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SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

Analysis Plan for Evaluation and Recalibration of Culebra Transmissivity Fields

AP-114, Revision 1

Task Number 1.4.1.1

Effective Date: 02/14/08

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1. Introduction

This Analysis Plan directs the evaluation and recalibration of transmissivity (T) fields for the Culebra Dolomite Member of the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) site. Culebra T fields are used to model groundwater flow for performance assessment (PA) calculations for the WIPP. For the 2004 WIPP Compliance Recertification Application (CRA-2004; DOE, 2004), T fields were developed by McKenna and Hart (2003) using **MODFLOW-2000** v. 1.6 (**MF2K**; Harbaugh et al., 2000) and **PEST** v. 5.51 (Doherty, 2000; McKenna, 2003) that were calibrated to heads assumed to represent equilibrium-state conditions as well as to transient heads arising from hydraulic testing activities. Under this analysis plan, the sensitivity of those T fields to different boundary conditions and hydrogeologic conceptualizations will be evaluated, and new T fields will be calibrated incorporating data from wells that have been drilled and/or tested since the data cutoff date employed by McKenna and Hart (2003) (Figure 1).

The factors/features to be evaluated include: (1) the northern and eastern fixed-head boundary conditions used by McKenna and Hart (2003); (2) alternatives to the no-flow southwestern boundary condition, including the possibility of recharge to the Culebra in that area; (3) allowing hydraulic anisotropy and storativity (S) to vary spatially; and (4) using "soft" geologic data to alter the probabilities of relatively high T in certain areas. The first three of these factors will be evaluated either using the T fields developed for CRA-2004 (DOE, 2004) by Holt and Yarbrough (2003) and McKenna and Hart (2003), or as part of the development and calibration of new T fields. The fourth factor will require generation of new base T fields, and will be combined with the inclusion of new data to calibrate the new fields.

The modeling that remains to be completed will be performed using **MF2K** v. 1.6 and **PEST** v. 9.11 (Doherty, 2004).

