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Analysis Report for Task 5 of AP-114: Generation of Revised Base Transmissivity Fields

(AP-114: Analysis Plan for Evaluation and Recalibration of Culebra Transmissivity Fields)

Task Number 1.4.1.1

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1 Introduction

This document records the activities done for Task 5 of AP-114 (Beauheim 2008), "Analysis Plan for the Evaluation and Recalibration of Culebra Transmissivity Fields." This task is generally the same as Task 2 of AP-088 (Beauheim 2002), and borrows heavily from the report for that task (Holt & Yarbrough 2002). In this task, the base transmissivity fields (T-fields) were generated. The base T-fields will be calibrated to head and drawdown data in Task 7. Because the calibration task requires that at least 100 T-fields be adequately calibrated, a greater number (in this case 1000) of base T-fields were produced during this task. This will allow preliminary screening of base T-fields to select which ones to calibrate, if desired, and for T-fields that don't calibrate as well as others to be discarded. Each field was required to be equally probable and have appropriate geostatistical variance from the other fields. The following subtasks were required to accomplish this task:

1. Linear Regression Analysis – find appropriate values for the regression equation developed during AP-088 Task 2 and verify that the model still applies with the addition of new transmissivity values.
2. Creation of "Soft Data" from Geological Map Data – take new data obtained during Tasks 1A and 1B of AP-114 (Powers, 2007; 2006), and use newest halite margins and other geological data to create appropriate input files for GSLIB codes.
3. Indicator Variography – analyze transmissivity data to define an appropriate variogram and variogram model.
4. Conditional Indicator Simulation – use the variogram model parameters and geological and soft data to create 1000 conditional realizations of spatial locations of high and low T in the central Culebra zone.
5. Construction of Transmissivity Fields – use regression coefficients and indicator fields to create base transmissivity fields representative of the Culebra for use in calibration.

The digital representations of all geologic boundaries (e.g., halite margins, gypsum lines) used in this report are presented in Johnson (2008).

The activities and results for each of these subtasks are described fully below. The following acquired and commercial-off-the-shelf (COTS) software was used:

- VARIOWIN version 2.21 – COTS software for variogram generation.
- SISIM version 2.0 – Sequential Indicator SIMulation program, part of GSLIB 2.0. Qualified under NP 9-1 (see Appendix D).
- ADDCOORDS version 2.0 – Add coordinates to output from SISIM. Part of GSLIB 2.0. Qualified under NP 9-1 (see Appendix D).
- MATLAB 7.5 – COTS software for data analysis.
- Mathcad – COTS software for data analysis.
- GNUPLOT 4.2 – COTS software for producing graphs/plots.
- Additional pre- and post-processing utilities were written and used for this analysis. All such utilities were qualified under NP 9-1, and are documented with source code in the relevant appendices.

2 Conceptual Model

The conceptual model for base field creation was originally explained in Holt &Yarbrough (2002), as Subtask 1 of Task 2 of AP-088. While the data used have been updated and improved, the model itself has changed very little. Therefore, much of this chapter is taken directly from the Analysis Report for Task 2 of AP-088. Any deviations from the original model due to updates in data or process are clearly called out.

A conceptual model of the geology of the Culebra dolomite located in the area of the WIPP site is shown in Figure 2-1. Geologic controls on Culebra transmissivity are identified and a linear mathematical model relating these controls to transmissivity is constructed. Holt & Powers (1988), Beauheim & Holt (1990), and Holt (1997) have described the geology and geologic history of the Culebra. The following conceptual model is developed from their work and is consistent with their interpretations. It is important to note that we follow Holt (1997) and assume that variability in Culebra transmissivity is due strictly to post-depositional processes. Throughout the following discussion, the informal stratigraphic subdivisions of Holt & Powers (1988) are used to identify geologic units within the Rustler Formation (Figure 2-2).

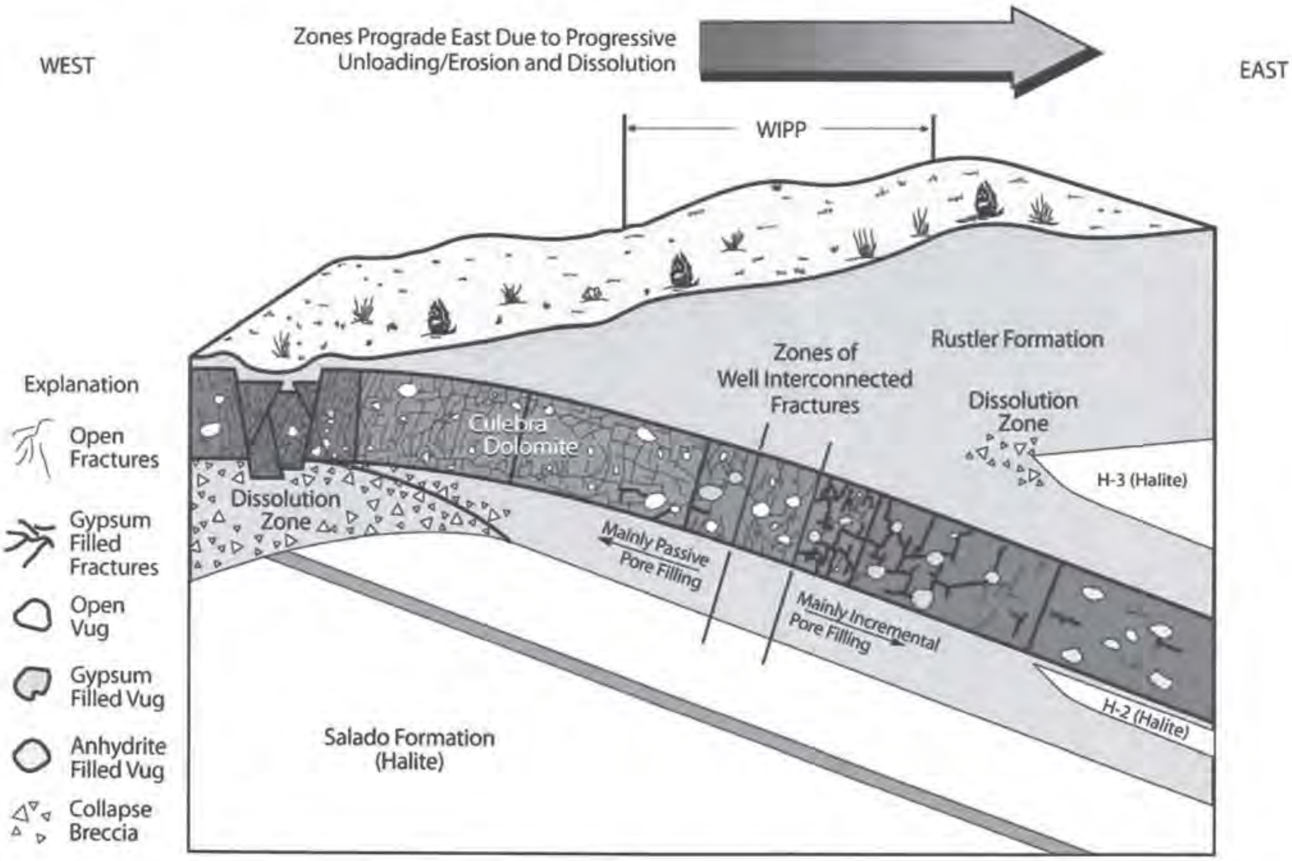

Figure 2-1: A conceptual view of the geology of the Culebra dolomite in the area of the WIPP site. T values decrease as depth increases to the east, and fractures increase over the Salado dissolution area. Halite appears above and below the Culebra dolomite along the eastern side of the model domain.

