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WASTE ISOLATION PILOT PLANT

FINAL REPORT

Culebra Hydrogeology Conceptual Model
Peer Review

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1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) Performance Assessment (PA) methodology uses conceptual models that represent specific features of the disposal system. The regulations applicable to WIPP require that all PA conceptual models be peer reviewed, and 24 conceptual models were peer reviewed for the original Compliance Certification Application (CCA). Historically, the EPA has also required that any "significant" changes to previously peer-reviewed conceptual models again be peer reviewed prior to approval and incorporation into the PA baseline.

The Culebra Hydrogeology Conceptual Model describes the overall hydrogeologic framework of the Culebra Dolomite Member of the Rustler Formation, the stratigraphic unit that has been found to be the most significant potential groundwater transport pathway for radionuclides released from the WIPP repository by inadvertent human intrusion. The Culebra Hydrogeology Conceptual Model is of significance to the WIPP PA because it provides the basis for development of transmissivity (T) fields used in numerical calculations of radionuclide transport through the Culebra. The original conceptual model for Culebra hydrogeology developed for the CCA was found to be "inadequate, but of no consequence" by the Conceptual Models Peer Panel constituted to review it (and other conceptual models). That Panel found that the conceptual model "failed to correlate the detailed hydrogeology of the Culebra with its tested hydrologic character" but that adequate data existed from hydraulic testing to develop a numerical model. In addition, the original conceptual model hypothesized that, apart from the anthropogenic influences of WIPP itself, the Culebra was effectively at hydraulic steady state. Subsequent monitoring has shown that water levels in the Culebra are steadily rising.

Sandia National Laboratories (SNL) proposes to modify the Culebra Hydrogeology Conceptual Model to incorporate additional information that has been obtained and developed since the CCA in order to demonstrate that the conceptual understanding of the Culebra is adequate to support the development of T-fields. The proposed Revised Culebra Hydrogeology Conceptual Model (RCHCM) describes how the hydraulic properties of the Culebra are related to geologic features and processes. By correlating the measured hydraulic properties at individual well locations to the geologic conditions at those locations, a basis can be developed for assigning hydraulic properties at untested locations where the geologic properties are known.

Detailed descriptions of the model components have been presented to the Peer Review Panel through written documentation and oral presentations. The Panel's determination of the adequacy of the conceptual model for the purpose of developing transmissivity (T) fields to be used in PA calculations of radionuclide transport through the Culebra is the subject of this report. To make their determination, the Panel reviewed sedimentological, geochemical, hydrologic, numerical simulations, and geostatistical information that SNL integrated to form the conceptual model. The Panel also reviewed the method by which that information was used to develop calibrated T-fields.

It is important for the reader to note that the scope of this peer review and the focus of the Panel were specifically on the proposed Culebra Hydrogeology Conceptual Model and the Panel did not broaden its review to other related models.

The peer review was performed in strict accordance with the requirements of U.S. Department of Energy (DOE), Carlsbad Field Office (CBFO) Management Procedure (MP) 10.5, Rev. 7, *Peer Review*. This procedure was developed in accordance with and implements the guidance in NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories*. The peer review process consisted of an in-depth analysis and evaluation of:

1. Validity of assumptions;
2. Alternate interpretations;
3. Uncertainty of results and consequences if wrong;
4. Appropriateness and limitations of methodology and procedures;
5. Adequacy of application;
6. Accuracy of calculations;
7. Validity of conclusions; and
8. Adequacy of requirements and criteria, in accordance with approved technical and quality assurance requirements and the applicable peer review plan(s).

In preparation for the peer review, the Panel was provided with pertinent documents, identified by DOE and SNL. The Panel convened for the peer review meeting in Albuquerque, New Mexico from August 11 to 14, 2008, at which time SNL provided briefings and responded to questions from the Panel members during the meetings. SNL subsequently provided written responses to the Panel members' written questions. The Panel was given the full cooperation of the DOE and SNL throughout the peer review. Representatives of the EPA, DOE, the New Mexico Environment Department (NMED), and the public were invited to observe the peer review process.

2. MODEL DESCRIPTION

The WIPP is located in the Permian Salado formation at a depth of 650 m (2,150 ft) below ground surface. It is overlain by a succession of Permian and Triassic beds, with an unconformity between the Triassic Santa Rosa and Tertiary Gatuna formations. The Culebra Dolomite of the late Permian Rustler Formation is the most transmissive saturated unit above the WIPP repository.

Performance Assessment modeling of WIPP includes human-intrusion scenarios resulting from drilling into the repository. One of the identified scenarios for release of radionuclides to the accessible environment is by transport of radionuclides by groundwater flow within the Culebra, following drilling intrusion.

The objective of the RCHCM is to provide a suite of transmissivity fields (T-fields) for the Culebra that are:

- Geologically based,
- Consistent with observed groundwater heads,
- Consistent with groundwater responses in the Culebra to pumping tests, precipitation, and anthropogenic impacts, and
- Consistent with water chemistry.

3. INFORMATION USED TO DEVELOP RCHCM

3.1 Geology

The geology of the Rustler Formation is known from more than 20 years of study of drill cores and mine shafts related to the WIPP Site, as well as from wells drilled for potash, oil and, gas exploration. General geological information on the Rustler Formation is found in Holt and Powers (1988); Powers and Holt (1999, 2000); and Powers et al. (2006). Details of the sedimentology of the Rustler Formation, emphasizing sedimentary features found in drill cores and mine shafts (air intake shaft, waste shaft, exhaust shaft), are reported in Holt and Powers (1988) and Powers and Holt (1999, 2000). Mapped facies boundaries between mudstone and halite from four units in the Rustler Formation are detailed in Powers and Holt (1995) and Powers (2002). New information on Rustler Formation mudstone-halite facies relations and mapped boundaries, obtained since the last CCA, is based on geophysical logs from numerous oil and gas wells and coring of 16 new Rustler hydrology wells drilled since 2003 (Powers, 2007, Task 1A of AP-114).

Recent studies have also focused on dissolution of halite in the underlying Salado Formation because such dissolution may influence the hydrological properties of the overlying Culebra Dolomite Member of the Rustler Formation (Powers, 2002). Comprehensive analysis of the Culebra Dolomite Member, including rock mineralogy, fractures, and cements, that form the basis for modeling transport processes is reported in Holt (1997). Finally, Powers studied the surface geomorphology in the southeastern arm of Nash Draw and adjacent areas including part of the WIPP Site to determine whether karst features exist at these locations and whether recent recharge through anhydrite/gypsum members of the Rustler Formation could be identified.

3.2 Hydrogeology

Beauheim (2008 presentation) described the current well network as consisting of:

- 90 Culebra wells drilled and/or cored on 63 pads,
- 60 wells purposely drilled to the Culebra,
- 12 wells completed to the Culebra on multiwell pads,
- 18 wells of opportunity – holes drilled for other purposes converted to Culebra wells, and
- 2 pre-WIPP wells tested and/or monitored.

Of these wells, 19 have been completed since the CCA.

Monitoring of groundwater levels and/or fluid pressures has been undertaken since 1977. Since 2002, wells have been instrumented and allow recording of hourly measurements. The monitoring well network in both the Magenta and Culebra has shown a gradual rise in groundwater levels over the last two decades. Three anthropogenic mechanisms have been identified as potential causes of the long term rise in water levels:

- Leakage from the Intrepid East tailings pile/pond, north and west of the WIPP Site,
- Leakage between formations via poorly cased or improperly plugged boreholes, and
- Leakage of brine injected at depth for secondary oil recovery or salt water disposal through poorly plugged or cased boreholes.