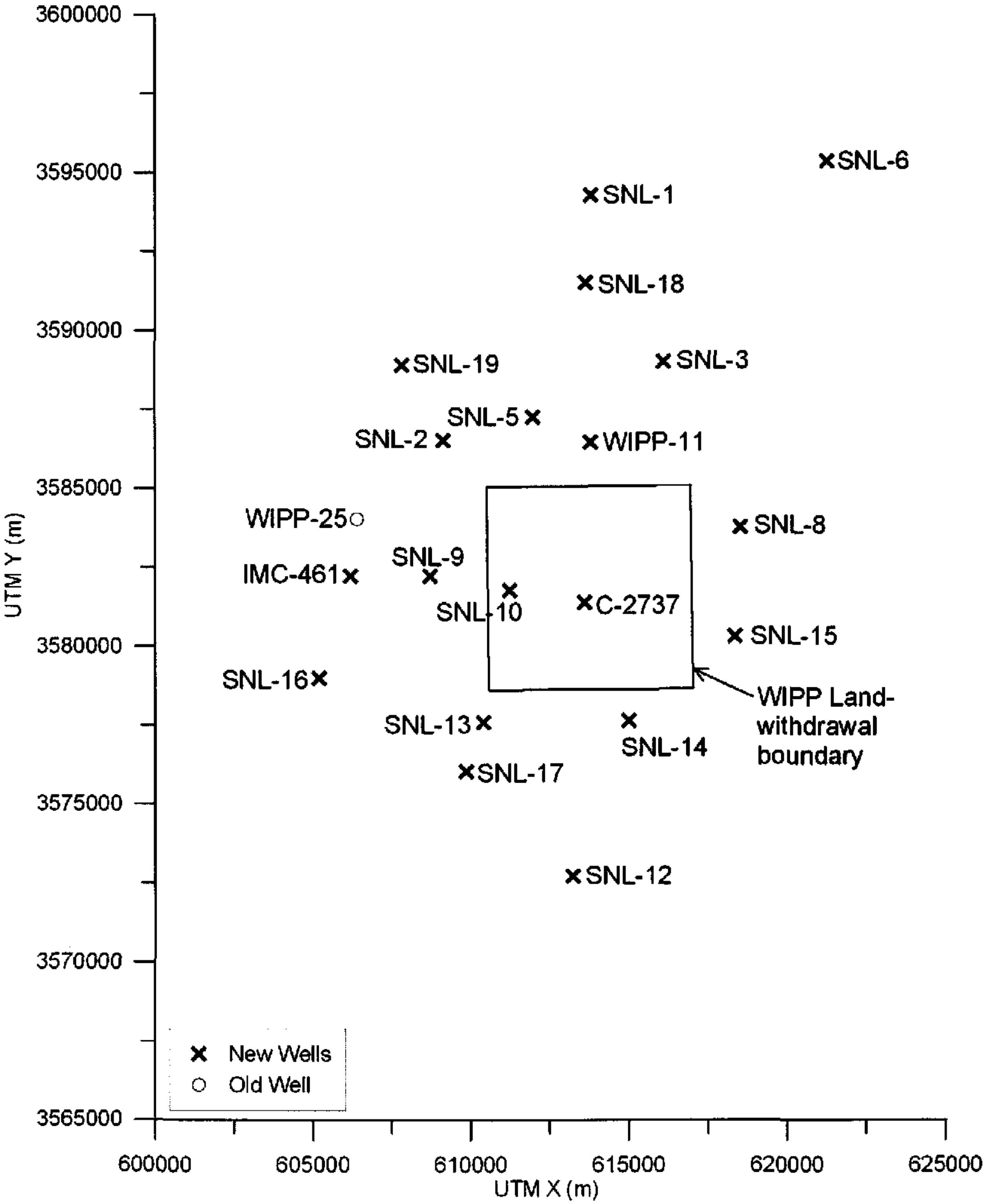

Figure 1. Locations of Culebra wells providing new information for modeling.

2. Motivation for Study

The CRA-2004 T fields were developed using a reasonable numerical implementation of the conceptual model of the Culebra. However, alternative ways of implementing features of the conceptual model, as well as slight variations on the conceptual model, are possible and should be examined to ascertain their potential effects on performance metrics such as the travel time from an intrusion borehole to the site boundary. The principal alternatives to be considered are discussed below.

2.1 Northern and Eastern Boundary Conditions

The T fields developed for the 2004 CRA used constant-head boundary conditions on the north, east, and south, and no-flow boundaries (representing flow down the axis of Nash Draw) on the west (Figure 2). Head values for the boundaries were estimated by fitting a Gaussian trend surface to heads measured in late 2000 (Beauheim, 2002a) and extrapolating that surface to the boundaries of the model domain (McKenna and Hart, 2003). The resulting heads along the northern and eastern model boundaries showed a slight gradient to the east, whereas the 3D basin-scale modeling results of Corbet and Knupp (1996) showed gradients to the west across the same region. As the primary flow direction in both the CRA-2004 T fields and the model of Corbet and Knupp (1996) is to the south, the east-west component of the gradient along the boundaries is probably not of great importance. Nevertheless, geologic and new hydrologic information will be reviewed to see if an alternative definition of the northern and eastern boundary conditions can be developed that will be more consistent with the modeling results of Corbet and Knupp (1996). The sensitivity of travel times from a hypothetical radionuclide release point above the center of the WIPP disposal panels to the WIPP site boundary with respect to the northern and eastern boundary conditions will be evaluated.

2.2 Southwestern Boundary Condition

The 3D modeling results of Corbet and Knupp (1996) as well as water-level measurements indicate that a groundwater divide is present in the Culebra southwest of the WIPP site. For the CRA-2004 T fields, this groundwater divide was represented by a flow line extending southeast from the pond at the south end of the IMC tailings pile west of the WIPP site in Nash Draw (Figures 2 and 3). An alternative conceptualization of this groundwater divide is a groundwater mound resulting from infiltration into the Culebra in areas where it is unconfined. Hence, evidence of potential infiltration points will be sought on air photos and on the ground and, if the hypothesis appears to be feasible, infiltration will be implemented in the Culebra model so that the sensitivity of travel time with respect to alternative conceptualizations of the southwestern boundary condition can be evaluated.