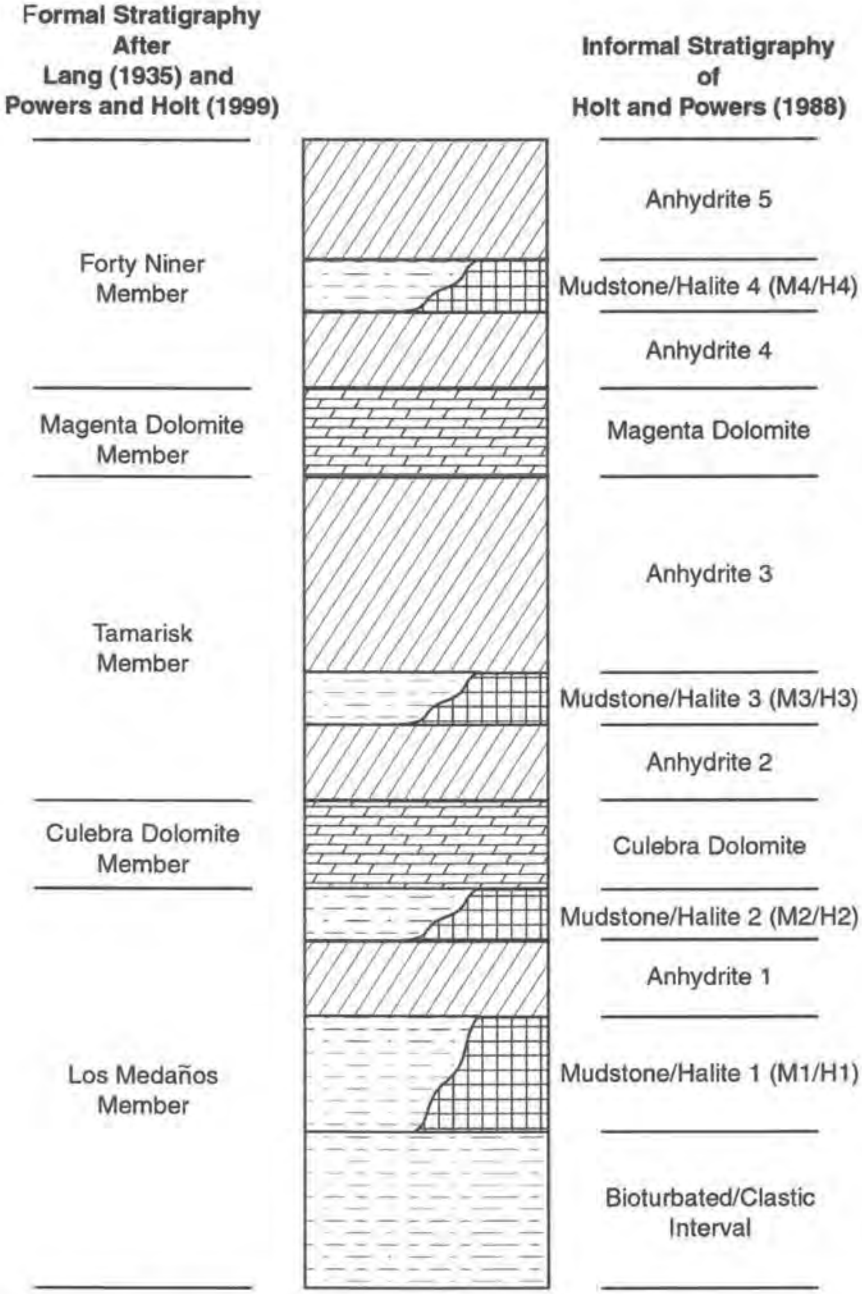

Figure 2-2: Stratigraphic subdivisions of the Rustler Formation.

We hypothesize that spatial distribution of Culebra transmissivity is a function of several geologic factors, including: 1) Culebra overburden thickness, 2) dissolution of the upper Salado Formation, and 3) the occurrence of halite in units above or below the Culebra. Each of these geologic controls can be determined at any location using geological map data. High T regions near the WIPP cannot be predicted using geologic data, as they represent areally persistent zones of well-interconnected fractures and fracture interconnection cannot be observed or inferred from core or geophysical log data. We therefore treat fracture interconnection as a stochastic process.

In the following, we define several indicator terms that identify the geologic zones that divide the model domain. The specifics of each hypothesized control are then outlined. Finally, a linear model relating these controls to Culebra transmissivity is presented.

2.1 Model Domain

The model domain has been expanded to the east relative to the domain used for the 2004 Compliance Recertification Application (CRA-2004; DOE (2004)) in order to reach an area where halite is present in all of the non-dolomite members of the Rustler Formation. This change was made in order to simplify the specification of the eastern boundary condition of the model. The new extent of the model domain is 601700 UTM NAD27 east to 630000 UTM NAD27 east and 3566500 UTM NAD27 north to 3597100 UTM NAD27 north. The domain is discretized into 100-m x 100-m cells, yielding a model that is 284 cells wide by 307 cells tall. The Culebra is modeled as a single layer that is of uniform 7.75-m thickness (DOE 1996). Figure 2-3 shows the model domain with the WIPP site boundary and the various wells.

2.2 Fracture Interconnection

The Culebra transmissivity data used in the modeling are the same as those used by Holt & Yarbrough (2002), supplemented by more recent data reported by Roberts (2006; 2007) and Bowman & Roberts (2008). The transmissivity data show a bimodal distribution (Figure 2-4). As closely spaced wells can show very different values, we hypothesize that higher transmissivity values reflect well-interconnected fractures at well locations. For example, wells WQSP-2 and WIPP-12 are only 454 m apart, but have T values differing by over two orders of magnitude. Lower transmissivities indicate regions where fracture interconnections are limited. Well-interconnected fractures occur in regions affected by Salado dissolution (e.g., Nash Draw) and in areas with complicated cement dissolution and precipitation histories (e.g., high-transmissivity zones near the WIPP site). The natural break between the measured $\log_{10} T$ (m^2/s) values at -5.4 described by Holt & Yarbrough (2002) can be seen in Figure 2-4. The fracture-interconnection indicator, I_f, is defined below:

$$I_f = \begin{cases} 1, \log_{10} T(m^2/s) \geq -5.4 \\ 0, \log_{10} T(m^2/s) < -5.4 \end{cases} \tag{2.1}$$

2.3 Overburden Thickness

We hypothesize an inverse relationship between Culebra overburden thickness and transmissivity. Overburden thickness is a metric for two different controls on Culebra transmissivity. First, fracture apertures are limited by overburden thickness (e.g., Currie & Nwachukwu 1974), which should lead to lower transmissivity where Culebra depths are greater (Beauheim & Holt 1990); (Holt 1997). Second, erosion of overburden leads to stress-relief fractures, and the amount of Culebra fracturing increases as the overburden thickness decreases (Holt 1997). The overburden thickness is shown in Figure 2-5. The depth to the Culebra is defined as $d(x,y)$ for all points in the domain.

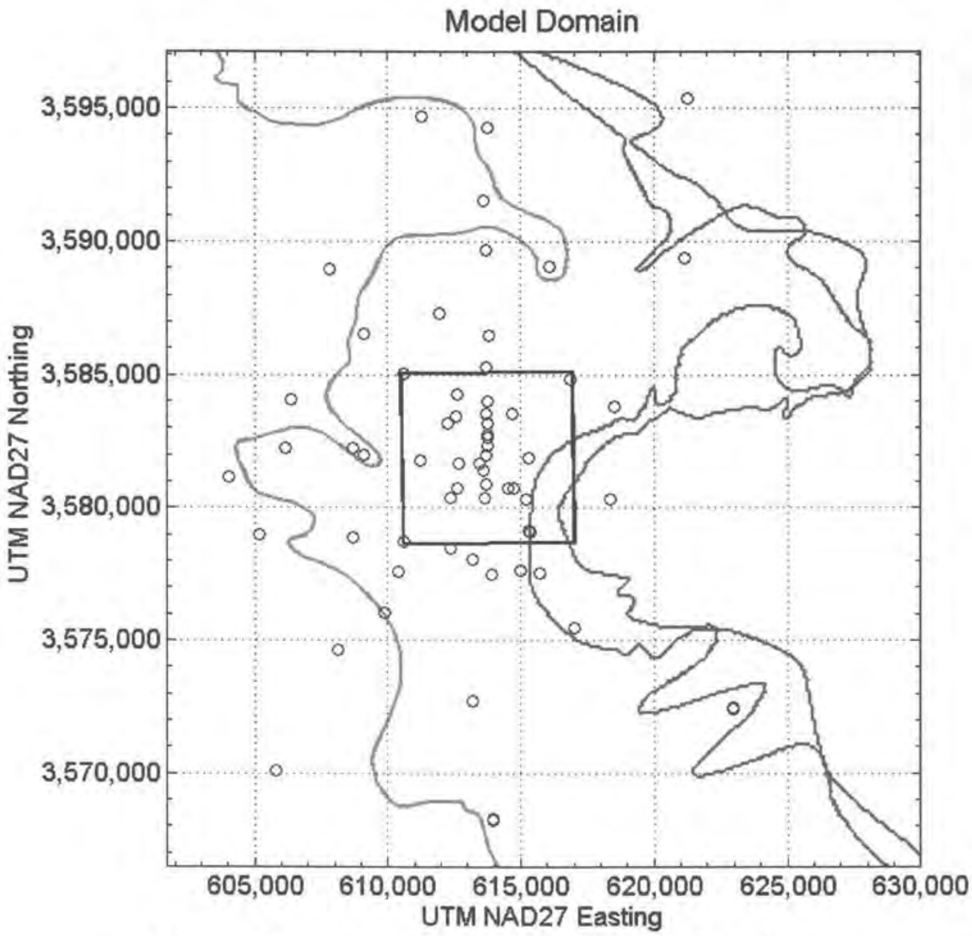

Figure 2-3: Modeling domain and well locations.