Modeling showed that only small volumes of water, well within the volumes potentially available, were leaking into the Culebra to account for the observed rise in water levels.

In addition to the anthropogenic sources, vertical leakage from the shallow water table in Nash Draw has also been identified as a potential source. Subsidence fractures and/or gypsum karst features could provide hydraulic connection (Powers, 2006). Leakage to the Culebra in the southeastern part of Nash Draw is used as a variable in the calibration of the T-fields model (see Section 4.4).

Perhaps the most important data set for the development of the transmissivity fields comes from the well testing in the Culebra Dolomite. Arguably this is one of the most extensively hydraulically-characterized carbonate units in the world. With the Culebra monitoring well network, there is an extensive database of observational responses that provides a large number of potential well pairs for calculating diffusivity, which is perhaps the best single parameter for defining connectivity and heterogeneity of the transmissivity field. The multi-well locations also have provided a basis for local scale determinations of storativity, anisotropy, fracture connectivity, and tracer transport. The conceptual models for well test analysis and for tracer transport that have been developed for the Culebra Dolomite are as advanced as any that the panel is aware of to understand flow and transport in fractured-porous systems.

3.3 Groundwater chemistry

Major ion groundwater chemistry from wells through the Rustler Formation and the Culebra Dolomite Member in particular, has been studied and interpreted by Ramey (1985), Bodine and Jones (1990), Siegel and Anderholm (1994), and Corbet (1997, 2000). These reports also discuss potential recharge areas for the Culebra Member as well as specific solute sources.

Bodine and Jones (1990) characterized Rustler groundwaters on the basis of major ion chemistry. They established, through the use of normative salt assemblages, that groundwaters received solutes from (1) dissolution of $CaSO_4$, either gypsum or anhydrite, (2) dissolution of halite, and (3) release of primitive "primary" brines trapped in the Rustler Formation and Salado Formations since the Permian that may have undergone diagenetic brine-mineral reactions. Several studies have classified Culebra Dolomite groundwaters into hydrochemical facies or zones on the basis of major ion chemistry (Ramey, 1985; Siegel and Anderholm, 1994; Corbet 1999, 2000). All studies have related Culebra groundwater chemistry to dissolution of gypsum/anhydrite, halite, and inputs of residual brines trapped in the Rustler and Salado Formations.

Domski and Beauheim (2008, AP-125 Analysis Report) used the latest information on Culebra groundwater geochemistry compiled from 59 analyses to classify groundwaters using the hydrochemical facies and salt normative groups of earlier studies. Hydrochemical facies A (concentrated, possible synsedimentary brine), B (relatively dilute $CaSO_4$ water), C (variable chemistry brine from middle of WIPP Site and west to Nash Draw), and D (potash mine anthropogenic brine) of Ramey (1985); Siegel and Anderholm (1994); and Corbet 1999, 2000) were expanded by Domski and Beauheim (2008) into hydrochemical facies A, B, B/C, C, A/C, D and E on the basis of ionic strength and major ion chemistry.

4. VALIDITY OF ASSUMPTIONS

4.1 Geological Conditioning of Transmissivity

The Culebra unit of the Rustler Formation is about 8m thick and has been described by Holt, Beauheim and Powers (2005) as follows:

> *"The Culebra consists of locally argillaceous and arenaceous, well- to poorly-indurated dolomicrite. Holt (1997) subdivided the Culebra into four distinct units (CU) ... which can be identified in the subsurface across the WIPP area. The Culebra overlies a mudstone unit (M2 of Holt and Powers, 1988) across much of the WIPP area...The lowermost unit (CU-4) shows evidence of*

> *syndepositional and post-depositional disruption caused by deformation of the underlying mudstone (Holt and Powers, 1990; Holt, 1997). Bedding plane fractures are common in CU-4 and form medium-scale (~1 m long and ~0.2 m thick) tabular blocks. The middle two Culebra units (CU-2 and CU-3) have similar character and are often not recovered in coring. These units contain numerous open and sulfate-cemented vugs, sulfate nodules, and discontinuous interbeds of poorly indurated silty dolomite CU-2 and CU-3 are intensely fractured with a hierarchy of superimposed block sizes resulting from the collapse of large vugs (Holt, 1997). The upper unit (CU-1) consists of well indurated dolomite with local interbeds of silty dolomite and is dominated by bedding plane fractures (spaced 0.1 to 0.6 m) and local subvertical fractures (spaced ~ 6 m) that bound large tabular blocks."*

The Tamarisk Member above the Culebra and the Los Medaños Member below the Culebra are a succession of mudstone/halite, anhydrite and clastic units. Of particular significance are the mudstone/halite units. These are interpreted by Powers and Holt (2000) as lateral facies equivalents of a large mudflat-salt pan complex.

Pumping tests in the Culebra show T values that range over ten orders of magnitude. The distribution is bi-modal, separated at $\log_{10}$ -5.4 m^2/s. In the documents provided by DOE and in the presentation by SNL, transmissivities less than $\log_{10}$ -5.4 m^2/s are referred to as "unfractured" or low T, and transmissivities greater than $\log_{10}$ -5.4 m^2/s are referred to as "fractured" or high T. The term "unfractured" is used to denote features that are not hydrologically significant, and does not imply any geomechanical properties. Indeed, many of the sections that are identified as "unfractured" contain discontinuities that have been cemented and filled by sulfate and/or halite.

Hart, Holt and McKenna (2008) identify three geologic factors that are significant influences on the transmissivity:

- Culebra overburden thickness,
- Dissolution of the upper Salado Formation, and
- Occurrence of halite in units above or below the Culebra.

<u>Culebra overburden thickness.</u>

A significant update to the hydrogeologic conceptual model has been the inclusion of geologic factors for controlling the transmissivity fields. The relationship between transmissivity and depth attempts to apply a single regression to three very distinctly different geologic settings: the zone where the Culebra Dolomite transmissivity has been influenced by dissolution of the

underlying Salado Formation, a zone with complete filling of vugs in the Culebra Dolomite by $CaSO_4$ and halite in the East, and a transition zone between the two.
The regression supposes a linear relationship between depth and the log of transmissivity. Although the overall regression appears to have a very high correlation coefficient, most of the correlation appears to come from the east and west zones and not from the transition zone which is the most important for WIPP transmissivity concerns. In the transition zone the depth-transmissivity relationship appears very weak.

The RCHCM hypothesizes that a depth-transmissivity relationship is caused by opening of fractures by unloading. However, the model provides no analytical geomechanical rationale or evidence for such a cause. Studies of depth-transmissivity relationships in crystalline rock, such as those done for the Swedish radioactive waste characterization programs, show nonlinear relationships of log transmissivity to depth. The most significant unloading often occurs within a few tens of meters of the surface. Furthermore laboratory studies of aperture closure with stress show that most of the closure happens within the range of normal loads of zero to a thousand pounds per square inch.

In summary, a depth transmissivity relationship appears to hold for the parts of the flow system that are least significant to the Culebra conceptual model. In the critical transition zone between Salado dissolution on the west and full vug and fracture filling in the east, the depth control on transmissivity appears secondary to other factors such as the presence or absence of vugs and fractures filled by $CaSO_4$ and halite.