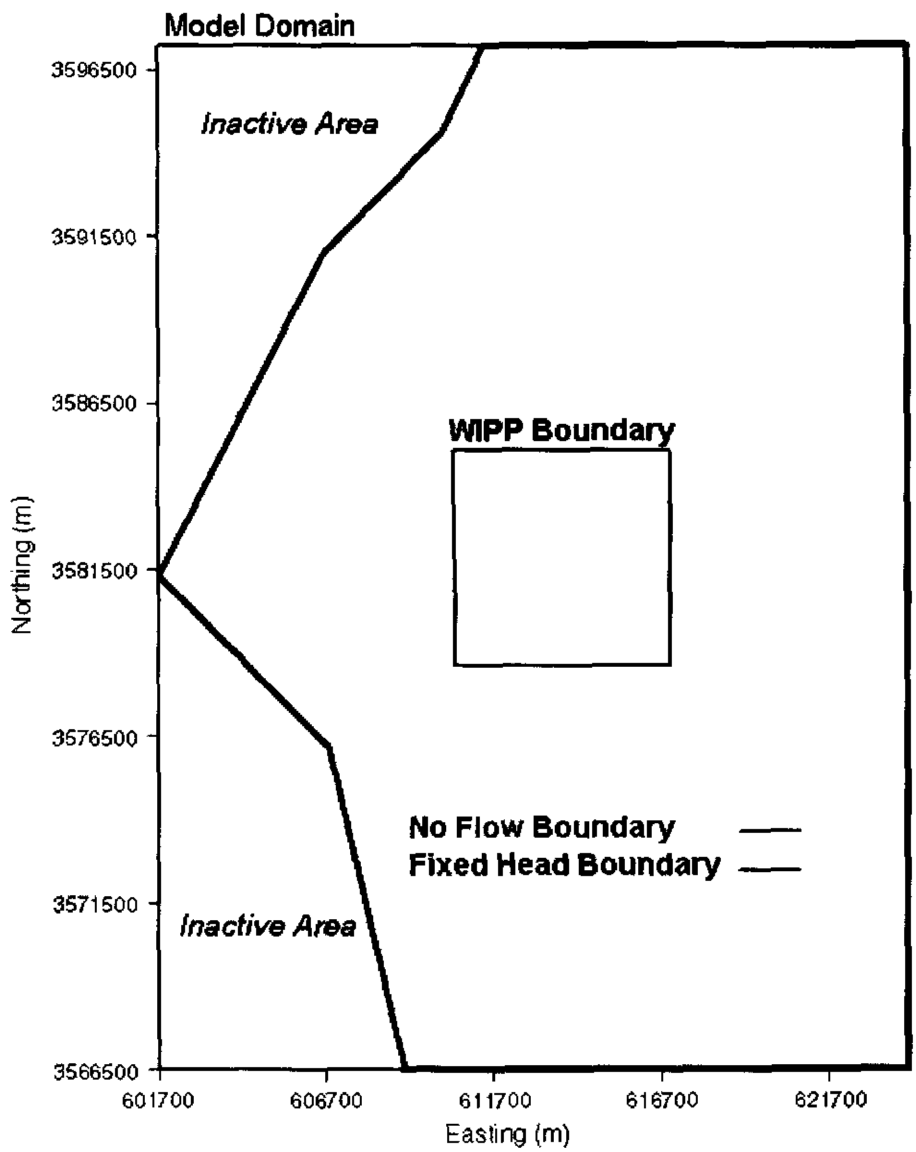

Figure 2. Culebra modeling domain and boundary conditions.