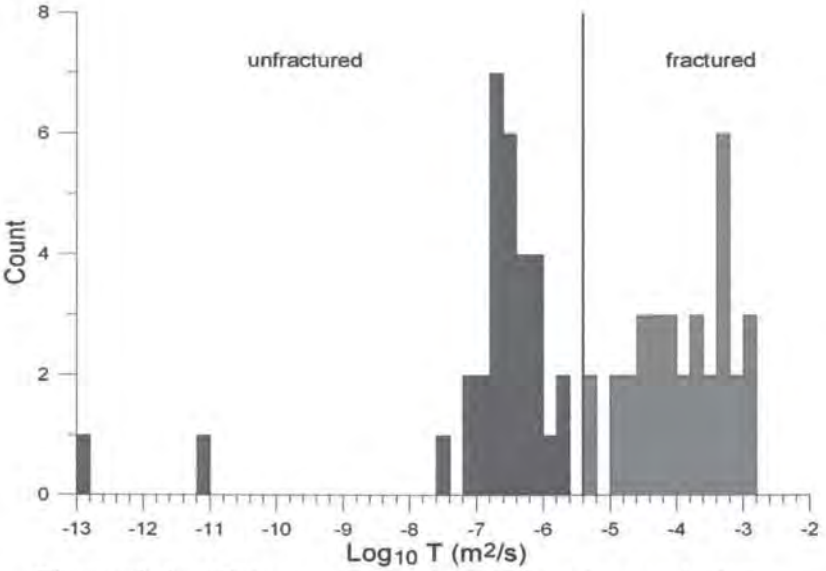

Figure 2-4: Histogram of $\log_{10}$ Culebra transmissivity.

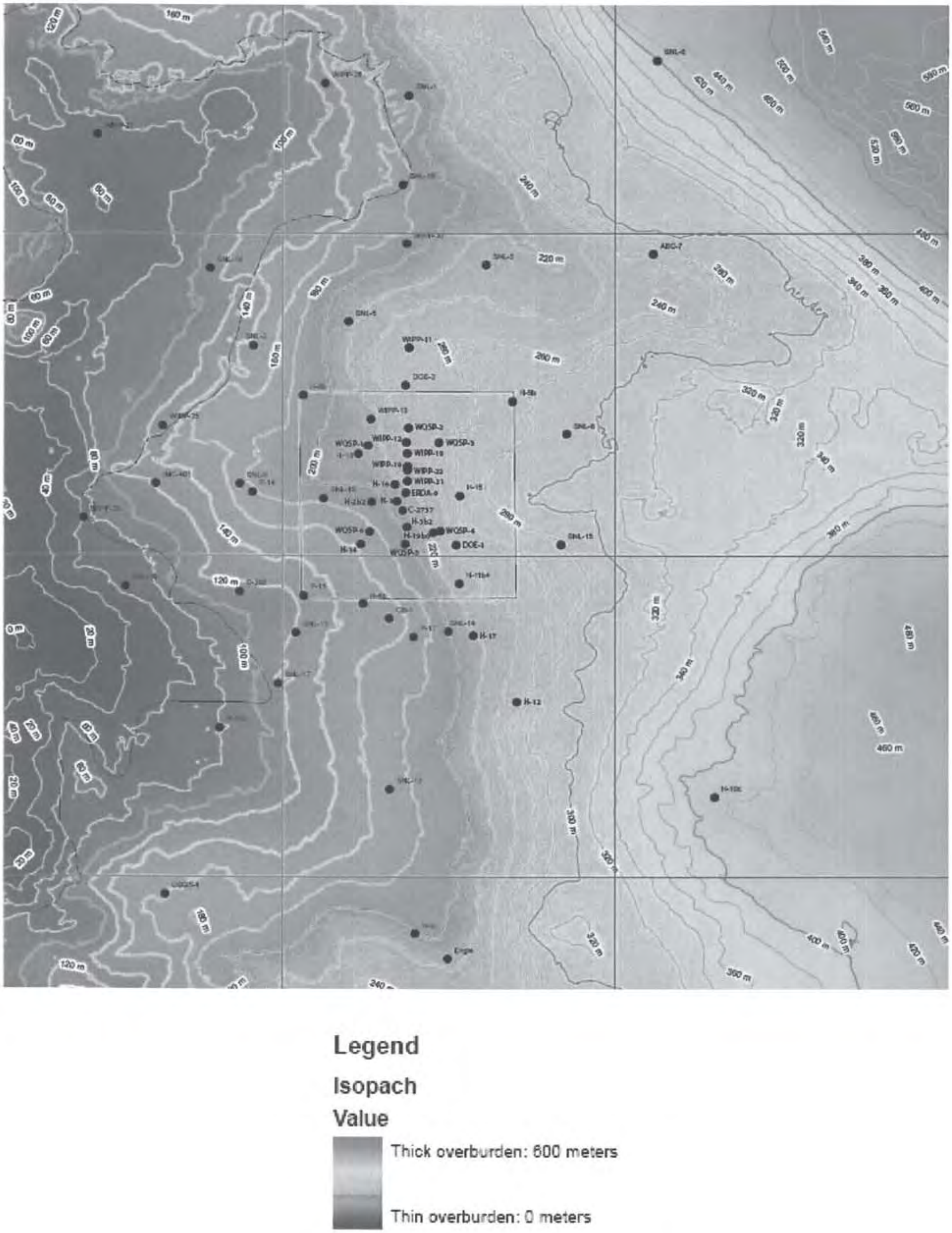

Figure 2-5: Thickness of overburden above the Culebra.

2.4 Salado Dissolution

South and west of the WIPP site, Cenozoic dissolution has affected the upper Salado Formation (Figure 2-1). Where this dissolution has occurred, the rocks overlying the Salado, including the Culebra, are strained (leading to larger apertures in existing fractures), fractured, collapsed, and brecciated (e.g., Beauheim & Holt 1990). All WIPP wells within the dissolution zone fall within the high-transmissivity population, and we hypothesize that all regions affected by Salado dissolution have well-interconnected fractures and high transmissivity. The indicator for Salado dissolution is I_D, and is defined to be 1 in areas of the domain where we believe dissolution has occurred, and 0 otherwise.

The Salado dissolution margin has been updated (see Appendix G) based on reinterpretation of borehole logs in the vicinity of H-9. This analysis has, specifically, placed the H-9 well east of the dissolution line, where previously it was considered to be within the area affected by Salado dissolution. The Salado dissolution margin, reflecting the change near H-9, is shown in Figure 2-6.

2.5 Halite Overlying or Underlying the Culebra

Significant changes to the locations of the M3/H3 and M2/H2 intervals have been made since CRA-2004 as part of Task 1A of AP-114 (Powers 2007). As such, the Rustler halite margins shown in Figure 2-6 are as defined in Powers (2007).

Both wells (H-17 and H-12) located where halite occurs in the Tamarisk Member (M3/H3 interval) but not in the Los Medaños Member (M2/H2 interval of Holt & Powers 1988) of the Rustler Formation (Figure 2-6) show low transmissivity. No wells are located in the regions where halite is present in the upper Los Medaños (M2/H2) but not in the Tamarisk (M3/H3), but these regions are also likely to have low transmissivity because it is unlikely that the M2/H2 halite would survive in regions of high transmissivity--halite units very close (several m) to the Culebra would likely be dissolved by undersaturated Culebra waters if transmissivity, and hence flux, were high (see Holt et al. 2005). For example, the H-19 hydropad is located near the halite margin in the M3/H3 interval. H-19 shows high transmissivity, and cores from the Tamarisk show evidence of dissolution and collapse (Mercer et al. 1998). We, therefore, assume that high-transmissivity zones do not occur in regions where halite is present in the M2/H2 or M3/H3 intervals, and that I_f will always be 0 in this zone.

2.6 Halite Bounding the Culebra

Wells SNL-6 and SNL-15 are new wells drilled since Holt & Yarbrough (2002), and are located east of the M2/H2 and M3/H3 halite margins, where halite is present in both intervals (Figure 2-6). As predicted by Holt (1997), the Culebra itself was partially cemented with halite at these locations, and measured transmissivities were extremely low. For example, the T value at SNL-15 was found to be 1.4×10^{-13} m^2/s (see Roberts 2007). Due to these new observations, we assume that transmissivity in the region where halite occurs both above (in the M3/H3 interval) and below (in the M2/H2 interval) the Culebra is lower than where halite occurs in only one interval. The indicator term I_H is defined to be 1 at any point where halite is present in both the M2/H2 and M3/H3 margins and to be 0 elsewhere.

