines representing qualified (solid lines, blue points and labels) and unqualified (dashed lines, black points and labels) data sets



NOTE: 2002 Repository Lower Block (shown in turquoise) will not be used in any LA calculations.

Figure IV.2-2. Closer view of contour lines representing qualified and unqualified data sets



NOTE: 2002 Repository Lower Block (shown in turquoise) will not be used in any LA calculations.

Figure IV.2-3. Detail of contour lines representing qualified and unqualified data sets

IV.3 DATA QUALIFICATION REPORT (D. GILLIES)

Report on Data Review and Qualification of
Data File "gwl_sspac2.asc" Contained in DTN: MO0212GWLSSPAX.000

By: Daniel C. Gillies
Data Qualification Team Member
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Yucca Mountain Project Branch
Denver, Colorado

INTRODUCTION

This data review and qualification exercise was conducted in accordance with the data qualification plan described in Attachment III of the Unsaturated Zone Technical Work Plan (BSC 2002 [160819]). The data qualification plan is entitled "Data Qualification Plan for U0000, Development of Numerical Grids for UZ Flow and Transport Modeling (DI: ANL-NBS-HS-000015 REV 01)". The data qualification review was conducted in accordance with OCRWM procedure AP-SIII.2Q REV 01 ICN 0 using the technical assessment approach. The data evaluation consisted of mathematical and visual comparison of two water-table contour maps, one qualified and one unqualified. The qualified data set exists as an ASCII file derived from the ARCINFO file "pot_contours_e00" which is contained within DTN: GS010608312332.001 [155307]. The unqualified data set exists as an ASCII file derived from the VULCAN layer file "GWL-SSPAC" which is contained within DTN: MO0110MWDGFM26.002 [160565]. The unqualified data set, which is to be used as input to U0000, was submitted to the TDMS as the file "gwl_sspac2.asc" within DTN: MO0212GWLSSPAX.000 [161271].

The criterion for qualifying the unqualified data set was that the elevation difference between the unqualified and qualified data sets be within ±10% of the total UZ Grid vertical extent of 600 m (i.e., the criterion is ±60 m) within the current repository footprint as defined in *Repository Design, Repository/PA IED Subsurface Facilities Plan Sht. 1 of 5, Sht. 2 of 5, Sht. 3 of 5, Sht. 4 of 5, and Sht. 5 of 5*. (BSC 2002 [159527]), and less than ±15 % of the total UZ Grid vertical extent (i.e., ±90 m) for other areas outside the repository footprint but still within the UZ Model Grid area.

DATA PROCESSING STEPS

1. The qualified data set for the Yucca Mountain site area water-table map (DTN: GS010608312332.001 [155307]) was retrieved from the Automated Technical Data Tracking (ATDT) system of the YMP Technical Data Management System (TDMS). The particular FTP data file extracted (/pub3/gis/baseline/hydr/g02078.zip) was unzipped (using Winzip) and the Arc export coverages were converted to the appropriate Arc/Info coverages using Arc Toolbox 8.2 (see footnote 1). The qualified data set was projected in Universal Transverse Mercator (UTM) meters and represents elevation of the water table in meters above mean sea level. (week of January 6, 2003).

2. Using Excel and Arc Toolbox 8.2 (see footnote 1), data files representing the boundaries of the UZ flow and transport model (Domain2002.bnd) and the potential repository footprint (Repository02_Table.xls) were retrieved from the ATDT of the TDMS under DTN:

LB0208HYDSTRAT.001. Coordinate data in these files were used to generate point coverages of the UZ 2002 model boundary and the outlines for the three discrete blocks of the 2002 proposed repository boundary. Both of these data files were projected in Nevada State Plane (NVSP) meters. (February 3–6, 2003)

3. The unqualified data set for the site area water-table map (DTN: MO0212GWLSSPAX.000 [161271]) was retrieved from the ATDT of the TDMS. The particular data file extracted (gwl_sspac2.asc) was downloaded using Excel and then processed using Arc Toolbox 8.2 (see footnote 1) to generate a plotted point coverage of the unqualified water-table map in Nevada State Plane meters. The unqualified data set was plotted along with the boundaries of the UZ model and the proposed repository footprint (see attached Figure IV.3-1). This map represents elevation of the water table in meters above mean sea level and includes data points representing contours and points of discrete measurements of the water table. (February 3–6, 2003)

4. Approval for use of ARCINFO V7.2.1 (see footnote 2) was received from YMP Software Configuration Management and the software was installed on a personal computer at the USGS in Denver. (February 6, 2003)

