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SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

Analysis Plan for Evaluation and Recalibration of Culebra Transmissivity Fields

AP-114

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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 WIPP Compliance Recertification Application (CRA; 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 northeastern 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 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 using the base T fields developed for the WIPP CRA (DOE, 2004) by Holt and Yarbrough (2003) and possibly the ensemble average of the 100 calibrated T fields produced by McKenna and Hart (2003). 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 will be performed using **MF2K** v. 1.6 and **PEST** v. 5.51 and 9.X (Doherty, 2004).

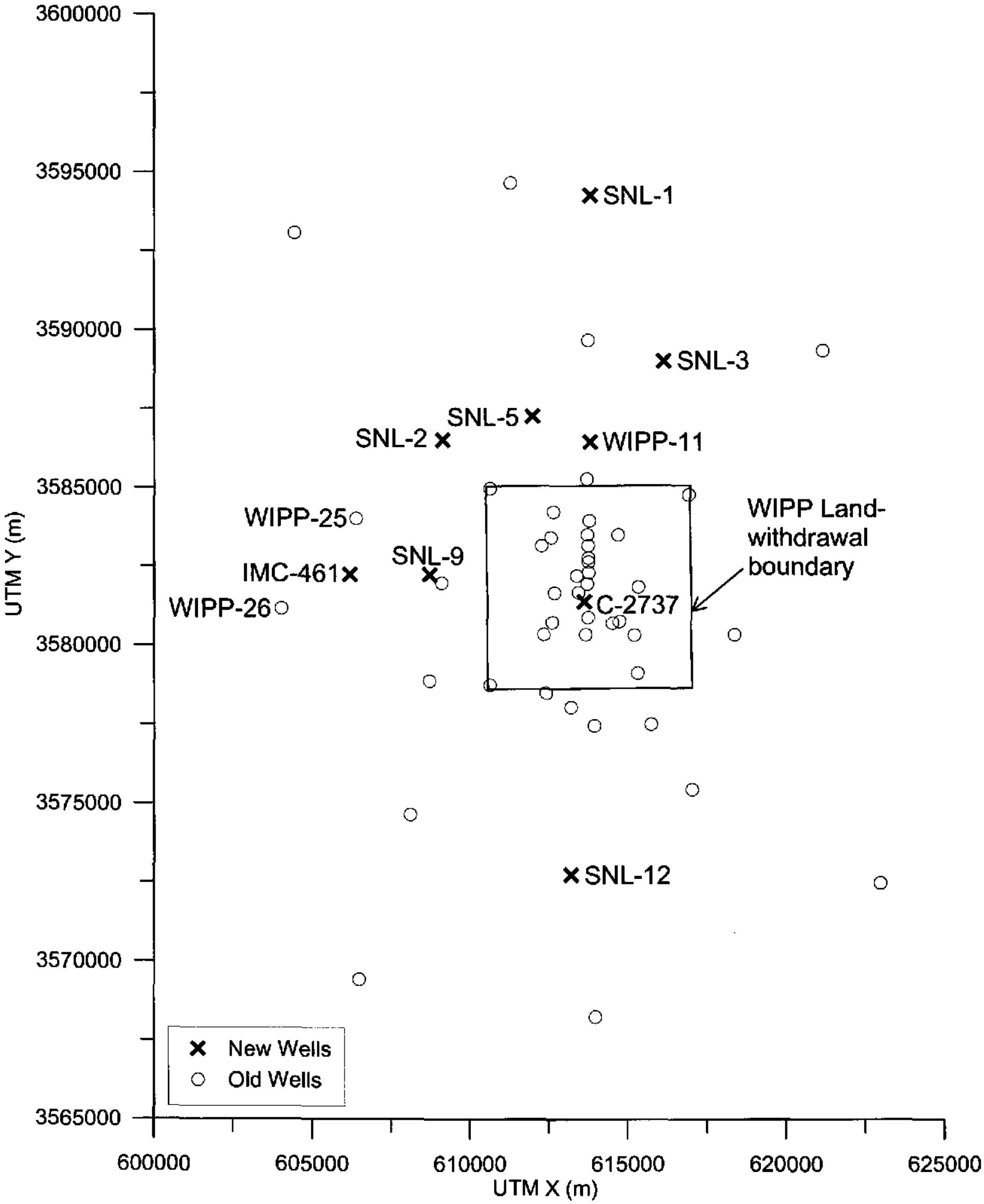

Figure 1. Locations of Culebra wells providing new information for modeling.