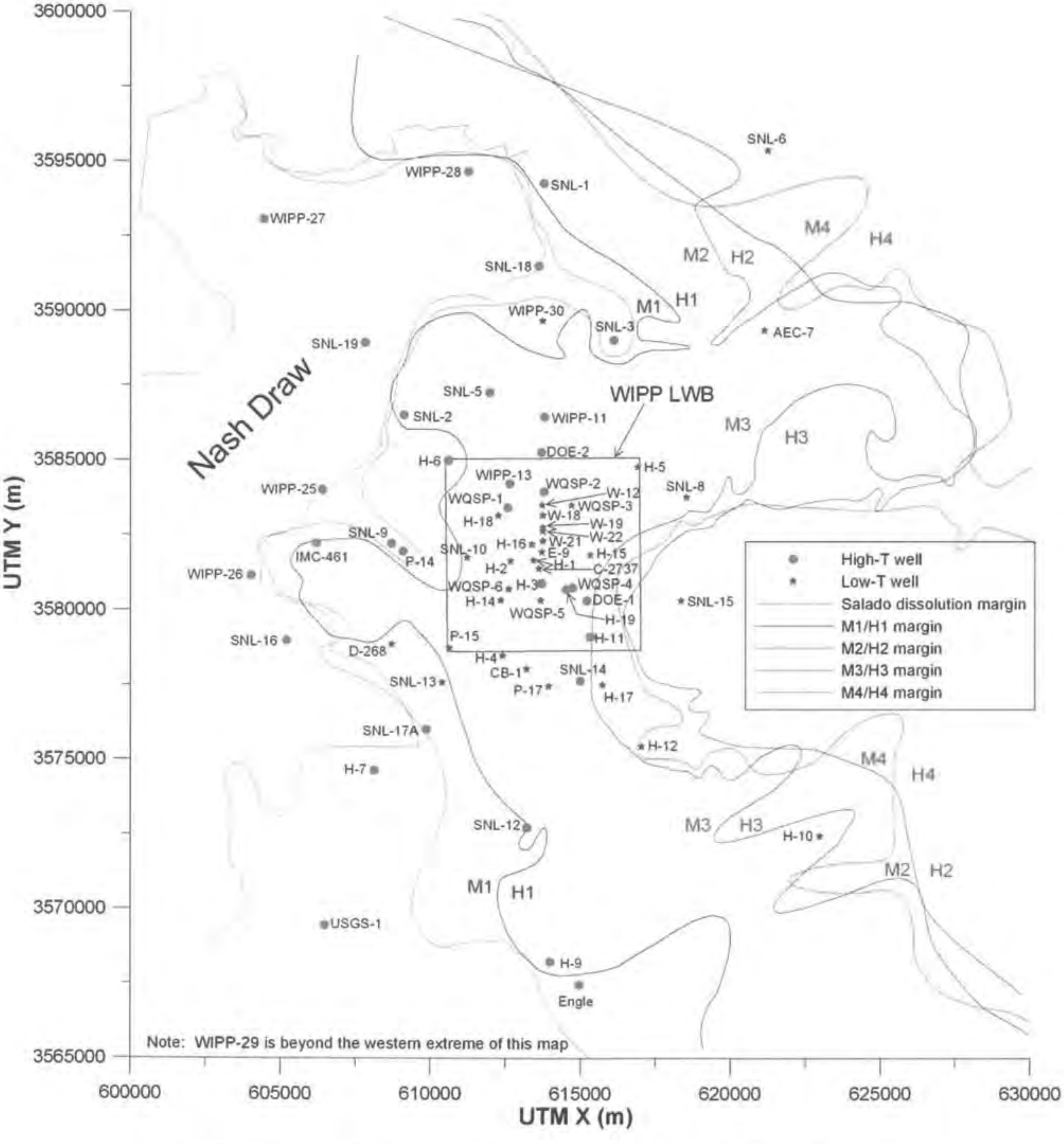

Figure 2-6: Salado dissolution and Rustler mudstone/halite margins.

2.7 High-Transmissivity Zones

High-transmissivity zones within the Culebra occur between areas affected by Salado dissolution and where halite is present in the M2/H2 and/or M3/H3 intervals (Figure 2-6). In these zones, fractures are well interconnected, and fracture interconnectivity is controlled by a complicated history of fracturing with several episodes of cement precipitation and dissolution (Beauheim & Holt 1990; Holt 1997). Unfortunately, no geologic metric for fracture interconnectivity is identifiable in cores or from subsurface geophysical logs, and fracture interconnectivity can only be identified from *in situ* hydraulic test data.

Because of this lack of a geologic metric, we consider the spatial location of high-transmissivity zones to be a stochastic process that cannot be predicted deterministically. Instead, the spatial layout of these zones is created using geostatistical indicator kriging with conditioning data. This is a change from Holt & Yarbrough (2002), where the only conditioning information was based on the known well T-values. We have, for example, added hydraulic information to the geostatistical model to increase the likelihood of high T being placed between two wells that hydraulic testing has shown to be well connected. Likewise, areas where there is evidence of high levels of gypsum will be given a slightly lower probability of being in a high-T zone. This allows us to merge both hydraulic and geologic data in the creation of high-T zones, while still keeping zone placement and shape a stochastic process. Details regarding the soft data used are presented in Section 4.

2.8 Linear Transmissivity Model

Using hypothesized geologic controls on Culebra transmissivity, we can construct the following linear model for $Y(x,y) = \log_{10}T(x,y)$

$$Y(x,y)=\begin{cases}\beta_1+\beta_2 d(x,y)+\beta_3+\beta_4 & \textit{Salado Dissolution} \quad I_D=1, I_f=1, I_H=0\\ \beta_1+\beta_2 d(x,y)+\beta_3 & \textit{Central High}-T \quad I_D=0, I_f=1, I_H=0\\ \beta_1+\beta_2 d(x,y) & \textit{Central Low}-T \quad I_D=0, I_f=0, I_H=0\\ \beta_1+\beta_2 d(x,y) & M2/H2\oplus M3/H3 \quad I_D=0, I_f=0, I_H=0\\ \beta_1+\beta_2 d(x,y)+\beta_5 & M2/H2\,\&\,M3/H3 \quad I_D=0, I_f=0, I_H=1\end{cases} \tag{2.2}$$

where $\beta_{1\,...\,5}$ are regression coefficients, the two-dimensional location vector (x,y) consists of UTMX and UTMY coordinates, $d(x,y)$ is the overburden thickness, I_f is an indicator of whether fracturing is present in the Culebra, I_D is the Salado dissolution indicator, and I_H is the halite bounding indicator. In this model, regression coefficient β_1 is the intercept value for the linear model. Coefficient β_2 is the slope of $Y(x,y)/d(x,y)$. Coefficients β_3, β_4, and β_5 represent adjustments to the intercept for the occurrence of interconnected fractures, Salado dissolution, and halite bounding, respectively. Although other types of linear models could be developed, our model is consistent with our conceptual model relating transmissivity to geologic controls and can be tested using published WIPP geologic and transmissivity data.

Because there are only two data points for transmissivity in the zone where Culebra is bounded by halite, and both are significantly lower than any other transmissivity values in the model, there were two possible options for assigning T values in this area. The first was to assign a constant transmissivity value for the entire zone. The second was to include the $\beta_5 I_H$ term in Equation 2.2 to take into account the very low T zone. To keep the conceptual model consistent for all zones, and recognizing that the base fields are primarily a starting point for following inverse calibration, the second approach was taken.

The end result of applying the process described in this document was 1000 base transmissivity fields, all of which share certain geologic features, but which are all different. This difference is provided by the stochastic placement of high-T areas in the central zone. These areas are placed using the GSLIB Sequential Indicator Simulation (SISIM) routine. This routine uses geostatistical methods to create indicator (boolean value) fields that are random, but whose randomness is constrained by statistical parameters passed as input. The discussion of soft data in Section 4 and the varigoram creation in Section 5 discuss how these inputs were defined. The final geologic features, and the "zone" they belong to, are presented in Figure 2-7.