5. Using ARCINFO V7.2.1 (see footnote 2), the qualified water-level data (both contours and points of measured data) were converted from UTM coordinates to NVSP coordinates and plotted for visual inspection and evaluation (see attached Figure IV.3-2). For this map, two water-level data points (USW G-2, UE-25 WT #6) in the northern part of the UZ model area were removed from the plotted data because they have been interpreted to represent perched water (USGS 2001 [157611], Section 5.1.4.) rather than the regional water table. (February 6–13, 2003)

6. Visual comparison of the two data sets, both plotted at the same scale in NVSP coordinates, was made by overlaying one plot upon the other and then visually comparing the water-table values represented by each map, particularly in areas where differences in values were the greatest.

7. Using ARCINFO V7.2.1 (see footnote 2), identical grids were created for both water-table maps by first converting both data sets to spatial vector representations using triangulated irregular networks and then converting to a raster representation. The resulting grid consists of 134 columns and 200 rows of 60-meter square grid cells covering the domain of the UZ model. (February 13–14, 2003)

8. ARCINFO V7.2.1 (see footnote 2) was then used to compare the two water-table maps by subtracting the elevation of the water table at each grid cell for the qualified map (DTN: GS010608312332.001 [155307]) from the corresponding grid-cell elevations for the unqualified map (DTN: MO0212GWLSSPAX.000 [161271]) (i.e. difference = unqualified - qualified). (February 19, 2003)

9. Using ARC/GIS 8.2 (see footnote 1), the difference between the two water-table maps and the UZ model and proposed repository boundaries were displayed (see attached Figure

IV.3-3) for visualization purposes and to corroborate the visual comparisons made in 6 above. (February 19, 2003)

Results of Technical Evaluation of Data

The data plotted in the difference map (Figure IV.3-3) indicate clearly that the unqualified water-table map meets the criteria specified for this evaluation in that everywhere within the proposed repository boundaries (areas pb1, pb2, and lb in Figure IV.3-3) the differences between the two water-table maps are less than 60 m. Furthermore, everywhere outside the proposed repository boundaries but within the UZ model boundary, the differences between the two water-table maps are less than 90 m.

Within the boundaries of the proposed repository, the largest differences between the two maps occur along the northwestern edge of potential repository area "pb1" where water-table elevations for the unqualified map are as much as 30 to 40 m higher than for the qualified map. Throughout most of the area of the proposed repository (areas pb1, pb2, and lb), differences between the two maps are less than 10 m, as indicated by the bright orange and red colors in Figure IV.3-3.

Outside the proposed repository boundaries but within the UZ model boundary, the differences between the two water-table maps are greatest in the extreme northern part of the UZ model area where water-table elevations for the unqualified map are 50 to 60 m higher than the qualified map.

Overall, the differences in the two water-table maps coincide with the gradient of the water-table surface (northwest to southeast), as indicated by the elongated area of significant difference just northwest of repository area "pb1" and by the distinct east-west bands of difference across the northern part of the UZ model area. In this context, the differences between the two maps indicate that the unqualified map represents a steeper gradient from northwest to southeast on the water table surface than is represented by the qualified map. The impact of this overall difference between the two maps on determinations of repository performance cannot be determined with the data analyzed in this evaluation.