2. Motivation for Study

The CRA 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 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 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, 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 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 (Figure 3). An alternative conceptualization of this groundwater divide is a groundwater mound resulting from

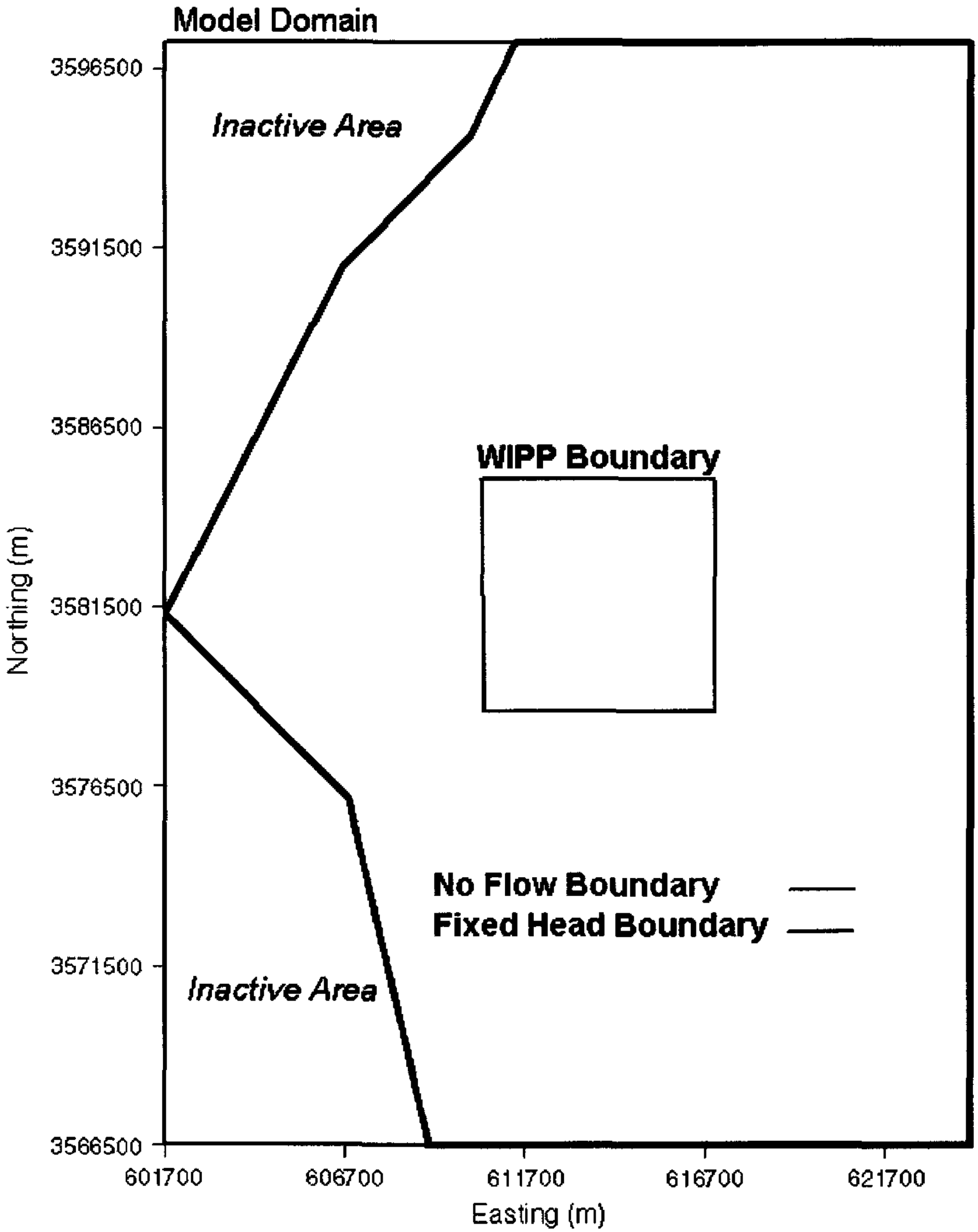

Figure 2. Culebra modeling domain and boundary conditions.