<u>Dissolution of the upper Salado Formation.</u>
Nash Draw, west of the WIPP, has been recognized as resulting from Salado dissolution with the edge of the dissolution zone marked in part by Livingston Ridge. Above the Salado dissolution zone, fractures in the Culebra Dolomite are well developed and open, and transmissivity values fall within the high-T category.

<u>Occurrence of Rustler Formation halite in units above or below the Culebra.</u>
East of the M2/H2 transition, the halite facies H2 and H3 are present below and above the Culebra. Wells SNL-6 and SNL-15 drilled in this region show low transmissivities of $\log_{10}$ -11.1 m^2/s and $\log_{10}$ -12.9 m^2/s, respectively. In the area between the M2/H2 transition and the M3/H3 transition, for example wells H-12 and H-17, transmissivities are low, although not as low as east of the M2/H2 transition.

The Salado dissolution zone and the occurrence of halite above and below the Culebra allow these two zones to be defined as high-T and low-T respectively.

Between these two zones, the central zone exhibits both high-T and low-T areas. In order to extend geological conditioning of transmissivity, the extent of gypsum infilling of fractures and vugs has been used to develop "soft data." Beauheim and Holt (1990) postulated that there was an inverse relationship between the amount of infilling of fractures and vugs by gypsum, and transmissivity. Hart et al. (2008) developed this into a quantitative model using drillhole data, and defined a gypsum index that included a ranking based on the amount of gypsum present and the occurrence of large-scale gypsum-infilled fractures. A critical gypsum index of 2.5 was shown to separate high-T and low-T locations with high accuracy.

The hydraulic connectivity and lack of connectivity between well pairs has been incorporated into the RCHCM in the construction of base fields using soft data. Cells between wells that show diffusivity > 0.2 m^2/s were assigned a probability of having a low-T (P_{low}) of 0.25 to increase the likelihood of developing a path between the wells with a high-T.

Within the central zone, 46 wells were used to develop a variogram for high-T and low-T. The indicator variogram was fit with a spherical model with a range of 2195 m.

The indicator variogram, known T values and soft data, were used to construct stochastic realizations of indicator fields. The average indicator values for 1000 realizations are shown in Figure 6-2 of Hart et al. (2008). It shows low-T values east of the M2/H2 margin, high-T values west of the Salado dissolution margin, a zone of generally low-T extending northeast-southwest across the WIPP, and a linear zone of high-T extending into the WIPP from the south. From the indicator field realizations, base T-field realizations were constructed using regression equations specific to the zone (Salado dissolution, halite bounded, halite zone 2 and the central high-T and low-T zones) and the indicator terms.

The geological conditioning of transmissivity to a combination of cementation indicators and depth appears to be reasonable and valid. Since the CCA, SNL has obtained a significant amount of additional data targeted at providing local and well-to-well diffusivity data, and an understanding of the relationship between the geology and transmissivity. The specific genesis of some features, such as the high-T feature that extends into the southern part of the WIPP and terminates at a low-T area, cannot be determined. However, well test data provide strong evidence of the feature, and limited cores through the Culebra show that transmissivity values are strongly influenced by the presence or absence of $CaSO_4$ cements and fracture fillings. While it would be more satisfactory to be able to provide a single, well-supported theory for the presence or absence of $CaSO_4$ cements and fracture fillings in the Culebra Dolomite, there are many possible reasonable explanations.

Holt (RCHCM presentation 2008) stated that the gypsum cements and fracture fillings in the Culebra Dolomite had once been removed by dissolution across much of the WIPP Site. According to Holt, areas of current low-T in the Culebra probably were refilled by later stage precipitation of gypsum cement and fracture filling.

One of Holt's arguments for precipitation rather than dissolution was the lack of continuous north-south pathways for evaporite-dissolving fluids. This view assumes that the flow in the Culebra is strictly two-dimensional with no significant vertical component. Although possible, the Panel did not feel there was a convincing body of evidence to validate this geological basis for interpreting the relative timing of formation of dissolution and precipitation of gypsum cements and fracture filling in the Culebra.

The lack of a defined basis for the high-T linear feature that extends southwards from within the WIPP site means that the potential for similar features elsewhere in the model domain outside the area of intensive well-to-well testing cannot be dismissed. However, a similar feature elsewhere in the model domain would likely have limited effect upon the flow field and pathways from the repository to the land withdrawal boundary (LWB).

4.2 Culebra T-Field

Geostatistics provides the primary basis for populating the transmissivity fields, based on the assumption that values of a parameter are spatially correlated. The method uses a "variogram" which shows the similarity of parameter values as a function of the distance between measurement points. To use the variogram requires the assumption that the parameter values are point values or all represent similar "support" areas.

Strictly speaking, this is not the case for transmissivity values from well tests except perhaps for the very low transmissivity values. A transmissivity value from a well test represents an area or volume that may affect equivalent radii of several kilometers along high diffusivity pathways. Although the transmissivity values that are used for T-field conditioning are stated to be early time values, even these transmissivity values may be reflecting varying areas of the Culebra.

The treatment of transmissivity fields as point or limited area (model grid blocks 100m x 100m) values does not so much represent an error as a lost opportunity. Because many of the highest values of transmissivity are clustered over the WIPP site and along identified flow channels, the use of geostatistics and point transmissivity values does not have a major effect on the quality of the resulting transmissivity fields. Furthermore, the data from the large number of potential pumping and observation well pairs provide a significant base of soft data for conditioning the transmissivity field. With respect to the use of later time well-test pressure data, there is a lost opportunity to use these data as an additional calibration tool for understanding transmissivity spatial distributions.

The well test analysis methods that are incorporated in the nSIGHTS program are perhaps the most sophisticated in professional use today. Knowing the diffusivity values of the Culebra, which are well-established from interference tests, the distance and area that the transmissivity value represents can be estimated with some confidence. As mentioned above, this distance can be hundreds of meters to kilometers, or areas that are considerably larger than the model grid cells. Furthermore, the pressure derivative curve and the low dimension interpretations provide information on the shape, for example channelization, of the conducting feature.

A further technique of transmissivity analysis that could have been considered is the comparison of pressure derivative curves that are normalized for flow rate from different wells. The normalized derivative plot is a powerful tool for showing which wells are pumping the same spatial region and which wells are affecting different regions. This kind of information provides a further hydrogeologic basis for conditioning transmissivity fields to well tests information.

Although late-time pressure-derivative data are not being used in the generation of the T-fields, the density of data across the WIPP site and along the channel feature to the south of the WIPP site, assures that the transmissivity fields that are derived assuming point equivalence are likely to be valid. Nonetheless, further confidence in the transmissivity fields could be developed by utilizing the late-time well test behaviors.

The representation of transmissivity fields and stochastic variables is well established in groundwater flow modeling. Stochastic representations capture the variability of transmissivity within a groundwater flow unit as well as the uncertainty in transmissivity values at unmeasured points. Stochastic modeling becomes even more powerful and useful when it is combined with geologic information and direct measurements to condition the transmissivity fields. The concentration of data for conditioning transmissivity fields within the WIPP boundary helps avoid one problem with stochastic models, namely, that purely stochastic representations provide an insufficiently constrained range of scenarios to have a useful predictive value. In summary, the Panel concurs with the use of stochastic representations particularly as they are conditioned by geologic data and direct measurements by well tests.