RECOMMENDATION

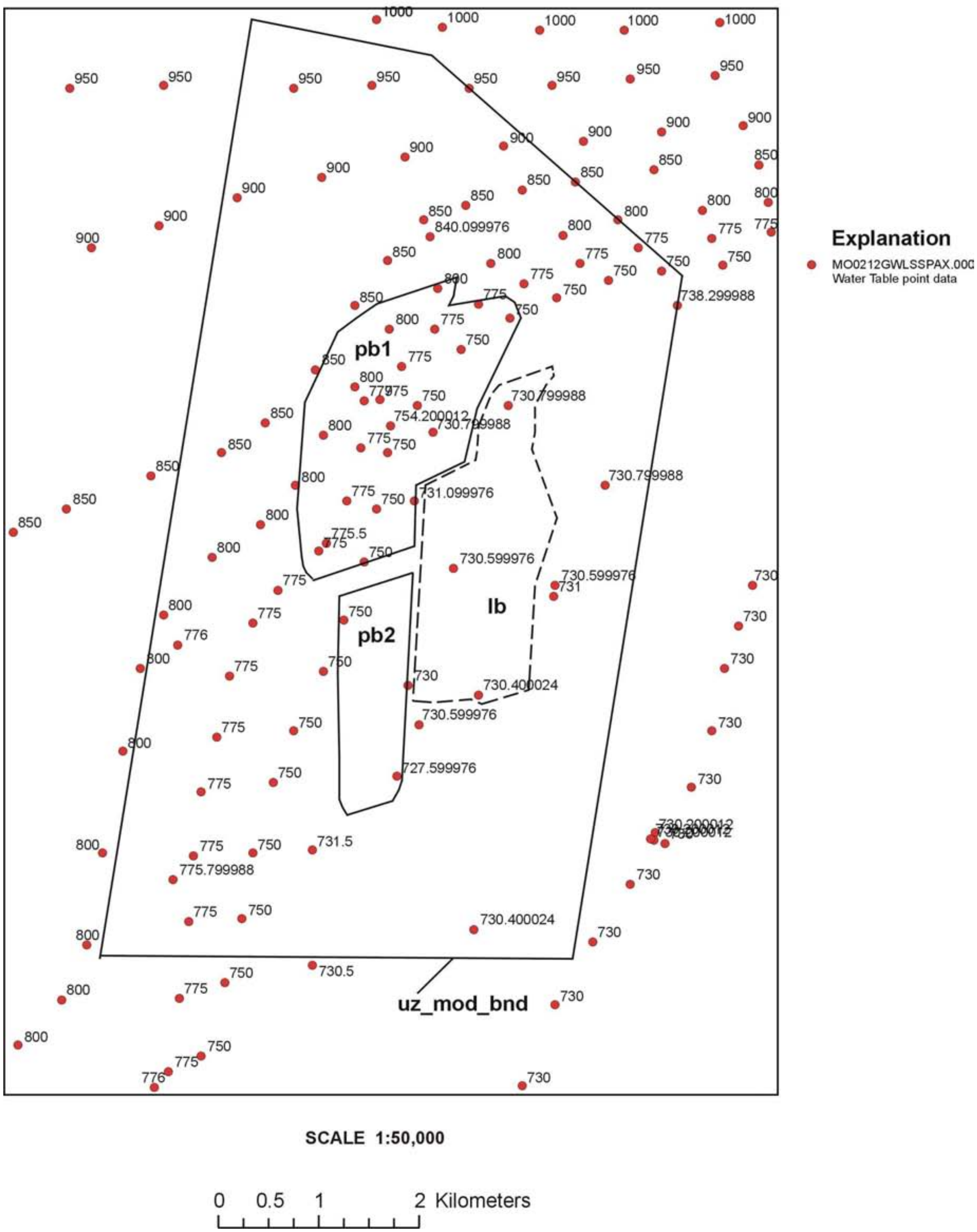
Based on the foregoing analysis, this member of the Data Qualification Team recommends that the data set in the file "gwl_sspac2.asc" within DTN: MO0212GWLSSPAX.000 [161271] representing the water table within the boundary of the UZ flow and transport model be declared "qualified". This recommendation is based on the conclusion, as described above, that the data set unambiguously meets the criteria set forth in the data-qualification plan referenced above.

Footnotes:

[1] Although Arc Toolbox 8.2 and ARC/GIS 8.2 are not baselined within the YMP by the Software Configuration Management organization, none of the operations performed with this software were quality affecting because the software was used solely for retrieval and display of data and was not used to perform calculations or obtain solutions.

[2] ARCINFO V7.2.1 is baselined within the YMP by the Software Configuration Management organization as STN/CSCI Number 10033- 7.2.1- 01 (USGS 2000 [148304]).