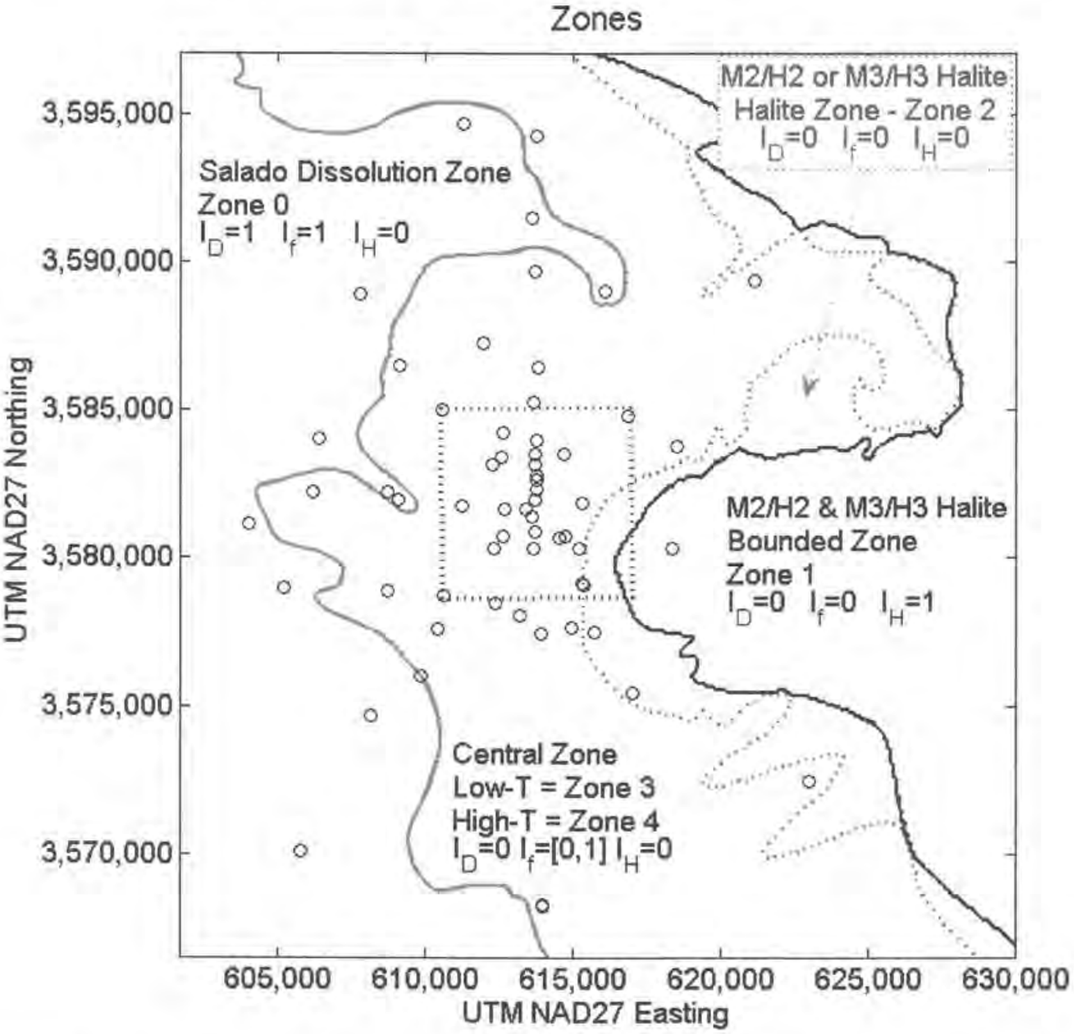

Figure 2-7: The final conceptual model zones, with indicator values and zone numbers, as discussed in Section 3 and Equation 3.1.

3 Subtask 1 – Linear Regression Analysis

The linear regression model finds the best fit for the known transmissivity data based on a multi-line regression. The wells are separated into three groups: wells in the Salado dissolution zone, wells with low T, and wells with high T. The graph displayed in Figure 3-1 shows the known well values along with the regression lines. The discriminator for low/high T is a measured $\log_{10} T$ value less than or greater than -5.4. Wells that are bounded by halite (the fourth group discussed in Section 2, containing SNL-6 and SNL-15) were not included in the regression analysis, as they are essentially singleton zone outliers. Instead, the $\beta_5 I_H$ term is added post regression, with the β_5 value chosen to yield values close to both to those measured at SNL-6 and SNL-15 (presented in Table F-1 of Appendix F); this value is directly modified during the calibration stage in Task 7. The final regression equation and a table of the β values are shown below.

$$T(x,y) = \beta_1 + \beta_2 \cdot d(x,y) + \beta_3 \cdot I_f(x,y) + \beta_4 \cdot I_D(x,y) + \beta_5 \cdot I_H(x,y) + \varepsilon \qquad (3.1)$$

Table 3-1: Beta values for the regression Equation 3.1.

β_1	β_2	β_3	β_4	β_5
-5.69805	-3.48357×10^{-3}	2.06581	0.68589	-4.75095

For the β values shown above, R^2=0.92 and F=216. The data and Mathcad sheet used to calculate these values are provided in Appendix A.

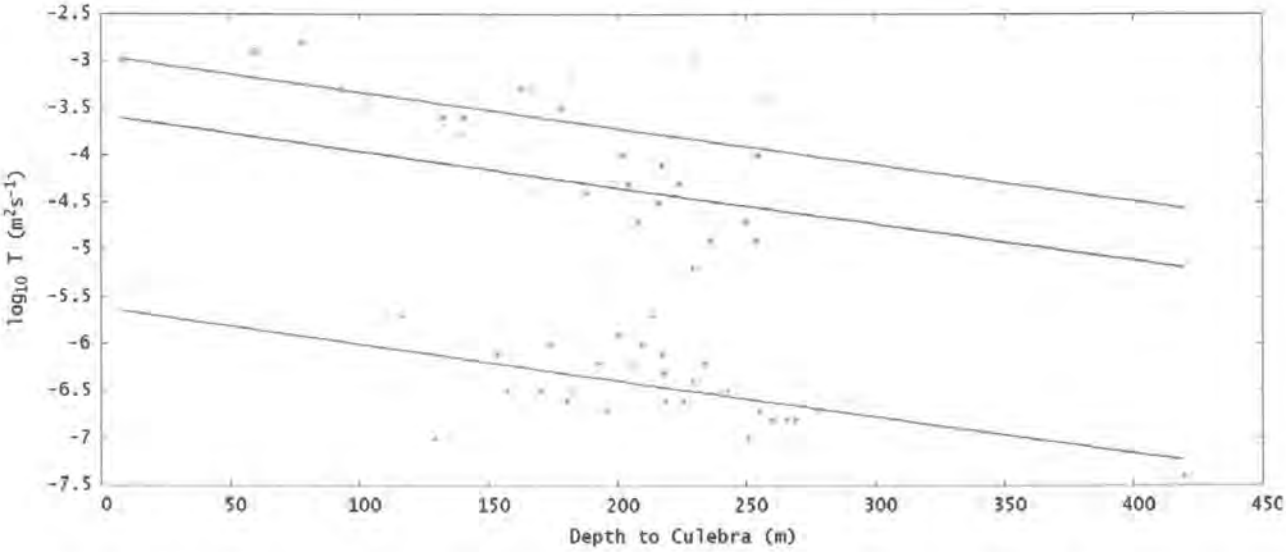

Figure 3-1: Regression lines for three different zones: low-T wells (blue), high-T/non-dissolution wells (green), and wells within the Salado dissolution zone (red).

4 Subtask 2 – Creation of "Soft Data" and Geologic Data Files

Because the indicator simulation used in subtask 4 is a random process, but there is some known geologic and hydraulic information, a set of "soft data" must be prepared to maintain the geologic conceptual model through the stochastic simulations. These soft data define probabilities, P_{low}, where P is the likelihood that a new well at a given point would have a low-T value. The composition and creation of the soft data is discussed in the following sections.

To create the soft data, the entire domain is discretized into 100-m square grid cells. This yields a model domain that is 307 cells tall along its north-south axis, and 284 cells wide along its east-west axis. The hard data are defined as $P_{low} = 0$ for wells where $\log_{10} T$ (m^2/s) is greater than -5.4, and $P_{low} = 1$ for all low-T wells, where the P value is assigned to the cell that contains the well. The soft data are given P values between 0 and 1, and are assigned on a cell-by-cell basis. The transmissivity values for all of the wells are presented in Listing A.1, in Appendix A.

The indicator field does not include information from the Salado dissolution margin, or information regarding the very-low transmissivity zone. As such, it will be combined with these other geologic margins later on. Using too much soft data can be problematic for the geostatistical simulators, and as such, gridding systems are used rather than placing values for every cell within a zone. It is important to remember this, and that the indicator field created from the soft data is used solely for placement of high T areas within the central zone, when examining the soft data. Any cells outside the central zone, as described in Figure 2-7, are going to be replaced in future subtasks, and will not directly affect the final T fields.

4.1 Halite Bounding

Two geologic margins, M2/H2 and M3/H3, are defined in Powers (2007) as areas of transition from mudstone to halite below and above the Culebra, respectively. An illustration of the geology is shown in Figure 2-1. Wells penetrating the Culebra in areas that are bounded both above and below by halite have been found to have very low T values, less than 10^{-11} m^2/s (see Roberts 2007). Wells bounded by only one margin (H-12 and H-17) have also been shown to have lower than average T values, as discussed in Section 2.5.

Because the geology where halite is present does not predict high-T fractures, the combined M2/H2 and M3/H3 margins, where the Culebra is bounded by either margin, was assigned $P_{low} = 1$. This ensures that no high-T areas will be placed on the boundary itself. It does not prevent the simulation from placing high T indicators on either side of the boundary, however, and so in the final fields, the entire halite zone will be replaced with values directly from the regression equation, eliminating any high-T indicators that may have been placed east of the margin by the simulation.

4.2 Gypsum Cements

Beauheim and Holt (1990) suggested that amount of gypsum cements in fractures and vuggy porosity within the Culebra Dolomite Member of the Rustler Formation showed an inverse relationship with Culebra transmissivity (T). They postulated that gypsum fracture fillings limited Culebra T by closing fracture apertures and filling critical fracture junctions. Beauheim and Holt illustrated a qualitative relationship but did not develop a quantitative model relating T to gypsum content because too few well locations had both measured T values and describable core. Since 1990, however, the Culebra has been cored and hydraulically tested at 24 additional locations, providing sufficient data to construct a quantitative model linking Culebra T with the presence of gypsum cements.