The RCHCM assumes that the T-field will not change over the PA period, except for the effects of potash mining. These potential impacts are handled stochastically elsewhere in the PA by increasing the T-value. Continued dissolution of the Salado Formation has the potential to increase the T-values along the margin of the dissolution zone. However, the rate of dissolution is unlikely to result in eastward migration of the dissolution margin to an extent that would significantly change the T-field. The model assumption of a constant T-field, modified stochastically by potash mining, is therefore reasonable and valid.

4.3 Groundwater Flow

Densities of Culebra groundwater vary between 1,000 and 1150 kg/m^3 (Holt, Beauheim and Powers, 2005). In order to account for the effect of variable density on the hydraulic heads, all measurements have been converted to equivalent freshwater heads. This procedure is well accepted in the evaluation of groundwater flow fields and is appropriate and valid for the WIPP area RCHCM.

The Culebra Dolomite is well known to be a porous fractured formation. Fractures serve as preferential pathways for flow. For the purposes of transport calculation the full spectrum of porosities that are present in the rock from pores to fractures must be considered. The transmissivity fields, however, primarily control the flux of groundwater that moves across the WIPP site. The regional model that uses the transmissivity fields is concerned with this flux. As long as the focus of this conceptual model is primarily one of flux and not velocity, a porous representation of the transmissivity fields is appropriate.

The primary controls on the head distributions in a steady-state numerical model, in addition to the transmissivity distributions, are the boundary conditions and the fluxes. One of the inherent dangers of model construction is the over-calibration of the model through manipulation of the boundary conditions. The main area of the model where boundary conditions are being adjusted to fit the head values is through the southern portion of Nash Draw. In that area, recharge is added to create a groundwater ridge running southwest of the site. Head values south of the site are also controlled in part by the specifications of the sinusoidal boundary condition of the south end of the model. For the most part these adjustments are sufficiently far from the WIPP boundary, that the transmissivity fields within the WIPP site and the down gradient region south of the site are being controlled primarily by the directly measured well test values. These well test values have sufficient spatial density, both in terms of single wells and interference data, to provide coverage to assure representative transmissivity fields in the portions of the model that matter most.

4.4 Groundwater Chemistry

Theoretically, knowledge of the chemical composition of the Culebra Dolomite groundwaters can be used in conjunction with the detailed geology of the Rustler Formation to test the accuracy of the Culebra flow field modeling. That is, given a defined flow path, one should be able to predict the types of water-rock reactions (i.e., dissolution) along that flow path, and then predict the chemical composition of the resulting water at any point along the flow path. Previous work (Ramey, 1985; Bodine and Jones, 1990; Siegel and Anderholm, 1994; Corbet 1997, 2000; Domski and Beauheim, 2008) on the major ion chemistry of the Culebra Dolomite Member has shown that solutes are primarily derived from:

- Dissolution of $CaSO_4$, either gypsum or anhydrite,
- Dissolution of halite,
- "Primary" syndepositional brines ultimately formed from evaporated seawater, and
- Potash mining activities.

In the area south and west of the WIPP site, relatively dilute waters dominated by Ca and SO_4 indicate an origin from dissolution of gypsum and/or anhydrite (type B of Domski and Beauheim, 2008). Recent field work suggests that the source of this dissolved $CaSO_4$ could be an area of Nash Draw where the A-3 and A-5 gypsum/anhydrite units of the Rustler Formation exhibit karst features and are actively undergoing dissolution (Powers, 2006). This example shows good correspondence between the geology of the Rustler, Culebra geochemistry and flow field modeling.

A second area to the east of the WIPP site (2 wells- SNL 6 and SNL 15) contains Culebra Dolomite with extremely low transmissivity. Brines from this undissolved, unaltered part of the Rustler Formation may be "trapped" Permian evaporated seawater (type E of Domski and Beauheim, 2008). The very low transmissivity, cementation of the Culebra Dolomite by halite, and halite-rich evaporites (H-2 and H-3 units that underlie and overlie the Culebra) from this area support the conclusion from the Culebra groundwater chemistry that these are trapped "primary" brines.

A third water of Domski and Beauheim (2008), type D, is saline brine with high potassium concentrations, located within Nash Draw (WIPP 27 and WIPP 29 wells). These waters are clearly anthropogenic with solutes derived from nearby potash mining activities.

The remaining hydrochemical facies of Domski and Beauheim (2008), facies A, C, A/C, and B/C are more problematic, but are important because they comprise every Culebra groundwater sampled within the WIPP boundary (21 wells from Domski and Beauheim, 2008). There is no consensus in the literature, including Domski and Beauheim (2008), relating transmissivity, flow fields, geologic features, and groundwater chemistry for these wells. Unresolved questions about these Culebra groundwaters from these wells include:

- Whether solutes in the Culebra are derived from dissolution of $CaSO_4$ and halite within the Culebra Dolomite, or whether solutes are derived from dissolution of units above or below the Culebra Dolomite.
- Whether vertical leakage through overlying units is an important solute source in the Culebra Dolomite, as suggested by Corbet (1997, 2000).

- Although a source of NaCl is needed for these waters, particularly on the east side of the WIPP site, it is not known whether this NaCl source is from dissolution of the margins of associated Rustler halite units (H2 and H3) or from halite cements within the Culebra. The locations of the halite dissolution that supplies Na and Cl to particular wells in the Culebra Dolomite are not well known.
- Additional solutes (i.e., Mg, K) present in facies A, C, A/C, and B/C waters cannot be derived from the dissolution of halite, gypsum, or anhydrite, but the sources of these solutes are not clear (trapped evaporated seawater brines from units above, below or lateral to the Culebra Dolomite or dissolution of minerals in the Rustler Formation such as polyhalite).
- Physical mixing of different groundwater with different sources of ions is hypothesized by Domski and Beauheim (2008), but the nature of such mixing is poorly known.

In view of these unresolved issues, the Panel submitted Question 17 "*How do you show consistency between the geochemistry and the flow models, particularly in terms of mixing volumes and fluxes?*" SNL responded, in part, as follows:

> *"This is slated for future work in Task 3 of AP-125 after the new T fields are completed. Reverse particle tracking will be used to determine the pathway by which the water at a sampled well arrived at that location for each T field. In addition to providing a trajectory, the reverse particle tracking will also reveal the relative velocities of water movement toward the wells. The groundwater chemistry at the wells will be compared to the present-day chemistry along the projected flow paths to see if it is consistent with current conditions or suggests changes in the flow field have occurred."*

The Panel considers that the absence of demonstrated consistency between the groundwater geochemistry, the Rustler geology, and the Culebra flow field within the WIPP boundary is currently a weakness in the RCHCM. However, this should be rectified by the planned future work.

4.5 Boundary Conditions

The lateral boundary conditions for the MODFLOW simulations are as follows (Hart and McKenna, 2008 presentation):

- No-flow boundary along the northwestern portion of Nash Draw,
- Constant head boundary for the halite-bounded zone fixed at ground surface, ten cells into zone,
- Constant head boundary along the northern limit of the model based on observed heads in the area,

- Constant head boundary along the southern portion of the western boundary and the southern boundary, based on observed heads in the area.

The choice of boundary conditions and values are considered reasonable and valid.