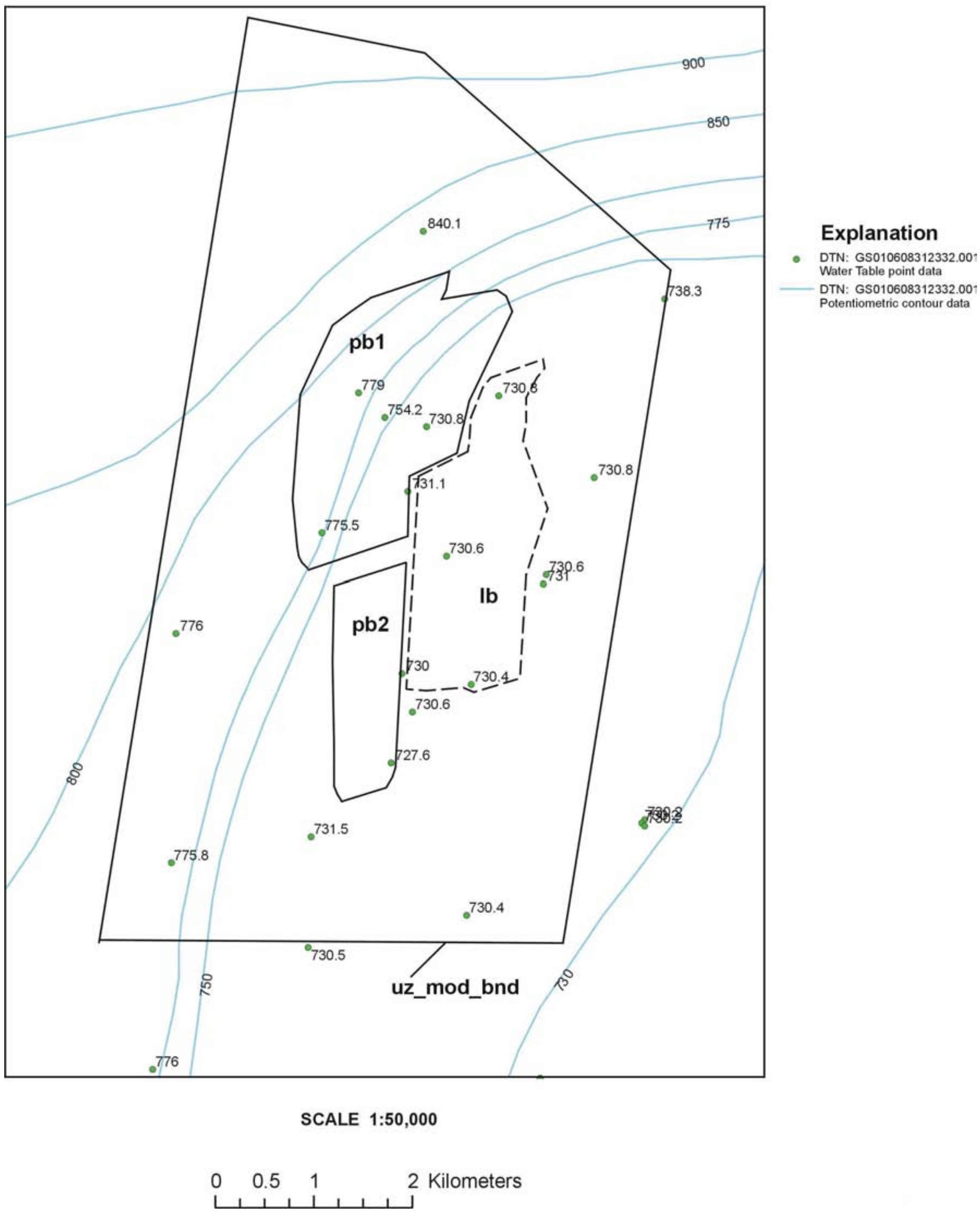
Data Qualification Plan for U0000, *Development of Numerical Grids for UZ Flow and Transport Modeling* (DI:ANL-NBS-HS-0000015 REV 01)



NOTE: 2002 Repository Lower Block (lb, shown by dashed line) will not be used in any LA calculations.

Figure IV.3-1.