In Appendix F, we construct a simple quantitative model relating Culebra gypsum content to T and develop maps showing the spatial occurrence of gypsum in the Culebra using a gypsum index that accounts for the relative gypsum content in the Culebra units defined by Holt (1997). Using a critical value of the gypsum index, the high-T/low-T status of Culebra well locations can be predicted with an accuracy of greater than 97% for WIPP well locations where both sufficient core and T data exist. Maps showing the location of no gypsum (Figure 4-1) and low gypsum (Figure 4-2) are created using the critical gypsum index value. These maps reveal that regions of no gypsum occur predominantly where Salado dissolution has affected the Culebra and that the low-gypsum region in the WIPP area is similar to the high-diffusivity region defined by Beauheim (2007) (Figure 4-3). Soft data are used to incorporate information about the influence of gypsum content on Culebra T, and this use of soft data is described below.

In all cases where sufficient core and T data exist, wells with no gypsum (Figure 4-1) have high T, due to well-interconnected fractures. To account for this relationship, cells are assigned a value of $P_{low} = 0.05$ where there is no gypsum present. As can be seen in Figure 4-1, this is a fairly large area; rather than give all the cells in the area such a low P value, cells were selected from a 13-cell tetrahedral grid to receive soft data assignments (Figure 4-4). After some experimentation, a value of 13 cells was used as the grid spacing because it provided sufficient definition of the boundaries without overwhelming the simulation program.

In all cases where sufficient core and T data exist, wells outside of the low-gypsum region (Figure 4-2) have low T, as fracture interconnectivity is limited by gypsum cements. Areas outside of the low-gypsum region are given P_{low} values equal to 0.95, to increase the likelihood of low T.

Because the areas of no-gypsum and high-gypsum content cannot, by definition, overlap, the high-gypsum data are sampled on the same tetrahedral grid used by the no-gypsum data. By using fractional likelihoods and sparse sampling, these soft data do not overwhelm the random sampling algorithm of SISIM and allow for greater variation between base field realizations. The high/low-gypsum content map is shown in Figure 4-2. The low-gypsum region is not sampled, since it overlaps the no-gypsum region. Instead, the high-gypsum region is used. The area of high gypsum directly north of the WIPP Land Withdrawal Boundary (LWB) is sampled using a square 3-cell grid, to compensate for the diffusivity soft data described in the next section.

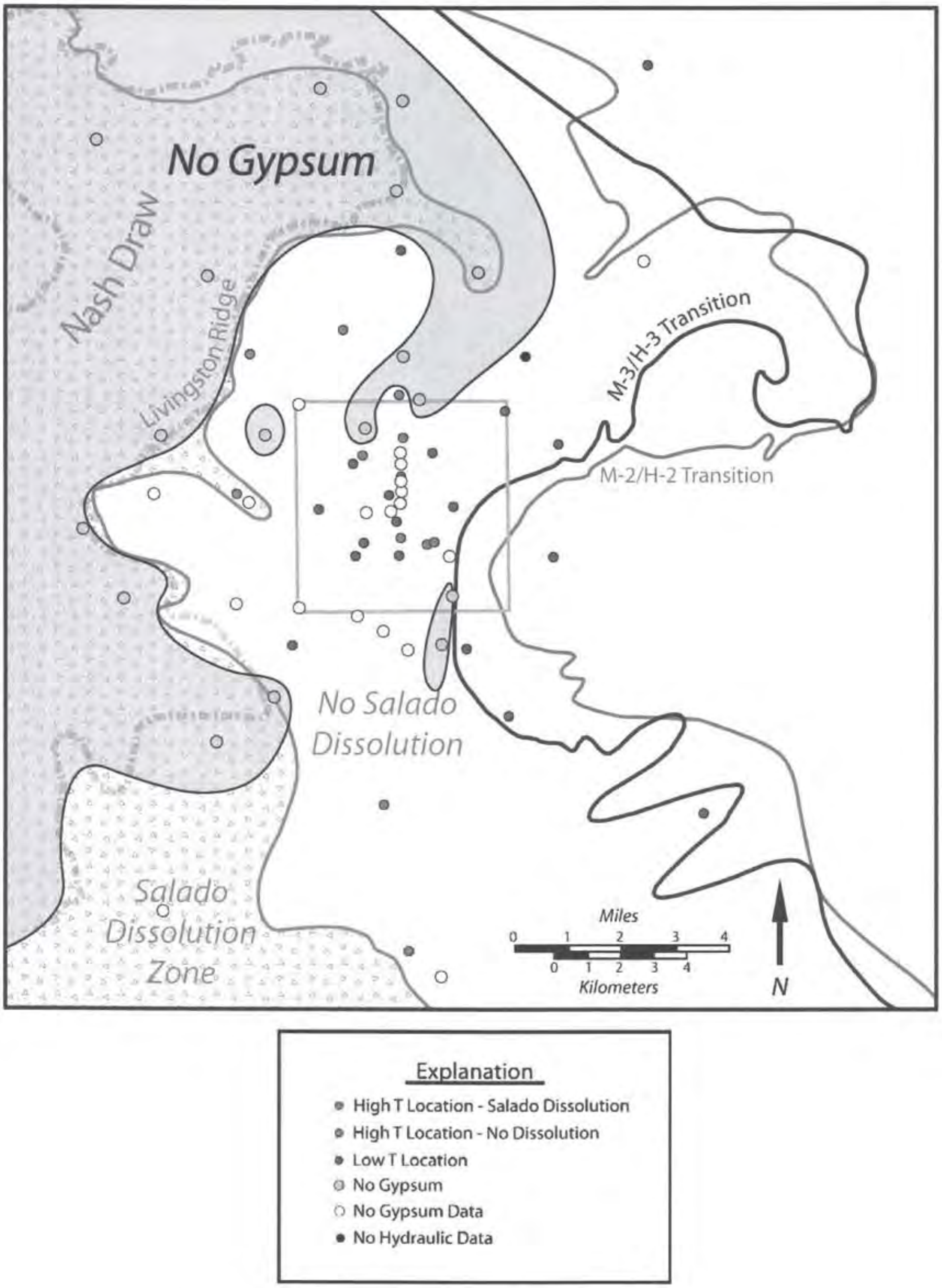

Figure 4-1: This figure, taken from Appendix F, shows the areas where no gypsum has been found in core samples. A selection of points within this area received low *P* values, indicating the likelihood of having higher T values.

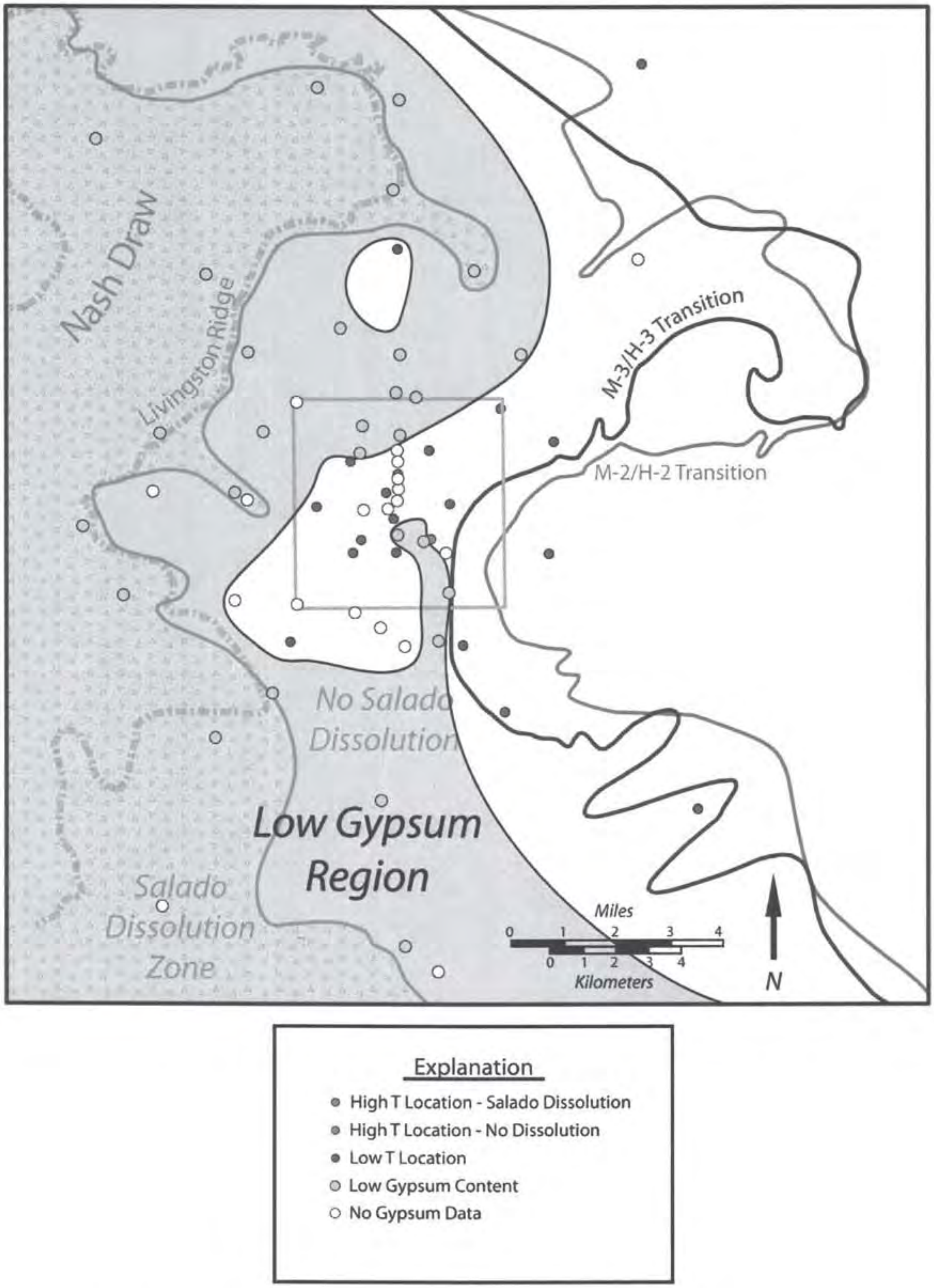

Figure 4-2: This figure, taken from Appendix F, shows the areas where wells have either no or low gypsum content. The areas not shaded, therefore, are likely to have high gypsum content and lower T, and this inverse area receives high *P* values in the soft data.