A numerical model of the complete groundwater basin in which WIPP is located was developed by Corbet (2000). The model included nine hydrostratigraphic units from the top of the Salado Formation to ground surface. The western, eastern and southern boundaries were represented by no-flow conditions. The northern boundary condition is not identified. Recharge was applied at the ground surface throughout the model domain. Hydraulic conductivities were selected to reflect the Salado dissolution zone in the west, significantly lower hydraulic conductivities in the east, and intermediate values between these areas. Corbet's model was able to reproduce the general pattern of heads and groundwater flow in the Culebra.

The T-fields numerical model does not include vertical recharge or leakage during calibration, apart from a limited area of the model adjacent to Nash Draw. The Panel recognizes that as the model area decreases in area (from the basin wide model of Corbet to the RCHCM T-fields model), the importance of vertical leakage diminishes relative to horizontal flow.

Corbet (2000) notes that:

> *"One parameter for which an upper limit can be estimated is the vertical conductivity of the confining unit, averaged over areas that are large enough to be used for simulations. Results suggest that this value is not larger than 10^{-12} m/s, because all steady-state calculations that use a larger value result in maximum head differences between the Culebra and the Magenta Dolomites of only 20 m."*

Corbet's model with 2 km by 2 km cells is much less detailed than the T-fields model that uses 100 m by 100 m cells. Limited areas of higher conductivity zones could therefore be present allowing vertical leakage, without significantly influencing the head distribution between the Magenta and Culebra Dolomites in Corbet's model. However, these could be significant in the T-fields model. In particular, there are geochemical data from the WIPP area that may require the inclusion of an element of vertical flow to adequately explain the observed water chemistry (see Section 4.3). In view of these differences between the Corbet and T-fields models the Panel submitted Question 39, "*In the basin-wide model developed by Corbet (2000), vertical leakage to the Culebra takes place through strata above the Culebra. How is the absence of vertical leakage in the T-field model (except for recharge near Nash Draw) reconciled with areal recharge and leakage in the Corbet model? What would be the effect of including vertical leakage as an optimization parameter in the T-field calibrations?*" Extracts from the response provided by SNL are presented below.

"Our evolving understanding of the geologic and hydrologic conditions at WIPP lead us to consider the Corbet (2000) basin-wide model no longer a good representation for modeling, although it enabled evaluation of some limiting or bounding conditions with respect to recharge of the Culebra."

"The geology and hydrology of the Culebra in the eastern part of WIPP and farther east are now known to differ from conditions assumed by Corbet (2000). Wells such as SNL-6 and SNL-15 show that the Culebra is sandwiched between halite beds and also contains halite as fracture and pore fillings. Hydraulic observations in these wells also reveal that the fluid pressures within the Culebra are far above fluid pressures for areas farther west and are estimated to be a large fraction of the lithostatic load at these locations."

"There is no halite in Rustler units M2/H2, M3/H3, or M4/H4 across much of the WIPP site. Nevertheless, there are several observations at WIPP and elsewhere that indicate no effective vertical infiltration into the Culebra from the surface, and this also contrasts with the assumptions made for the Corbet (2000) model."

"Solute chemistry of the Culebra is not consistent with dominantly vertical recharge over the WIPP site area."

"Freshwater heads calculated for the Culebra are distinctive from freshwater heads from Magenta at all common locations across the WIPP site, indicating lack of good vertical communication between them. This is consistent with low-permeability intervals between the Culebra and the surface."

"Gypsum-filled fractures and sulfate cements in the Dewey Lake, and local perched groundwater on the gypsum cements, argue strongly against continuing vertical infiltration of meteoric water across the site, as assumed by the Corbet model."

"The main use by WIPP of the basin-scale model developed in Corbet and Knupp (1996) and discussed in Corbet (2000) was to gain insight into the groundwater flow in the formations overlying the Salado over tens of thousands of years, and to develop a conceptual understanding of how the regional groundwater flow may respond to climate change (e.g., the climate index). ... Our current understanding is that modem-day recharge varies significantly over the basin-scale modeling domain, and that it very likely varied significantly in the past several thousand years as well."

"Vertical leakage (or recharge) is currently included as an optimization

> *parameter in the T-field calibration process, although only in the areas of Nash Draw identified by Powers (2006) as potential recharge areas. However, in the calibrations thus far performed, PEST output does not indicate that the T-field calibration process is very sensitive to the recharge rate. One could speculate about the impact of allowing recharge in other areas of the model, but our current understanding of the hydrostratigraphy in the WIPP vicinity indicates that recharge should be minimal in areas of the model domain outside of Nash Draw."*

SNL also noted in the response that the basin scale model is currently being reconstructed and will account for new data and refined interpretations related to regional geology, hydrostratigraphy, and recharge. In considering the available published information and the response by SNL, the Panel recommends that SNL confirm the consistency between the basin scale model, the T-fields model and the groundwater geochemistry, in finalizing the RCHCM.

Changes in boundary conditions with time (climate effect factor) are handled elsewhere in the PA and therefore were not considered in the Peer review.

5. ALTERNATE INTERPRETATIONS

5.1 Geological Controls on Transmissivity

Early workers, for example Snyder (1985), interpreted lateral changes from halite to mudstone in the Rustler Formation (the M1/H1, M2/H2, M3/H3 and M4/H4 transitions) to have been produced by present-day dissolution of Rustler halite by dilute groundwaters. Furthermore, Snyder (1985) postulated that dissolution of halite below the Culebra Dolomite (from the Los Medaños Member) causes the dolomites to "settle and fracture and transmit groundwater more readily." It is now known from the RCHCM that transmissivities in the Culebra Dolomite are controlled by a complex variety of surface depositional and burial processes that have occurred within and below the Culebra Dolomite. Holt and Powers (1988) and Powers and Holt (1999, 2000) have shown from study of mine shaft exposures and cores that mudstone-halite lateral transitions in the Rustler Formation may be interpreted as lateral facies changes, not massive dissolution of halite. In addition, gypsum and halite vug and fracture fillings and cements within the Culebra exert a major control on transmissivities. Where these cements, vug and fracture fillings are present, transmissivities are low; where these cements and fracture fillings have been removed by dissolution, transmissivities are high, enhanced by fracturing of the vuggy porosity. The RCHCM also shows that fracturing in the Culebra Dolomite and high transmissivity is related to dissolution of the underlying Salado Formation in Nash Draw to the west of the WIPP site.

One key assumption in the hydrogeologic conceptual model is that the mudstone-halite transitions in the Rustler Formation are depositional rather than being the product of solution. In other words, the mudstone is a primary depositional unit rather than a residual material from solution activities. Observations of the mudstone in the shafts and boreholes suggest that the mudstone is not a solution product. Hence it is inferred that the boundary of the mudstone and the halite is a facies boundary. One uncertainty in this interpretation is the appearance that the mudstone-halite boundary closely parallels the Salado dissolution front. In light of this uncertainty, the Panel submitted Question 41 "*How does one reconcile the parallel appearance of the Nash Draw dissolution front (age ~.5 my) with a Permian facies boundary (~200 my)?*" Excerpts from the response provided by SNL are presented below.

"There are two likely significant contributors to the apparent parallelism of the Nash Draw margin and the halite depositional margins: topography and modest removal of H1 along the margin of Nash Draw."

"The difference in thickness of H3 in the depositional basin compared to the thickness of M3 across the structural trend northeast of WIPP is about half of the relative uplift of the Culebra from basin to top of the structure. The stratigraphic relationships in M3/H3 from basin to uplift indicate that halite was not removed by dissolution over the uplifted area. From this, we infer that halokinesis at the time of M3/H3 deposition accounts for about half of Culebra deformation across this trend. Overlying units are also deformed, and it may be that as much as half of the deformation due to halokinesis is much later, perhaps relatively recent from a geological perspective. This latest movement most likely has the most effect on current surface topography. This aspect has not been directly examined in detail."