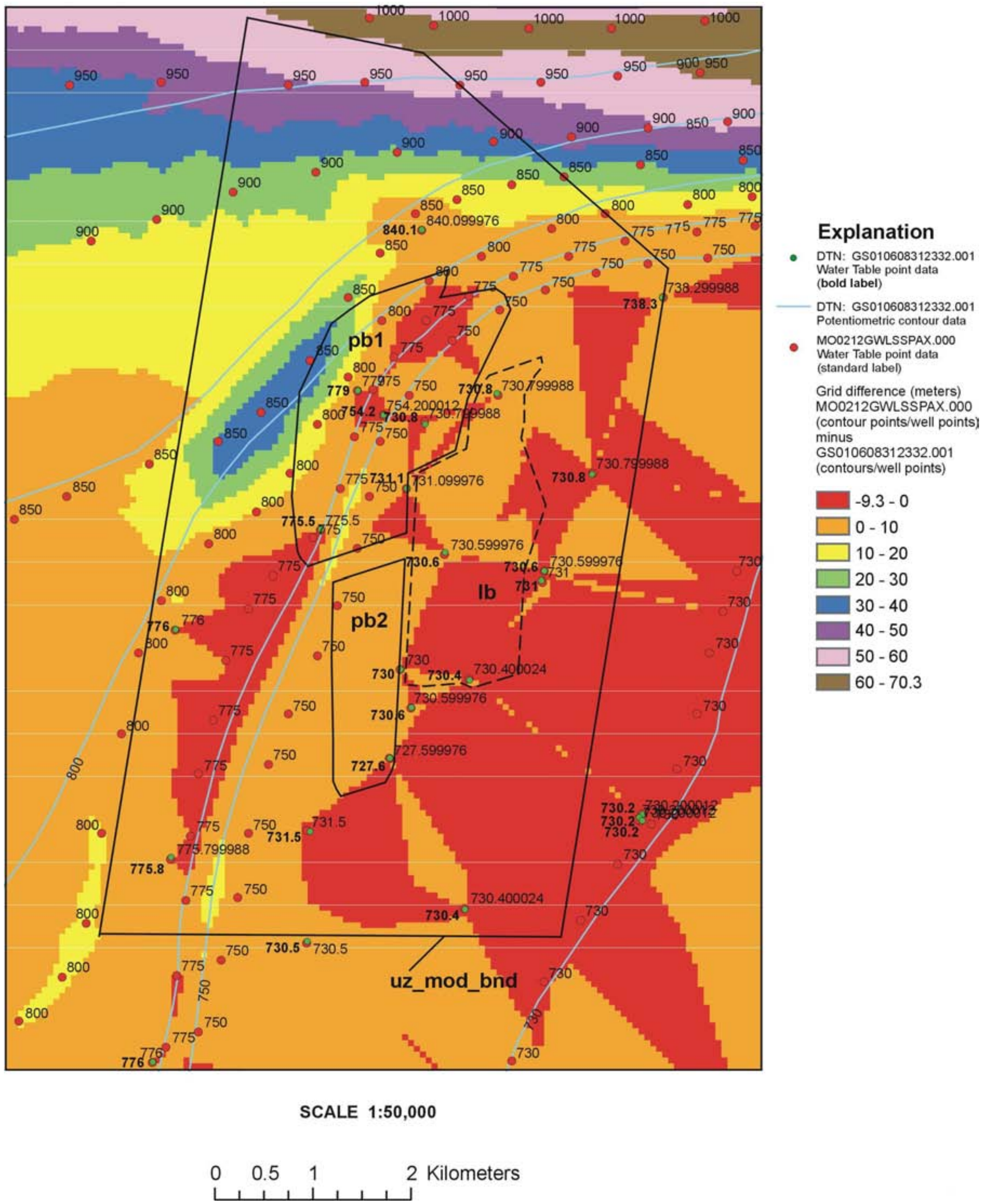
Data Qualification Plan for U0000, *Development of Numerical Grids for UZ Flow and Transport Modeling* (DI:ANL-NBS-HS-0000015 REV 01)



NOTE: 2002 Repository Lower Block (lb, shown by dashed line) will not be used in any LA calculations.

Figure IV.3-2.

Data Qualification Plan for U0000, *Development of Numerical Grids for UZ Flow and Transport Modeling* (DI:ANL-NBS-HS-0000015 REV 01)



NOTE: 2002 Repository Lower Block (lb, shown by dashed line) will not be used in any LA calculations.

Figure IV.3-3.

IV.4 DATA REPORT SUPPLEMENTAL FILES (T. VOGT)

Inclusions:
The ASCII files attached to this document.
a). gwl_sspac2_utm_lines.dat.
b). gwl_sspac2_utm_points.dat.
c). uz_border_utm.dat.
d). pot_contours_e00_dxf_bydgi_Q_sorted.dat
e). wells_csv_utm.dat.