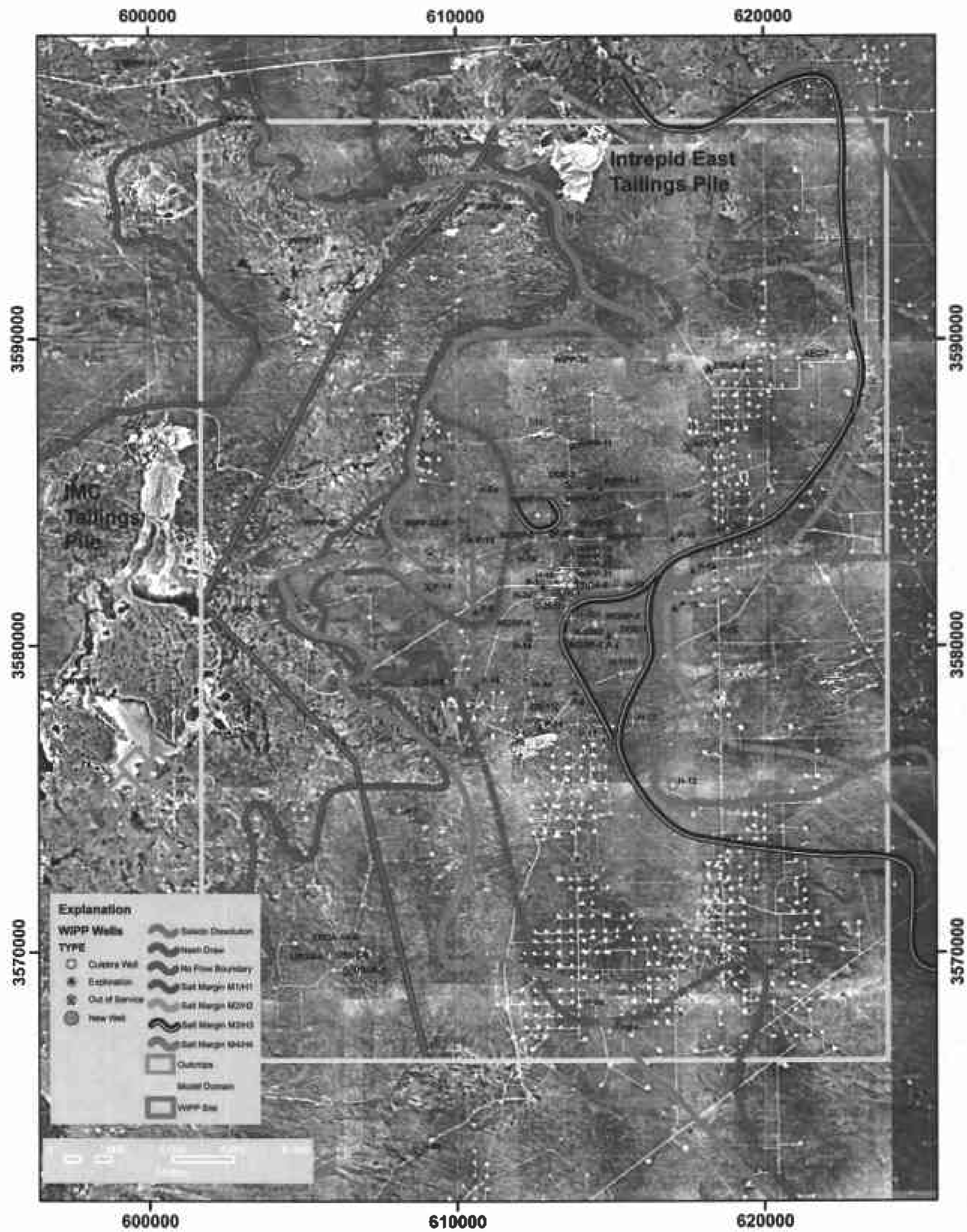

Figure 3. Air-photo map of WIPP area showing halite and dissolution margins and tailings piles.