The Panel acknowledges the plausibility of structural controls on the distribution of Rustler mudstone-halite facies transitions and on the present-day topography. However, the RCHCM would benefit from further study of how these structures and possibly the modern deformation of salt in the underlying Salado and Castile Formations may have controlled the thickness and facies transitions of the Rustler Formation M/H units as well as the present day geomorphology of Nash Draw and other areas northeast and east of WIPP.

Several geoscientists, most recently Hill (2006), have hypothesized that the hydrology of the Culebra Dolomite may be impacted by "intrastratal karst" at the WIPP Site. This hypothesis is based on the idea that surface infiltration of meteoric waters will feed karst aquifers that form as lateral migration of dilute waters dissolves evaporites. Such development of karst aquifers could produce vastly greater groundwater flow in the units above the WIPP repository (Hill, 2006). The evidence given by Hill (2006) for such karst aquifers includes insoluble residues and collapse breccias in the Rustler Formation, lack of surface runoff at the WIPP Site, and Well WIPP-33 sinkholes and caves. Powers (2006, Analysis Report for Task 1B of AP-114) found significant evidence for karst development and recharge in Nash Draw, west of the WIPP Site, but not at the WIPP Site proper. In Nash Draw, Powers (2006) documented sinkholes in the gypsum of the A-3 and A-5 Anhydrites. There, a flooding event in 2004 strongly suggests recent recharge to the Culebra Dolomite through active sinkholes in Rustler gypsum units.

Lorenz (2006) and Powers (Culebra Conceptual Peer Review Meeting, August 11, 2008) convincingly argued that no unequivocal karst features exist at the WIPP Site. Some of the points made by Lorenz (2006) and summarized by Powers are:

- "There have been no observed cavernous porosity or tool drops in the Culebra at WIPP or in wells more than a few hundred meters east of the upper Salado dissolution line."
- "Cores, logs, and shafts do not show cavernous porosity that has been filled."
- "Hydraulic testing of WIPP holes away from Nash Draw shows no evidence of intersecting such cavernous porosity."
- "There are no open fractures in the lower part of the Rustler in WIPP shafts to carry water."
- "Broad gravity anomalies at the surface are not a response to small open conduits or caves at depths of hundreds of feet."
- "WIPP-33 encountered cavernous porosity in the Magenta and higher units; this location has a surface depression, and it also has a shallow gravity anomaly. It is 0.5 mi. west of WIPP, near Nash Draw."
- "WIPP-14 encountered neither cavernous porosity nor mud-filled porosity in the Rustler. Cuttings reported as "mud, mud, mud" below Culebra are through an interval with normal lithology, including anhydrite, based on geophysical logs."

These and other arguments made by Lorenz (2006) and Powers (2008) have convinced the Panel that significant karst features are not present at the WIPP site.

5.2 Recharge and Vertical Leakage

The RCHCM incorporates vertical recharge (leakage) to the Culebra only in a limited area of Nash Draw where surface water has been inferred to have collected following storm events (Powers, 2006). Leakage to the Culebra from potash mining activities may also be taking place in the Salado dissolution zone of Nash Draw based on groundwater geochemistry data (Domski and Beauheim, 2008). No additional areas of the RCHCM incorporate vertical leakage to the Culebra. However, leakage from anthropogenic sources such as potash tailings areas, incompletely sealed potash exploration holes, and incompletely sealed oil and gas wells have been identified as possible sources of the long term increase in groundwater levels in the Culebra.

Water level observations in the Culebra show short term fluctuations that have been correlated with precipitation events. While these responses indicate continuity for the transmission of pressure transients, they do not necessarily signify significant hydraulic interconnection and leakage/recharge. Other short term fluctuation in Culebra water levels have been interpreted as resulting from oil well drilling activities although this has not been definitively confirmed from drilling records in all cases.

A numerical model of the complete groundwater basin developed by Corbet (2000) incorporates recharge at the ground surface and leakage to the Culebra throughout the model domain. This model is discussed in Section 4.4 above, together with the SNL response to Question 40 regarding the absence of vertical leakage in the T-fields model and its inclusion in the Corbet model.

5.3 Major Transmissivity Features

Major features, such as contiguous high or low T zones have been identified by well testing, incorporated into the RCHCM and developed in the T-fields calibration process. In particular, well-to-well testing has identified a high transmissivity linear feature extending south from within the WIPP area, with an area of low-T within the WIPP area at the northern limit of this feature.

One of the limitations of the stochastic model as it is implemented using geostatistical methods is its ability to capture the larger structure of the transmissivity field in areas of sparse well test coverage. In the regions of dense well test coverage, that is, over the WIPP site and to the immediate south of the site, the calibration points are sufficiently dense that there should be an accurate view of the transmissivity field. In other parts of the model region, the geostatistical model does not produce high-T channels or low-T regions with the same shape or form as seen in the regions with higher data density. If the data density were equal over the entire model region, features similar to those identified in the areas of dense data coverage might be expected to be seen elsewhere.

As a practical matter, however, the details of hydraulic structure over most the model are unlikely to have significant impacts on the flow paths downgradient from the WIPP repository. The high density of coverage and the well-calibrated portions of the model are precisely in the regions that have the greatest significance. That said, one valuable use of the transmissivity field model would be to check the sensitivity of the fluxes and flow paths to undiscovered or undetected features, and assess the impacts of such features on the models of the performance assessment.

6. UNCERTAINTY OF RESULTS AND CONSEQUENCES IF WRONG

The output (results) of the RCHCM is a series of T-fields for use in MODFLOW simulations of groundwater flow, and subsequent use of the output from the

MODFLOW realizations in PA codes. Implicit in the approach is recognition that although the actual T-field cannot be determined, a suite of T-fields can be constructed that encompass the response of the Culebra to the proposed PA scenarios. By the nature of the approach, uncertainty is incorporated into the results. At issue, therefore, is whether all of the uncertainty has been included in the development of the T-fields.

Based on the geological data, there is high confidence in the location of the margins of the principal zones (Salado dissolution zone, central zone and halite bounded zone). The margin between the Salado dissolution zone and the central zone is the most critical, since if it were to extend farther east than currently mapped, the zone of high-T would extend closer to the WIPP area. The extension of the Salado dissolution zone into the WIPP area is considered unlikely, based on the drillhole data along the western LWB. Furthermore, since equipotentials run approximately east-west in this area, and transport pathways from the WIPP repository are approximately north-south, eastward extension of the Salado dissolution zone would have only a minor impact on transport pathways and travel times.

The range of transmissivity values used to develop the basic T-field and subsequent calibration are based on values measured in well tests. Single pad tests are used to define local transmissivity, and well-to-well tests are used to define connectivity. There is high confidence in the values assigned to the high-T Salado dissolution zone and to the low-T halite-bounded zone. There is evidence that the halite-bounded zone contains heads that approach lithostatic pressure, further confirming the low-T values. In addition, any reasonably conceivable increase in the transmissivity of the halite-bounded zone would not materially alter the heads in the central zone, since the transmissivity of the halite-bounded zone is much lower than the overall transmissivity of the central zone.