a). gwl_sspac2_utm_lines.dat.

```
# Type: scattered data
# Version: 5
# Description:
# Format: free
# Field: 1 serial
# Field: 2 x
# Field: 3 y
# Field: 4 z meters
# Field: 5 nothing
# Field: 6 lineid
# Projection: Universal Transverse Mercator
# Zone: 11
# Units: meters
# Ellipsoid: Clarke 1866
# End:
00001 548661.5448 4069623.327 000000730.00 000000000.00 730
00002 548887.8903 4070156.603 000000730.00 000000000.00 730
00003 549012.2948 4070841.672 000000730.00 000000000.00 730
00004 549262.0524 4071932.889 000000730.00 000000000.00 730
00005 549461.9896 4072770.361 000000730.00 000000000.00 730
00006 549637.2776 4073404.891 000000730.00 000000000.00 730
00007 549964.0905 4074217.453 000000730.00 000000000.00 730
00008 550342.2254 4074852.692 000000730.00 000000000.00 730
00009 550720.5426 4075437.224 000000730.00 000000000.00 730
00010 551048.7626 4075844.07 000000730.00 000000000.00 730
00011 551325.7398 4076402.897 000000730.00 000000000.00 730
00012 551526.6375 4076961.449 000000730.00 000000000.00 730
00013 551651.2142 4077595.804 000000730.00 000000000.00 730
00014 551776.4964 4078027.306 000000730.00 000000000.00 730
00015 551927.2125 4078433.544 000000730.00 000000000.00 730
00016 552179.458 4078814.773 000000730.00 000000000.00 730
00017 552482.762 4079094.757 000000730.00 000000000.00 730
00018 553014.7211 4079248.763 000000730.00 000000000.00 730
00019 553547.1204 4079275.974 000000730.00 000000000.00 730
00020 554079.7055 4079252.48 000000730.00 000000000.00 730
00021 554663.3481 4079127.729 000000730.00 000000000.00 730
00022 555348.6857 4078927.265 000000730.00 000000000.00 730
00023 556034.2899 4078650.731 000000730.00 000000000.00 730
00024 556847.563 4078121.069 000000730.00 000000000.00 730
00025 557534.4057 4077489.542 000000730.00 000000000.00 730
00026 557967.4097 4076933.199 000000730.00 000000000.00 730
00027 558451.4027 4076300.964 000000730.00 000000000.00 730
00028 558834.0445 4075643.011 000000730.00 000000000.00 730
```

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00030	545360.8641	4070854.314	000000750.00	000000000.00	750
00031	545612.0495	4071539.813	000000750.00	000000000.00	750
00032	545888.41	4072276.127	000000750.00	000000000.00	750
00033	546114.9311	4072758.695	000000750.00	000000000.00	750
00034	546290.9342	4073190.372	000000750.00	000000000.00	750
00035	546441.2964	4073698.039	000000750.00	000000000.00	750
00036	546666.9394	4074434.167	000000750.00	000000000.00	750
00037	546842.2278	4075068.696	000000750.00	000000000.00	750
00038	546941.3499	4075728.323	000000750.00	000000000.00	750
00039	547141.7346	4076439.01	000000750.00	000000000.00	750
00040	547342.8107	4076946.855	000000750.00	000000000.00	750
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00042	547846.0477	4078064.309	000000750.00	000000000.00	750
00043	548046.8711	4078648.212	000000750.00	000000000.00	750
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00048	549483.6968	4081087.482	000000750.00	000000000.00	750
00049	549964.7589	4081292.017	000000750.00	000000000.00	750
00050	550471.268	4081471.288	000000750.00	000000000.00	750
00051	551003.4063	4081574.569	000000750.00	000000000.00	750
00052	551611.7871	4081627.41	000000750.00	000000000.00	750
00053	552245.609	4081654.976	000000750.00	000000000.00	750
00054	552803.5459	4081631.57	000000750.00	000000000.00	750
00055	553361.5655	4081582.803	000000750.00	000000000.00	750
00056	554122.6203	4081484.037	000000750.00	000000000.00	750
00057	554883.2331	4081512.045	000000750.00	000000000.00	750
00058	543704.1272	4073308.141	000000800.00	000000000.00	800
00059	544615.2718	4073793.096	000000800.00	000000000.00	800
00060	545044.75	4074251.019	000000800.00	000000000.00	800
00061	545296.3681	4074809.744	000000800.00	000000000.00	800
00062	545445.3181	4075723.106	000000800.00	000000000.00	800
00063	545644.6341	4076738.076	000000800.00	000000000.00	800
00064	545819.2128	4077575.458	000000800.00	000000000.00	800
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00071	548292.2947	4080981.899	000000800.00	000000000.00	800
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00073	549304.2559	4081644.705	000000800.00	000000000.00	800
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00078	552801.1588	4082316.2	000000800.00	000000000.00	800
00079	553536.4969	4082318.768	000000800.00	000000000.00	800
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00088	547558.3683	4080573.627	000000850.00	000000000.00	850
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00091	548618.1273	4082073.384	000000850.00	000000000.00	850
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00093	549605.9656	4082381.111	000000850.00	000000000.00	850
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00097	552673.039	4082696.101	000000850.00	000000000.00	850
00098	553737.7609	4082775.9	000000850.00	000000000.00	850
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00117	548106.2909	4083415.504	000000950.00	000000000.00	950
00118	549069.929	4083393.517	000000950.00	000000000.00	950
00119	549906.6024	4083421.793	000000950.00	000000000.00	950
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00137	551143.0371	4070620.886	000000729.40	000000000.00	729.4
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00140	552405.0319	4072298.836	000000729.40	000000000.00	729.4