2.3 Variable Hydraulic Anisotropy and Storativity

T-field modeling completed to date has treated the Culebra as hydraulically isotropic, primarily because of data and computational limitations, even though some hydraulic tests have provided evidence of anisotropy in transmissivity (Beauheim and Ruskauff, 1998). Similarly, storativity (S) of the Culebra has heretofore been fixed at a single average value, whereas it has been observed to vary over approximately four orders of magnitude (Beauheim and Ruskauff, 1998). Much of this variation is due to the Culebra being confined under the Livingston Ridge surface (which includes the WIPP site) but unconfined under parts of Nash Draw. However, to maintain computational tractability, the CRA-2004 T fields were calibrated assuming fully confined conditions everywhere using a single value of S throughout the model domain. Computer speeds and the efficiency of the calibration code (**PEST**) have now increased enough to allow calibration using variable anisotropy and S and, potentially, a mixture of confined and unconfined conditions. One approach might be to define two or three zones with each zone having different values of anisotropy and S. Alternatively, anisotropy and S could be allowed to vary in every cell in the model domain. Different possible ways of implementing variable anisotropy and S and their effects on the T fields and travel times will be investigated.

2.4 Conditioning on Soft Geologic Data

The base T fields used for the 2004 CRA included four zones defined by halite and dissolution margins. Within each of these zones, T values were assigned on the basis of the observed correlation between T and Culebra depth in that zone, with a stochastic component in the middle zone where both high and low T's are observed. Additional "soft" geologic data could be used to redefine the zones or alter the probability of high or low T at particular locations. For example, the high T's encountered at wells H-11, DOE-1, H-19, WQSP-4, and H-3 may be related to dissolution that has occurred along the M3/H3 margin. Therefore, other locations along the M3/H3 margin could be conditioned to have a higher probability of high T.

Paleovalleys represent other areas where Rustler properties, possibly including Culebra T, may have been altered in the past. Paleovalleys were cut into the uppermost sediments (Dewey Lake or Santa Rosa) during Miocene to Pleistocene time by streams, and filled with sediments of the Gatuña

Formation (Bachman, 1985). Concentration of water in these paleovalleys in the past may have led to alteration or dissolution of sulfate beds and cements in the lower Dewey Lake and Rustler, possibly including the Culebra. After defining the location and thickness of these valleys, we may be able to determine if Culebra T has been affected by their presence and, if so, condition the T fields in underlying areas.

2.5 Inclusion of New Data

The CRA-2004 T fields used all Culebra T data available as of September 2002, and were calibrated to steady-state heads measured in late 2000. T data are now available from tests completed recently at 19 additional new locations and one retested location: C-2737, IMC-461, SNL-1, SNL-2, SNL-3, SNL-5, SNL-6, SNL-8, SNL-9, SNL-10, SNL-12, SNL-13, SNL-14, SNL-15, SNL-16, SNL-17, SNL-18, SNL-19, WIPP-11, and WIPP-25 (retested) (Figure 1). T's from all of these tests will be used to refine the correlation between T and depth to the Culebra developed by Holt and Yarbrough (2002) that forms the basis for the assignment of T values in base T fields.

Long-term (19 to 32 days) pumping tests involving numerous observations wells were performed at SNL-9, SNL-14, and WIPP-11 in 2004 and 2005 to provide transient-response data that can be used in T-field calibration. Head data from 2007, which will include heads from numerous locations new since late 2000, will be used for the "steady-state" component of the new T-field calibration.

3. Information Sources

The modeling described in the previous section will require different types of data from various sources. The types of data required and the sources for each are discussed below.

3.1 Water Levels and Pressures

Observed water levels and pressures in Culebra wells provide the basic data against which Culebra T fields are calibrated. Water levels are measured monthly in all wells by Washington Regulatory and Environmental Services (WRES). Sandia receives a monthly data transmittal letter from WRES (e.g., Siegel, 2004), and the data are also published annually in the WIPP Site Environmental Reports (e.g., WRES, 2003). Sandia also measures water levels in some wells under Test Plan (TP) 03-01 (Chace and Beauheim, 2006) and TP 06-01 (Hillesheim, 2007) and the data are recorded in Scientific Notebooks. Fluid pressures in the Culebra are monitored in selected observation wells under these two TPs as well.