Uncertainty related to the T-field increases as data density for calibration decreases. As a result, uncertainty increases with distance from the LWB, which is the area of most intense investigations. However, since the PA is concerned only with transport to the LWB, this increase in uncertainty is not considered significant.

With the exception of modifications to the T-field due to potash mining, the RCHCM assumes that the T-field remains constant throughout the PA period. The Panel raised the question of the impact on transmissivity of subsidence over the repository. (Question 6. What evidence is there that the excavation induced strains that result from the mining of WIPP do not impact the predicted T fields?) The response noted that:

> *"Fracturing within units overlying the Salado caused by subsidence associated with repository closure (and attendant impact on transmissivity) has been eliminated from WIPP PA calculations on the basis of low consequence to the performance of the disposal system. ... The complete*

> *screening argument can be found in CRA-2004, Appendix PA, Attachment SCR, Section SCR-6.3.1.4 (DOE, 2004)."*

The response noted that assuming all the tensile strain was accommodated by fracture aperture changes the hydraulic conductivity would increase by about an order of magnitude. It was further noted in the response that:

> *"A change in hydraulic conductivity of one order of magnitude is well within the range of uncertainty already incorporated in the Culebra transmissivity field through the multiple realizations included in WIPP PA calculations."*

As noted above in Section 4.3, the T-fields model calibration excludes vertical leakage to the Culebra, except for a limited area of Nash Draw. In the response to Question 40, SNL notes that *"... for calibrations thus far performed, PEST output does not indicate that the T-field calibration process is very sensitive to the recharge rate."* However, the Panel notes that some vertical leakage may need to be included in the model to harmonize groundwater geochemistry data with the flow model.

The overall flow field in the Culebra is broadly controlled by the Salado dissolution zone, since this has the highest transmissivity and is continuous from north to south through the model domain. The central zone can be conceptually simplified and considered as bounded on the west by a constant head boundary, the dissolution zone, and on the east by a no-flow boundary, the halite-bounded zone. The variability of transmissivity is highest in the central zone, which includes areas of both low-T and high-T. However, the head distribution within the central zone will be relatively insensitive to variability in the T-fields, since it will be primarily controlled by the heads in the Salado dissolution zone.

If the T-field realizations for the central zone were uniformly too low compared with actual conditions, the travel times would be proportionally too low, for the same gradient and transport parameters. An error by orders of magnitude in the T-fields would be necessary to significantly affect the Culebra contribution to the overall radionuclide release. The Panel sees no basis for such an error. In summary, the Panel considers the uncertainty in the results to be acceptable, particularly in view of the small contribution from the Culebra to the overall radionuclide release.

As stated in section 4.4 (Groundwater Chemistry) the chemical data from wells in the WIPP Site can not be completely reconciled with the RCHCM because the sources of the principal solutes (Ca, Na, SO_4 and Cl), whether from dissolution of evaporite minerals (gypsum, anhydrite, halite) within, above or below the Culebra, are not completely understood. In addition, the sources of Mg and K present in Culebra waters are not well understood, whether trapped evaporated seawater brines from units above, below or lateral to the Culebra Dolomite or dissolution of minerals in the Rustler Formation such as polyhalite. Finally, physical mixing of different groundwater with different sources of ions is hypothesized by Domski and Beauheim (2008).

In view of these unresolved issues, the Panel submitted Question 16b "Does the water chemistry indicate that the source of solutes is from within the Culebra or from above the Culebra?" SNL responded as follows:

> *"The chemistry reflects waters that have dissolved calcium sulfate, dolomite, and halite- all phases which can be found in the Culebra as well as in the overlying units. However, the chemistry cannot identify which specific unit, Culebra or overlying, is the source of the solutes or to what degree the solutes are from either location. Less evolved waters, like those of Facies B and B/C or sulfatic weathering salt norm type waters, have a higher probability to have reacted relatively recently with units overlying the Culebra. More highly evolved waters have probably reacted more with the Culebra than the less evolved waters"*

The work of Domski and Beauheim (2008) is a good start at the understanding of the groundwater geochemistry. However, the basis for the mixing in terms of consistency with the flow model has not been demonstrated. Without this, there remains some uncertainty in the RCHCM, although the consequences in terms of the T-fields are unlikely to be significant for the PA.

7. APPROPRIATENESS AND LIMITATIONS OF METHODOLOGY AND PROCEDURES

The overall methodology is based on the understanding and correlation of geological observations and transmissivity data. The previous peer review of the Culebra hydrogeologic conceptual model presented criticisms that the transmissivity fields were not geologically based. The subsequent work on the Culebra hydrogeology subject to this peer review has provided a geologic basis using (1) a depth-transmissivity relationship and (2) a rationale for the distribution of fracture and vug filling based on the presence of overlying and underlying salts beds.

The depth-transmissivity relationship is hypothesized to be related to in situ stress; however, no quantitative geomechanical basis for this relationship has been presented. Furthermore, this relationship of transmissivity to depth is most appropriate in the eastern and western portions of the study region rather than the central portion, which is the most important for the model.
To date, other potential geomechanical drivers have not been considered for transmissivity controls. Contemporary methods for predicting fracture

transmissivity in petroleum reservoirs are making extensive use of geomechanical models that look at the concentration of curvature and deformation to predict the localization of fractures. Such methods may also be appropriate for the WIPP site, but have not been considered.

Although this peer review considers the geologic basis for transmissivity distribution to be incomplete, it is greatly improved compared to the CCA conceptual model. Uncertainties with geologic control are more than compensated by the improvements in the extensions of the hydrologic database. The additional testing of the Culebra and further analyses, particularly of hydraulic diffusivity from observational responses, have provided a firm database of direct transmissivity measurements that bolster confidence in the transmissivity fields in the portions of the model that are most important.

8. ADEQUACY OF APPLICATION

The Panel has identified three weaknesses in the RCHCM:

- Consistency between the T-fields model flow patterns and the geochemistry has not yet been shown, and
- The existing basin-wide model and the T-fields model are not consistent in the method of handling vertical leakage to the Culebra.
- While the Panel accepts the correlations of depth and evaporite-mineral fracture filling to transmissivity as valid, the mechanical and geochemical processes that control these correlations are incompletely understood.

With the above reservations, the Panel nevertheless concludes that the RCHCM is adequate to develop T-fields for application in the site flow model.

9. ACCURACY OF CALCULATIONS

The Panel has not checked the extensive calculations and computer codes for accuracy. Two of the principal software packages used in the analyses, MODFLOW and PEST have been widely used elsewhere in groundwater modeling, and can be reasonably expected to be free of coding errors. The Panel understands that data presented in reports have all been developed following SNL QA procedures.

10. VALIDITY OF CONCLUSIONS

The Panel believes that the conclusions in the RCHCM from the integration of geology and hydrology are valid, and can be used to develop T-fields for incorporation in the PA. Two of the model weaknesses identified by the Panel, namely the incomplete integration of the groundwater chemistry with the flow fields, and the development of consistent basin-wide and T-fields models are currently being investigated by SNL. While the Panel accepts that depth, and the presence of halite and sulfate pore fillings materials have a correlation with transmissivity, the reasons for the depth correlations and the geologic/geochemical processes that control pore-filling remain unclear.