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00142	553084.98	4073645.129	000000729.40	000000000.00	729.4
00143	553183.7477	4074406.18	000000729.40	000000000.00	729.4
00144	553231.5501	4075243.124	000000729.40	000000000.00	729.4
00145	553305.2267	4075928.019	000000729.40	000000000.00	729.4
00146	553404.9781	4076410.15	000000729.40	000000000.00	729.4
00147	553732.9287	4076893.065	000000729.40	000000000.00	729.4
00148	554163.3803	4077072.069	000000729.40	000000000.00	729.4
00149	554822.9167	4076998.301	000000729.40	000000000.00	729.4
00150	555280.2218	4076746.322	000000729.40	000000000.00	729.4
00151	555916.4329	4076089.266	000000729.40	000000000.00	729.4
00152	556526.8581	4075558.896	000000729.40	000000000.00	729.4
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00154	552817.0138	4070499.932	000000729.00	000000000.00	729
00155	553042.4839	4071286.777	000000729.00	000000000.00	729
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00157	553569.2356	4072936.815	000000729.00	000000000.00	729
00158	553794.5239	4073774.378	000000729.00	000000000.00	729
00159	553893.8314	4074383.292	000000729.00	000000000.00	729
00160	553841.5261	4074839.539	000000729.00	000000000.00	729
00161	553789.1283	4075321.139	000000729.00	000000000.00	729
00162	553863.9596	4075676.396	000000729.00	000000000.00	729
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00164	554877.9621	4075756.001	000000729.00	000000000.00	729
00165	555487.8534	4075377.769	000000729.00	000000000.00	729
00166	555921.0328	4074770.72	000000729.00	000000000.00	729
00167	544325.1352	4069734.999	000000775.00	000000000.00	775
00168	545131.1625	4071284.577	000000775.00	000000000.00	775
00169	545408.1336	4071843.39	000000775.00	000000000.00	775
00170	545685.0214	4072427.556	000000775.00	000000000.00	775
00171	545936.7281	4072960.929	000000775.00	000000000.00	775
00172	546112.1899	4073544.743	000000775.00	000000000.00	775
00173	546211.0477	4074280.439	000000775.00	000000000.00	775
00174	546309.8296	4075041.486	000000775.00	000000000.00	775
00175	546358.2495	4075700.937	000000775.00	000000000.00	775
00176	546432.1065	4076335.112	000000775.00	000000000.00	775
00177	546582.2932	4076893.485	000000775.00	000000000.00	775
00178	546706.9575	4077502.485	000000775.00	000000000.00	775
00179	546933.3027	4078035.761	000000775.00	000000000.00	775
00180	547185.7229	4078366.283	000000775.00	000000000.00	775
00181	547590.0979	4078748.05	000000775.00	000000000.00	775
00182	547867.2542	4079256.151	000000775.00	000000000.00	775
00183	548017.5329	4079789.172	000000775.00	000000000.00	775
00184	548193.3395	4080271.566	000000775.00	000000000.00	775
00185	548420.402	4080601.99	000000775.00	000000000.00	775
00186	548748.7153	4080983.493	000000775.00	000000000.00	775
00187	549178.8848	4081238.566	000000775.00	000000000.00	775
00188	549634.5905	4081443.003	000000775.00	000000000.00	775
00189	550191.7275	4081647.804	000000775.00	000000000.00	775
00190	550774.4056	4081801.988	000000775.00	000000000.00	775
00191	551509.3845	4081905.978	000000775.00	000000000.00	775
00192	552092.4124	4081958.73	000000775.00	000000000.00	775
00193	552700.7964	4082011.571	000000775.00	000000000.00	775
00194	553385.6906	4081937.893	000000775.00	000000000.00	775
00195	553994.4199	4081889.301	000000775.00	000000000.00	775
00196	554679.1365	4081866.329	000000775.00	000000000.00	775