3.2 Transmissivity

Hydraulic tests have been and are being conducted in new and recompleted wells under TP 03-01 (Chace, 2003; Chace and Beauheim, 2006). The data from these tests are being analyzed under AP-070 (Beauheim, 2004) to provide estimates of T, S (in the case of tests with observation wells), and flow dimension. Analyses completed to date are reported in Roberts (2006; 2007). All new T and S data will be added to the database used for modeling.

3.3 Geologic and Other Field Data

Geologic data are used to define halite margins in the Rustler, the limit of Salado dissolution, the presence and extent of paleovalleys, and potential areas of recharge to the Culebra. These data have a variety of sources. Geophysical logs for oil and gas wells drilled within the modeling domain are obtained from commercial sources. The presence and thickness of halite beds, the presence and thickness of paleovalleys, and the thickness of the interval from the Culebra to the Vaca Triste Sandstone within the Salado Formation (which is used as an indicator of Salado dissolution) can be inferred from these logs. Field surveys will be conducted in areas west and south of the WIPP site to identify possible areas of recharge to the Culebra. Air photos will be reviewed for possible evidence of paleovalleys and enclosed drainages that may indicate areas of infiltration. Information will also be sought from potash mining companies and regulatory agencies (Bureau of Land Management, New Mexico Office of the State Engineer) on current and historic water levels and fluid densities in potash tailings ponds within the Culebra modeling domain.

4. Analysis Tasks

4.1 Task 1—Field Data Assembly and Mapping

This task entails assembling and evaluating data for four specific purposes:

- Task 1A: Collect geophysical log data from additional boreholes within the Culebra modeling domain to improve the definition of Rustler halite margins and Salado dissolution margins (Powers, 2003), and provide revised maps of those margins.
- Task 1B: Review air photos and conduct field surveys of areas west and south of the WIPP site to identify possible areas of recharge to the Culebra.
- Task 1C: Review air photos, conduct field surveys, and review borehole data to delineate potential paleovalleys.
- Task 1D: Collect current and historic information on water levels and fluid density in potash tailings ponds within the Culebra modeling domain.

The analyst for Task 1 is Dennis Powers. Several analysis reports have been or will be prepared describing the data collected, presenting maps, and summarizing conclusions. Subtasks 1A, 1B, and 1D were completed under Revision 0 of this AP and are documented in Powers (2007; 2006a; 2006b). Subtask 1C may be deferred until after the completion of CRA-2009, or canceled altogether.

4.2 Task 2—Revision of Northern and Eastern Boundary Conditions

This task will involve redefining the location of the eastern boundary of the Culebra modeling domain and defining northern and eastern boundary conditions that are generally consistent with the modeling results of Corbet and Knupp (1996). McKenna and Hart (2003) developed a Gaussian trend surface fit to the late 2000 Culebra heads that included head data from well WIPP-29, even though that well is outside the model domain on the western side of Nash Draw. The head at WIPP-29 was over 6 m lower than at any other well, and caused significant curvature around a north-south axis in the Gaussian trend surface, inducing a west to east component to the gradient along the eastern portion of the northern model boundary. The modeling of Corbet and Knupp (1996), however, suggested an east to west component to the gradient in this vicinity, primarily because high heads were maintained in an area of very low Culebra T east of the WIPP site. Recent information from drilling and testing of new wells SNL-6 and SNL-15 supports the findings of Corbet and Knupp (1996), as halite is present in the Culebra at these locations and hydraulic heads are apparently higher than shown by the Gaussian trend surface fit of McKenna and Hart (2003).

The eastern model boundary will be shifted to the east to a location where halite is likely present in the Culebra along the entire boundary. High heads will be assigned along this boundary, and possibly throughout the region where the Culebra contains halite. Data from WIPP-29 will not be used in defining the initial head surface or boundary conditions for the model because that well is both outside the model domain and believed to be on the other side of a hydrologic divide from the portion of the Culebra within the modeling domain.