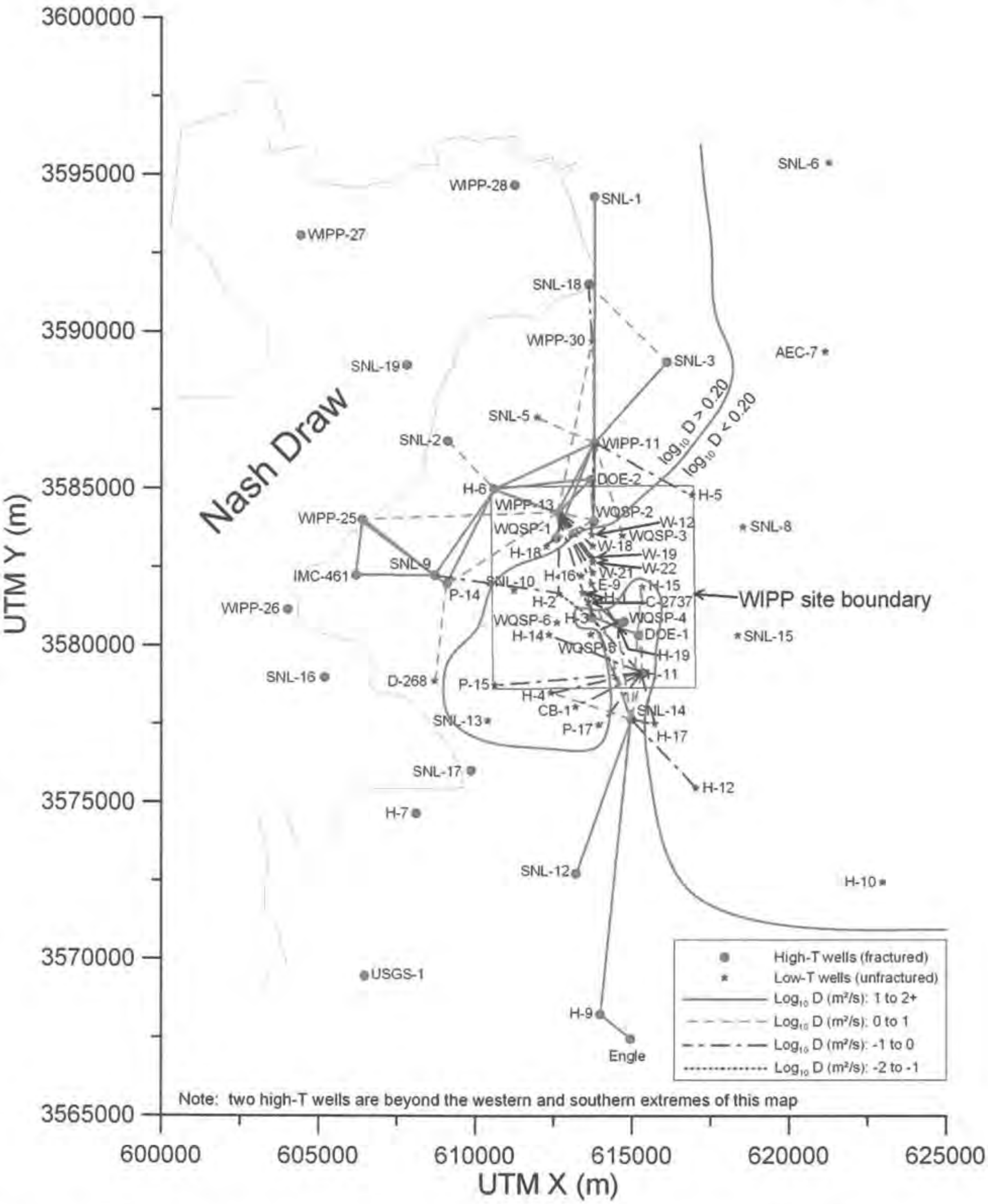

Figure 4-3: This map shows diffusivity values calculated between wells from pumping test data. Connections that have a $\log_{10} D > 0.20$ are included as conditioning data with a P_{low} = 0.25. See Beauheim (2007).

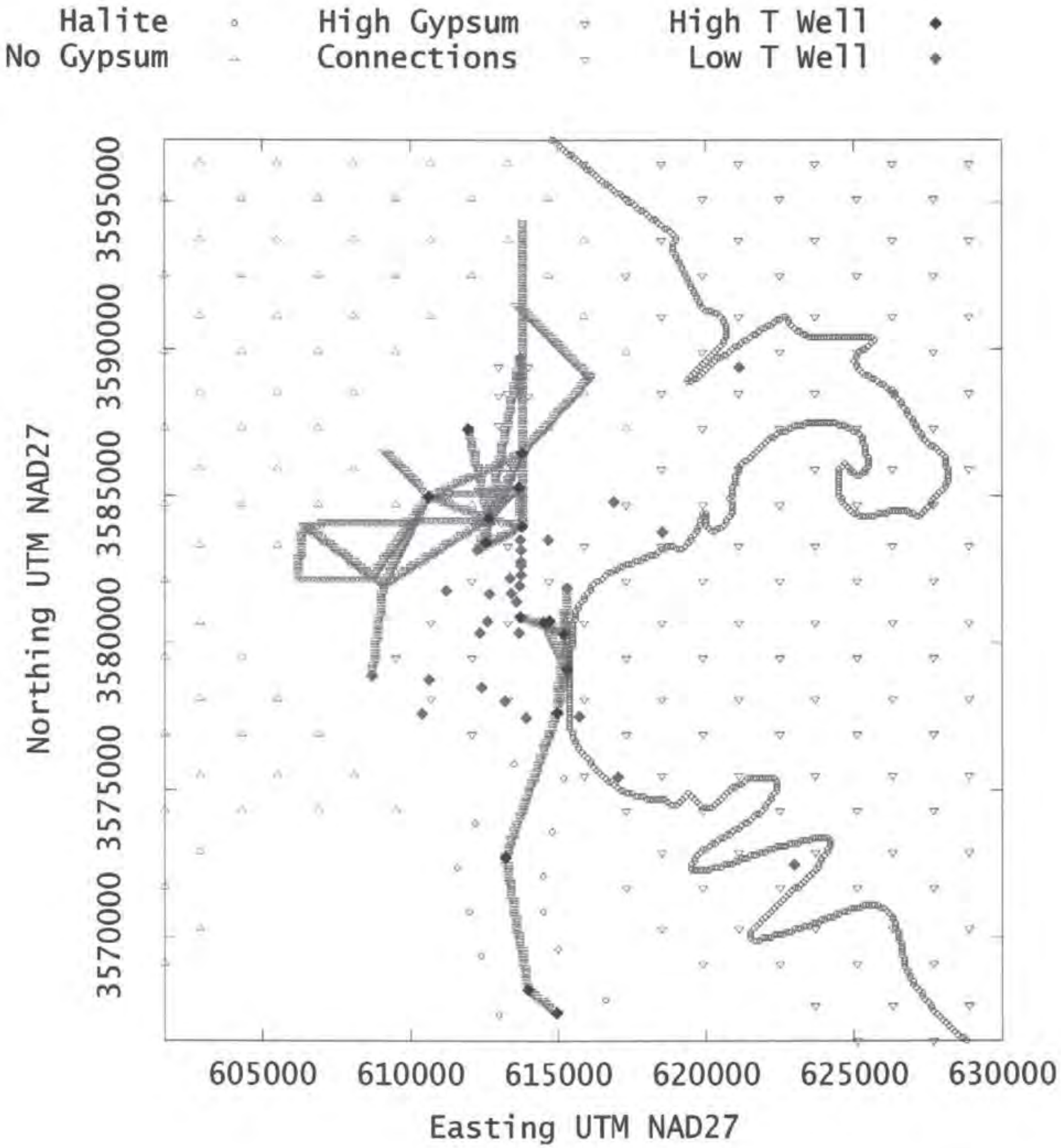

Figure 4-4: Soft data points generated during subtask 2. Hard data points (indicator values at wells) are included for reference.