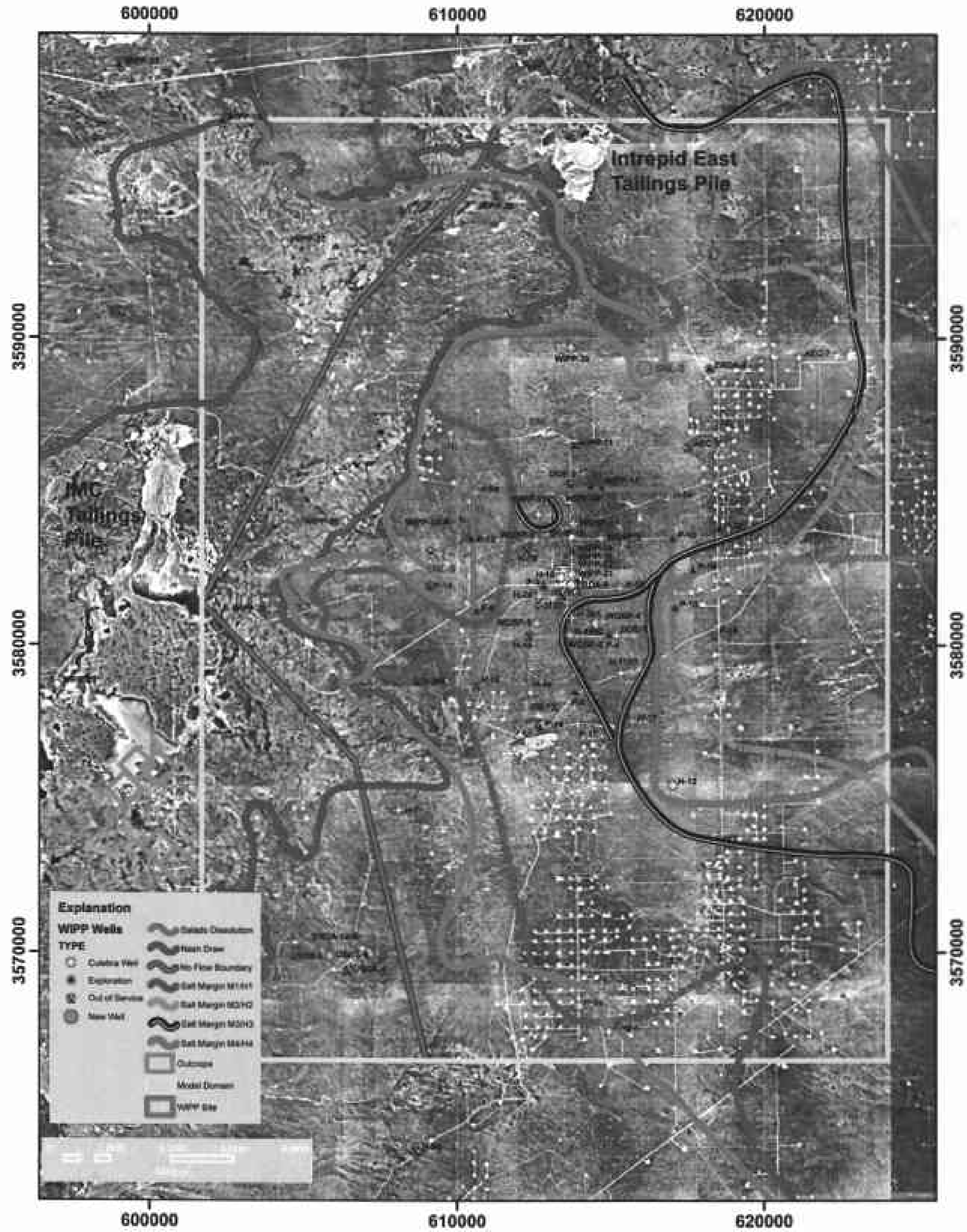

Figure 3. Air-photo map of WIPP area showing halite and dissolution margins and tailings piles.

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.

2.3 Variable Storativity

The storativity (S) of the Culebra varies 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 or all of Nash Draw. However, to maintain computational tractability, the CRA 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 at least a limited degree of calibration using variable S and a mixture of confined and unconfined conditions. One approach might be to define two or three zones with each zone having a different value of S. Alternatively, S could be allowed to vary in every cell in the model domain. Different possible ways of implementing variable 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 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 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 (or soon will be) available from tests completed recently at eight additional locations: C-2737, IMC-461, SNL-1, SNL-2, SNL-3, SNL-5, SNL-9, and SNL-12 (Figure 1). Additional tests are planned at WIPP-11, WIPP-25, and WIPP-26 in the next few months. 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.

Thirty-day pumping tests involving numerous observations wells are planned at SNL-9 and WIPP-11 that should be completed in time to provide transient-response data that can be used in T-field calibration. Head data from late 2004 or early 2005, which will include heads from 9 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, 2003) and the data are recorded in Scientific Notebooks. Fluid pressures in the Culebra are monitored in selected observation wells during pumping tests conducted under TP 03-01 (Chace, 2003).

3.2 Transmissivity

Hydraulic tests have been and are being conducted in new and recompleted wells under TP 03-01 (Chace, 2003). The data from these tests are being analyzed under AP-070 (Beauheim, 2000) to provide estimates of T, S (in the case of tests with observation wells), and flow dimension. 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 will be Dennis Powers. One or more analysis reports will be prepared describing the data collected, presenting maps, and summarizing conclusions. This task should be completed by January 2, 2005.