b). gwl_sspac2_utm_points.dat.

```
# Type: scattered data
# Version: 5
# Description:
# Format: free
# Field: 1 serial
# Field: 2 x
# Field: 3 y
# Field: 4 z meters
# Field: 5 nothing
# Projection: Universal Transverse Mercator
# Zone: 11
# Units: meters
# Ellipsoid: Clarke 1866
# End:
00197   549934.7009   4078317.511   000000731.00   000000075.00
00198   549954.5392   4078422.191   000000730.60   000000075.00
00199   550957.9105   4075942.986   000000730.20   000000075.00
00200   550943.9583   4075867.628   000000730.20   000000075.00
00201   550919.8218   4075886.21    000000730.20   000000075.00
00202   548298.8763   4080018.422   000000754.20   000000075.00
00203   547550.533    4074615.578   000000730.50   000000075.00
00204   548937.9009   4078590.268   000000730.60   000000075.00
00205   548721.8897   4079944.679   000000730.80   000000075.00
00206   547536.9601   4075762.012   000000731.50   000000075.00
00207   549195.1251   4077322.607   000000730.40   000000075.00
00208   547665.3293   4078837.709   000000775.50   000000075.00
00209   546196.0615   4077816.438   000000776.00   000000075.00
00210   554003.5086   4073547.907   000000728.40   000000075.00
00211   548492.1774   4077415.249   000000730.00   000000075.00
00212   548384.0448   4076498.678   000000727.60   000000075.00
00213   548550.4792   4079256.546   000000731.10   000000075.00
00214   548036.1233   4080263.769   000000779.00   000000075.00
00215   549150.8354   4074975.413   000000730.40   000000075.00
00216   545976.0659   4073388.771   000000776.00   000000075.00
00217   547532.598    4070438.344   000000730.70   000000075.00
00218   550163.1408   4070647.224   000000729.50   000000075.00
00219   553749.8504   4075888.251   000000729.10   000000075.00
00220   552638.0369   4077336.727   000000729.70   000000075.00
00221   554033.7734   4078702.345   000000729.20   000000075.00
00222   551157.2263   4081222.46    000000738.30   000000075.00
00223   549910.2107   4073295.822   000000729.70   000000075.00
00224   549472.4161   4080225.334   000000730.80   000000075.00
00225   548590.5811   4077020.978   000000730.60   000000075.00
00226   548697.2023   4081909.504   000000840.10   000000075.00
00227   552098.5592   4072564.207   000000729.60   000000075.00
00228   550445.345    4079419.617   000000730.80   000000075.00
00229   546148.4092   4075461.14    000000775.80   000000075.00
```

c). uz_border_utm.dat.

```
# Type: scattered data
# Version: 5
# Description:
# Format: free
# Field: 1 x
# Field: 2 y
# Field: 3 lineid non-numeric
# Projection: Universal Transverse Mercator
# Zone: 11
# Units: meters
# Ellipsoid: Clarke 1866
# End:
545424.894      4074660.473     border
546891.6686     4084063.045     border
548692.3813     4083719.43      border
551209.4659     4081498.819     border
550143.5585     4074676.925     border
545424.894      4074660.473     border
```

d). pot_contours_e00_dxf_bydgi_Q_sorted.dat

Type: scattereddata
Version: 7
Description: dxf from matt knop imported by bill @ houston - DGI
Format: free
Field: 1 x
Field: 2 y
Field: 3 z
Field: 4 lineid
Projection: Universal Transverse
Zone: 11
Units: meters
Ellipsoid: Clarke 1866
End:

533561.77	4051761.53	700	Q700
534098.7	4051863.88	700	Q700
534543	4051912.73	700	Q700
535182.83	4051960.55	700	Q700
535625.93	4051938.21	700	Q700
536034.79	4051876.43	700	Q700
536626.54	4051747.49	700	Q700
537126.92	4051571.41	700	Q700
537572.76	4051350.77	700	Q700
538035.04	4051189.89	700	Q700
538324.61	4051089.82	700	Q700
538799.58	4050942.94	700	Q700
539199.57	4050884.96	700	Q700
539562.7	4050882.86	700	Q700
539923.23	4050944.31	700	Q700
540122.71	4051020.25	700	Q700
540122.71	4051020.25	700	Q700
540127.57	4051022.1	700	Q700
540546.44	4051167.53	700	Q700
541005.93	4051323.18	700	Q700
541150.62	4051370.34	700	Q700
541150.62	4051370.34	700	Q700
541377.84	4051444.4	700	Q700
541795.46	4051573.31	700	Q700
542267.73	4051637.45	700	Q700
542647.34	4051678.59	700	Q700
543026.99	4051677.78	700	Q700
543452.42	4051596.95	700	Q700
543861.41	4051446.17	700	Q700
544072.28	4051339.64	700	Q700
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e). wells_csv_utm.dat.

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# Type: scattered data
# Version: 7
# Description:  csv of wells.e00 by matt knop
# Format: free
# Field: 1 trash1
# Field: 2 trash2
# Field: 3 trash3
# Field: 4 trash4
# Field: 5 wellid
# Field: 6 x
# Field: 2 y
# Field: 3 z
# Field: 4 trash5
# Projection: Universal Transverse Mercator
# Zone: 11
# Units: meters
# Ellipsoid: Clarke 1866
# End:
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