The analyst for Task 2 will be Kate Klise (6313). A description of how the new boundary conditions were developed, how they differ from the CRA-2004 boundary conditions, the simulation procedure, and analysis results will be included in the analysis report prepared for Task 7.

4.3 Task 3—Evaluation of Alternatives to Southwestern No-Flow Boundary Condition

This task was completed under Revision 0 of this AP. It used the results of Tasks 1B and 1D to define two alternative locations and properties of the southwestern model boundary. Fifteen CRA T fields (including the T fields with the 5th, 50th, and 95th ranking travel times) were recalibrated using the new boundary conditions. Travel times from a point above the center of the waste panels to the WIPP site boundary were determined using **DTRKMF** v. 1.0 and compared to the CRA results to determine what influence the boundary conditions have on the calculated travel times.

The analyst for Task 3 was Kate Klise, and the results are documented in Klise and Beauheim (2005). **PEST** v. 5.51 and **MF2K** v. 1.6 were used for this task to maintain consistency with the CRA T field calibration procedure.

4.4 Task 4—Evaluation of Effects of Storativity and Anisotropy Variations

This task will evaluate the effects of allowing storativity and hydraulic anisotropy to vary spatially during T field calibration on the goodness of fit of the calibration. T fields will be calibrated allowing S and anisotropy to vary within zones and/or on a cell-by-cell basis. Zones may be defined based on our geologic understanding of where the Culebra might be confined and unconfined, on the basis of pumping-test interpretations, and/or on the basis of additional information. Use of the cell by cell approach will assume that the variogram measured for T also applies to S and anisotropy. The sum of squared errors (SSE) of these T fields will be compared to the SSE of the same fields calibrated without varying S and anisotropy to see if allowing the variation improves the calibration; this comparison will most likely be done on a subset of all calibrated fields. The spatial distributions of S and anisotropy obtained from the calibrations will be examined to see if they are conceptually consistent with geologic and hydraulic-response information.

The analyst for Task 4 will be David Hart (6313). **PEST** v. 9.11 and **MF2K** v. 1.6 will be used for this task. The basis for the storativity and/or anisotropy zonation, the calibration procedure, and results will be described in the analysis report written for Task 7. This task should be completed by May 1, 2008.

4.5 Task 5—Generation of Revised Base T Fields

This task will use the output from Tasks 1A and 1C combined with recent T information (Roberts, 2006; 2007) to revise the correlation between T and depth of Culebra developed by Holt and Yarbrough (2002) and develop at least 100 new base T fields. The procedure to be used will be largely the same as that used in completing Task 2 of AP-088 (Holt and Yarbrough, 2002; 2003), although a different method may be developed to assign initial T values in the region where both low T and high T are possible.

The analysts for Task 5 will be Robert Holt (University of Mississippi) and David Hart (6313). An analysis report will be prepared describing the analysis procedure and results. This task should be completed by March 1, 2008.

4.6 Task 6—Calculation of Freshwater Heads and Compilation of Transient Heads to be Used in T-Field Calibration

To calculate freshwater heads, three things must be known:

- The elevation of the midpoint of the Culebra at a well,
- The height of the column of water in the well above the midpoint of the Culebra, and
- The density of the water in the well above the midpoint of the Culebra

The elevation of the midpoint of the Culebra is obtained by subtracting the depth to the Culebra from the surveyed ground-surface elevation at each well. The most recent well elevation survey data available will be used along with information on the depth of the Culebra at each well obtained from basic data reports, geophysical logs, and other sources to calculate the elevation of the midpoint of the Culebra. The height of the water column in each well will be obtained from water-level measurements made in all of the Culebra wells by WRES and/or SNL in 2007. The density of the water in each well will be obtained from specific-gravity measurements made on water samples from the wells or from simultaneous pressure and water-level measurements made in the wells (pressure-density surveys). The transient head data compiled by Beauheim (2003) have been supplemented by Toll and Johnson (2006a;b) with data from the long-term pumping tests conducted at WIPP-11 and SNL-14 in 2005.