11. ADEQUACY OF REQUIREMENTS AND CRITERIA, IN ACCORDANCE WITH APPROVED TECHNICAL AND QUALITY ASSURANCE REQUIREMENTS AND THE APPLICABLE PEER REVIEW PLAN(S)

The Culebra Hydrogeology Conceptual Model Peer Review has been conducted using a rigorous, procedure-controlled process in accordance with NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories* (NRC, 1988). The DOE Carlsbad Field Office (CBFO) Management Procedure (MP) 10.5, Revision 7, *Peer Review* (DOE, 2007) was prepared specifically for conducting peer reviews in accordance with NUREG-1297. The procedure and the Peer Review Plan have been coordinated to ensure compliance with all applicable requirements. Adherence to CBFO MP 10.5, Rev. 7 requires the peer review to be a documented, critical review performed by qualified peers who are independent of the original work being reviewed. CBFO MP 10.5, Rev. 7 also requires that the peer review panel submits a formal written report of the peer review findings and conclusions.

The Panel received background and orientation documents pertinent to the conduct of the peer review to read prior to the commencement of the peer review. The Peer Review Manager discussed the contents of the documents and answered questions the Panel had pertinent to the conduct of the peer review process. All Panel members certified that they read and understood the contents of the background and orientation documents prior to commencing the peer review.

The Panel attended briefings by SNL staff and was presented technical handouts and materials to review. The Panel conducted daily caucuses, caucus notes were recorded, and questions were presented for formal response by SNL. The Peer Review Panel consistently referred to CBFO MP 10.5, Rev. 7 and the criteria in NUREG-1297 as a guide for their review.

The work associated with the Culebra Hydrogeology Peer Review was assigned a Quality Level (QL) 1 determination in that it involves:

- Measurements of geological, ground water, meteorological, and topographical characteristics [Title 40 code of federal regulations Part 194 (40 CFR 194)]
- Computations, computer codes, models and methods to demonstrate compliance with 40 CFR 194
- Procedures to support the applications for certification and recertification in accordance with 40 CFR 194

To ensure the QL1 requirements were met, the peer review process was conducted and documented in a controlled manner and in compliance with the DOE/CBFO-94-1012, *Quality Assurance Program Document* (Rev 9) sections 1.1.2.5 and 5.4, and CBFO MP 10.5, Revision 7. The CBFO QA Manager appointed a QA observer who attended the peer review meetings. The CBFO QA Manager scheduled a surveillance of the peer review process and records prior to completion of the review. The DOE CBFO surveillance S-08-17, *Culebra Hydrogeology Peer Review Process,* was conducted from August 11-14, 2008. The scope of the surveillance was presented during the preamble to the peer review meeting and included:

- Surveillance Scope
- Surveillance Basis
- Surveillance Conduct
- Surveillance Terms
- Daily Schedule
- Questions/Comments

The surveillance was performed in accordance with CBFO MP 10.2, Surveillances, Revision 4 and evaluated the adequacy, implementation, and effectiveness of the peer review process in compliance with the following:

- U.S. Nuclear Regulatory Commission – Generic Technical Position (NUREG-1297), "Peer Review for High-Level Nuclear Waste Repositories," February 1988
- CBFO-94-1012, Quality Assurance Program Document (QAPD), Revision 8
- CBFO Management Procedure (MP) 10.5, Peer Review, Revision 7

The surveillance addressed:

- Selection of Peer Review Panel Members
- Peer Review Panel Member Qualifications
- Peer Review Panel Member Orientation
- Peer Review Panel Independence
- Peer Review Plan and Procedures
- Services Acquisition Documents
- The peer review process, including:
  - – Peer Review Manager tasks
  - – Peer Review Panel tasks
  - – Interface Requirements
  - – Peer Review Daily Caucuses
  - – Peer Review Process Records

The surveillance resulted in no concerns during the peer review meetings. The surveillance will conclude with the review and evaluation of the final Peer Review Report and related records currently scheduled for September 29-30, 2008. The results will be documented in a surveillance report.

Records generated as a result of the peer review process were maintained in accordance with CBFO MP 10.5, Rev. 7. Upon completion of the peer review process, the QA records (original, where possible) have been formally transferred to the CBFO Peer Review Manager for retention.

12. DISSENTING VIEWS

There were no dissenting views expressed by members of the Panel.

13. REFERENCES

- 40 CFR Part 191, Environmental Radiation Protection Standards For Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.
- 40 CFR Part 194, Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations.
- NUREG-1297, Peer Review for High-Level Nuclear Waste Repositories.
- Carlsbad Field Office Quality Assurance Program Document (QAPD) (DOE/CBFO-94-1012) sections 1.1.2.5 and 5.4.
- Carlsbad Field Office Management Procedure (MP) 10.5, Rev. 7 Peer Review.
- 2008 Culebra Hydrogeology Conceptual Model Peer Review Plan.
- Chapter 6, Chapter 2, Sections 2.1 and 2.2, Appendix PA and Attachment TFIELDS to Appendix PA from Title 40 CFR Part 191 Compliance Recertification Application for the Waste Isolation Pilot Plant, DOE/WIPP 2004-3231, 10 vols., U.S. Department of Energy, Carlsbad Field Office, Carlsbad. 2004.
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August 11-14 Culebra Hydrogeology Conceptual Model Peer Review Presentations and supporting documentation:

- Conceptual Model Peer Review of Culebra Hydrology, Rick Beauheim, 8/11/08 and 8/27/08 versions
- Overview of WIPP Performance Assessment, Joseph Kanney, 8/11/08 and 8/27/08 versions
- Geological Background for the Culebra Conceptual Model, Dennis Powers

- Well Map, untitled
- Hydrologic Setting and Hydrological Investigations of the Culebra, Rick Beauheim
- Chemistry of the Culebra Waters, Paul Domski
- Geologically Based Approach for Predicting Culebra Transmissivity, Robert Holt
- Summary of Conceptual Model and Supporting Field Evidence, Rick Beauheim
- Moving from a Conceptual Model to a Numerical Model, Hart, McKenna, Holt
- Base T-Field Generation, Hart & Holt
- T-Field Calibration Process – Stochastic Inverse Modeling: Motivation and Conceptual Approach, McKenna & Hart, 8/13/08 and 8/27/08 versions
- T-Field Calibration Process Implementation and Details, Hart & McKenna, 8/13/008 and 8/27/08 versions
- Preliminary Calibration Process Results, Hart & McKenna, 8/13/08 and 8/27/08 versions
- WIPP Culebra T-Field and S-Field Inverse Calibration Report Field r940coord_init
- WIPP Culebra T-Field and S-Field Inverse Calibration Report Field r940coord_last
- WIPP Culebra T-Field and S-Field Inverse Calibration Report Field r981coord_init
- WIPP Culebra T-Field and S-Field Inverse Calibration Report Field r981coord_last
- Use of Culebra T-Fields in WIPP Performance Assessment, Joseph Kanney
- Summary of Culebra Hydrology Conceptual Model and Numerical Implementation, Rick Beauheim
- Image – Central WIPP Wells 84-08
- Image – H-6C&M-1984-2008
- Image - N WIPP Wells 84-08
- Image - S WIPP Wells 84-08
- Basic Data Report for Drill Hole SNL-14 8-6-08
- Image – Topo vs. Halite Margins
- Culebra Photo Montages SNL-8 and SNL-10, Dennis Powers
- Culebra Hydrochemical Data Excel Tables
- SNL Formal Responses to 2008 Culebra Hydrogeology Conceptual Model Peer Panel questions.
- SNL Factual Accuracy Review Responses to Draft Report dated 9/10/08