4.2 Task 2—Sensitivity Analysis of Northern and Eastern Boundary Conditions

This task will involve redefining the Gaussian trend surface fit to the late 2000 Culebra heads by McKenna and Hart (2003), and using that redefined surface to define new fixed-head boundary conditions for the Culebra modeling domain. McKenna and Hart (2003) included head data from well WIPP-29 in their data set, 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. A new Gaussian trend surface will be defined by removing WIPP-29 from the data set. If supported by the data, a Gaussian function will be used that provides a trend surface with an east-to-west component to the gradient to be in qualitative agreement with the results of Corbet and Knupp (1996). The new trend surface will be used to define new boundary conditions for the groundwater flow model. CRA T fields d08r01, d12r07, and d10r09 (the T fields with the 5^{th}, 50^{th}, and 95^{th} ranking travel times, respectively) will be recalibrated using the new boundary conditions. Travel times from a point above the center of the waste panels to the WIPP site boundary will be 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(s) for Task 2 will be Sean McKenna and/or Tom Lowry (6115). **PEST** v. 5.51 and **MF2K** v. 1.6 will be used for this task to maintain consistency with the CRA T field calibration procedure. An analysis report will be prepared describing how the new boundary conditions were developed, how they differ from the CRA boundary conditions, the simulation procedure, and analysis results. This task should be completed by February 2, 2005.

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

This task will use the results of Tasks 1B and 1D to define one or more alternative locations and properties of the southwestern model boundary. CRA T fields d08r01, d12r07, and d10r09 (the T fields with the 5^{th}, 50^{th}, and 95^{th} ranking travel times, respectively) will be recalibrated using the new boundary conditions. Travel times from a point above the center of the waste panels to the WIPP site boundary will be 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(s) for Task 3 will be Tom Lowry (6115) and/or Sean McKenna (6115). **PEST** v. 5.51 and **MF2K** v. 1.6 will be used for this task to maintain consistency with the CRA T field calibration procedure. An analysis report will be prepared describing the justification for the boundary conditions evaluated, how the boundary conditions were implemented, the calibration procedure, and the analysis results. This task should be completed by March 1, 2005.

4.4 Task 4—Evaluation of Effects of Storativity Variations

This task will evaluate the effects of allowing storativity to vary spatially during T field calibration on travel times. CRA T fields d08r01, d12r07, and d10r09 (the T fields with the 5th, 50th, and 95th ranking travel times, respectively) will be recalibrated allowing S 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. Travel times from a point above the center of the waste panels to the WIPP site boundary will be determined using **DTRKMF** v. 1.0 and compared to the CRA results to determine what influence variable storativity has on the calculated travel times.

The analyst for Task 4 will be Tom Lowry (6115). **PEST** v. 9.X and **MF2K** v. 1.6 will be used for this task. An analysis report will be prepared describing the basis for the storativity zonation, the calibration procedure, and results. This task should be completed by April 1, 2005.

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 to revise the correlation between T and depth of Culebra developed by Holt and Yarbrough (2002) and develop 100 new base T fields. The procedure to be used will be the same as that used in completing Task 2 of AP-088 (Beauheim, 2002b).

The analyst for Task 5 will be Robert Holt. An analysis report will be prepared describing the analysis procedure and results. This task should be completed by March 1, 2005.

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

The calculation of freshwater heads will use water-level measurements made in all of the Culebra wells by WRES in late 2004 or early 2005 along with the results of recent pressure-density surveys and/or specific gravity measurements. The transient head data compiled by Beauheim (2003) will be supplemented with data from any 30-day pumping tests conducted in early FY05.

The analyst for Task 6 will be Richard Beauheim. An analysis report will be prepared describing the calculation procedure and results. This task should be completed by March 1, 2005.

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 fitting a Gaussian trend surface to the "steady-state" head data from Task 6 and may also use the information developed under Task 1B for Task 3. If the results of Task 4 show variable storativity to be important, storativity may be included as a calibration parameter. An evaluation may also be performed of the feasibility of attempting to match the well-to-well diffusivity obtained from hydraulic-test interpretations as part of the calibration process. For at least the first five T fields, no arbitrary limit will be placed on the number of optimization iterations that **PEST** can perform – optimization will continue until the value of the objective function does not improve over three successive iterations. The need for an iteration limit will be evaluated after five T fields have completed calibration. A minimum of 25 T fields will be calibrated.

PEST v. 9.X 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 CDF of travel times will be constructed for all of the newly calibrated T fields and compared to the CDF of travel times from the CRA.

The analyst for Task 7 will be Sean McKenna. An analysis report will be prepared describing the analysis procedure and results. This task should be completed by September 30, 2005.

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; routines qualified under NP 19-1);
- 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.X (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); and
- DTRKMF v. 1.0 (qualified under NP 19-1).

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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