The analyst for the remaining portions of Task 6 will be Patricia Johnson (6712). Several analysis reports will be prepared describing the calculation procedures and results. This task should be completed by February 15, 2008.

4.7 Task 7—Calibration of Revised T Fields

This task will use the new base T fields generated in Task 5 and the heads provided in Task 6 to calibrate revised T fields. Boundary conditions for the new T fields will be defined by the results of Task 2 and additional fitting of a trend surface to the "steady-state" head data from Task 6 as necessary and may also use the information developed under Task 1B for Task 3. If the results of Task 4 show variable storativity and anisotropy to be important, storativity and anisotropy may be included as calibration parameters. The well-to-well diffusivity information obtained from hydraulic-test interpretations may also be used in some way as soft information to constrain the calibration process. A minimum of 100 T fields will be calibrated.

PEST v. 9.11 will be used with **MF2K** v. 1.6 for this task to allow pilot points to be divided into different categories, with regularization occurring only within categories, and to allow for more efficient calibration using the new SVD-assist feature. After each T field has completed calibration, the travel time from a point above the center of the waste panels to the WIPP site boundary will be determined using **DTRKMF** v. 1.0. A cumulative distribution function (CDF) of travel times will be constructed for all of the newly calibrated T fields and compared to the CDFs of travel times from the 2004 CRA and CCA.

After the T fields have been calibrated and a CDF of travel time defined, a sensitivity analysis of the effects of the boundary conditions on the travel times will be conducted. This will be performed by perturbing some or all of the boundary conditions and recalibrating a subset of the T fields. Travel times will be calculated for the recalibrated T fields, and a CDF of the travel times will be compared to the CDF of travel times for the same T fields as they were originally calibrated.

The analysts for Task 7 will be David Hart, Sean McKenna, and Kate Klise (6313). An analysis report will be prepared describing the analysis procedure and results. This task should be completed by May 1, 2008.

5. Software List

The following computer codes may be used for different tasks associated with Culebra T fields:

- ESRI ArcInfo 8.1 (off-the-shelf software);
- GSLIB v. 2.0 (acquired; kt3d and sgsim routines qualified under NP 19-1; other routines will be qualified under NP 9-1 as needed);
- Mathcad 11 (off-the-shelf software);
- MF2K (MODFLOW-2000) v. 1.6 (qualified under NP 19-1);
- GMS v. 5.0 (off-the-shelf software);
- PEST v. 5.51 (qualified under NP 19-1);
- PEST v. 9.11 (to be qualified under NP 19-1);
- KaleidaGraph v. 3.52 (off-the-shelf software);
- MVS v. 6 (off-the-shelf software);
- Surfer v. 8 (off-the-shelf software);
- Matlab R12.0.1 (off-the-shelf software);
- DTRKMF v. 1.0 (qualified under NP 19-1); and
- VarioWin v. 2.21 (off-the-shelf software).

Whenever computer platforms (hardware and/or operating systems) change, kt3d, sgsim, MF2K, PEST, and DTRKMF will be regression tested per SP 19-1 prior to use on the new platform.

Off-the-shelf spreadsheet programs, such as Excel, and graphing programs, such as Grapher or SigmaPlot, may also be used for data manipulation and plotting. Any pre- or post-processors needed for data manipulation and transfer between codes will also be qualified as part of the analysis package.

6. Special Considerations

No special considerations have been identified.

7. Applicable Procedures

All applicable WIPP quality-assurance procedures will be followed for these analyses. Training of personnel will be done in accordance with the requirements of NP 2-1 *Qualification and Training*. Analyses will be performed and documented in accordance with the requirements of NP 9-1 *Analyses* and NP 20-2 *Scientific Notebooks*. All software used will meet the requirements of NP 19-1 *Software Requirements* and NP 9-1 as applicable. The analyses will be reviewed following NP 6-1 *Document Review Process*. All required records will be submitted to the WIPP Records Center in accordance with NP 17-1 *Records*.

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