4.3 Diffusivity and Hydraulic Connections

Expressions of hydraulic connections, or the lack thereof, between pairs of wells are also brought into the construction of the base fields using soft data. The diffusivity D (m^2/s) of the overall connection between any pumping and observation well has been calculated for many hydraulic tests that have been performed at the WIPP site (see Beauheim 2007), and a map of these values is shown in Figure 4-3. The cells between two wells that have a calculated $\log_{10} D$ (m^2/s) > 0.20 were given a value of $P_{low} = 0.25$, to account for the increased likelihood that a cell on the connecting line will be high T. Using a P value of 0.0 would have forced SISIM to create a direct path connecting two wells where a strong response to pumping was observed, and there is no geologic reason that these connections would have to be straight. By using fractional probabilities, the SISIM simulator will tend to provide a connection, but the connection can still be indirect.

In addition to the high-T connection lines, a set of low-T points was placed along the SNL-14/SNL-12/H-9 connection path to help keep the connection relatively narrow. Pumping at the SNL-14 well produced a well-defined and relatively strong response at the H-9 well nearly ten kilometers to the south. During testing of the hydraulic models, it was found that the only way to get this type of response was to have a relatively thin connective zone of high T. Without adding some low-T points along this path, SISIM tended to create a high-T area too large to allow any drawdown response to propagate from SNL-14 to H-9. Also, the type of response seems to indicate a somewhat linear feature, which is difficult to model on a 100-m grid scale. These low-T points were only guidance points, and many base fields still have large areas of high T that extend past these points. These points were assigned a $P_{low} = 1$, to ensure they would always impact the simulation.

4.4 Combined Soft Data

The final, combined soft data field is shown in Figure 4-4. For clarity, the hard data are also provided as filled diamonds, with purple points indicating low-T values, and black points indicating high-T values. The soft data were created in MATLAB, using the data files and scripts provided in Appendix B.

5 Subtask 3 – Indicator Variography

The geostatistical indicator simulations done as part of the base T-field development are only utilized in the central section of the model domain, between the dissolution area to the west and the low-T region to the east. Therefore, only wells in this middle section are used for construction of the indicator variogram. There are a total of 46 wells that provide information regarding $\log_{10} T$ that can be used in the calculation of the indicator variograms. The tab-delimited text file needed by VARIOWIN for the indicator variogram calculation is created in the "Indicator" worksheet within the *T_Wells_UTMNAD27.xls* file. The tab-delimited file contains 3 columns: the translated X and Y UTM coordinates and the indicator transformed values of $\log_{10} T$. The indicator value is determined by comparing each $\log_{10} T$ value to a threshold $\log_{10} T$ value, T_t. Those values less than or equal to the threshold are assigned an indicator value of 1.0, while $\log_{10} T$ values greater than the threshold are assigned a value of 0.0. More concisely:

$$I(x,y) = \begin{cases} 1 & \text{if } \log_{10} T < T_t \\ 0 & \text{if } \log_{10} T \geq T_t \end{cases} \tag{5.1}$$

where *I(x,y)* denotes the indicator value at well location *(x,y)*. The threshold value to discriminate between high and low $\log_{10} T$ is -5.4. This is the same value used in the calculations for the CRA-2004 (DOE 2004) base fields and is provided by the multivariate regression analysis. Note that the indicator values, *I*, are unitless as are the variogram values in the following discussion.

The three columns in the "Indicator" worksheet are saved as a tab-delimited text file called *T_ind.dat* and the five-line header (shown below) required by VARIOWIN is added to this file.

```
Culebra log10 T indicator data, July 2008
3
Trans_X
Trans_Y
Ind
```

The resulting *T_ind.dat* file is used as input to VARIOWIN.

The indicator variogram is fit with a spherical model. Compared to the other two commonly used variogram models, Gaussian and exponential, the spherical model produced the best fit to the experimental variogram. The variogram model parameters are given in Table 5-1, and Figure 5-1 shows the experimental and model variograms. The proportion of low-T values in the data set is 0.652. The variance of an indicator value is $(1.0-p)p$ where p is the proportion of high, or low, values. The variance for these indicator data is 0.227 and is used directly as the sill in the variogram modeling. The parameters in Table 5-1 are used as input to the SISIM program for creation of the stochastic component of the base T-fields. Further analyses with directional variograms calculated in the NE-SW and NW-SE directions to identify anisotropy are inconclusive (Appendix C).

Table 5-1: Variogram parameters for isotropic fit to indicator data variogram. Omnidirectional variogram calculated with a lag spacing of 500 m.

Parameter	Value
Model Type	Spherical
Nugget	0.0
Sill	0.227
Range	2195 m

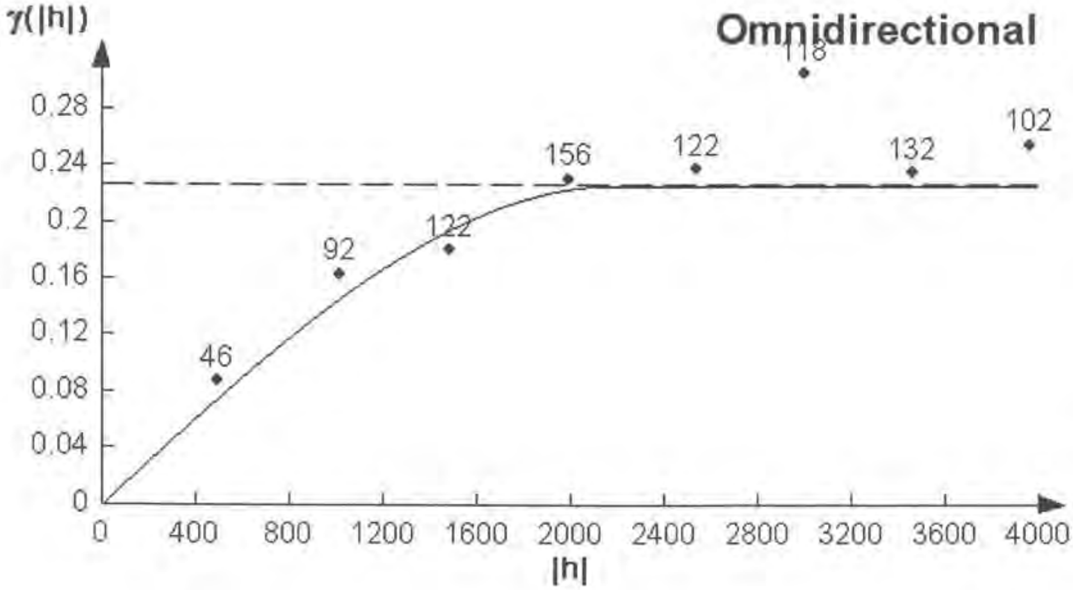

Figure 5-1: Experimental variogram (black dots) and spherical model (black line) for the indicator values. The X-axis is the separation, or lag, distance, in meters and the variogram function is shown on the Y axis (unitless).

6 Subtask 4 – Conditional Indicator Simulation

With the indicator variogram model, known T values, and soft data in place, we can now construct stochastic realizations of high-T zones using the GSLIB program SISIM (Deutsch & Journel 1998). The input to SISIM is a parameter file, the base for which is provided in listing D.3. The parameter file specifies that ten realizations are to be produced each time SISIM is run. A shell script changes the random number seed and output file name for each of ten batches. Each realization is extracted from the batch by using the GSLIB ADDCOORD code, which simply selects the correct set of N-by-M values and adds X and Y coordinates to them. The result is a GEO-EAS formatted file that contains X, Y, and Z coordinates, followed by a low-T indicator value. This is the inverse of the indicator value I_f used in the regression equation. ADDCOORD also uses a configuration file which is created by the shell script. An example is provided in listing D.4, and a sample completed field is presented in Figure 6-1.

Statistics for the resulting fields were compiled in MATLAB, and the average value and standard deviation are presented in Figures 6-2 and 6-3 respectively. These figures show the impact of conditioning information on the overall fields. The combined M2/H2 and M3/H3 margins have, as desired, a standard deviation of 0 and are constant at the proper value. Areas designated as higher likelihood of high T do, in fact, show an average value that trends towards the high-T value (in this case, 0), but they still have a standard deviation that is non-zero, indicating that there is still stochastic variability in those areas. The same is true in areas outside the low-gypsum region. Additionally, areas where there were no conditioning information have even higher standard deviations, indicating that placement in those locations is a fully stochastic process. Though there are some artifacts from the grids used in the average and standard deviation fields, the individual realizations, such as Figure 6-1, do not show these artifacts. Additionally, the majority of the artifacts occur outside the central zone, which is the only place the indicator fields are used. We believe that the indicator fields created by this process are the best possible combination of hydraulic and geologic conditioning given current data. The shell script and MATLAB source code used for Subtask 4 are presented in Appendix D.

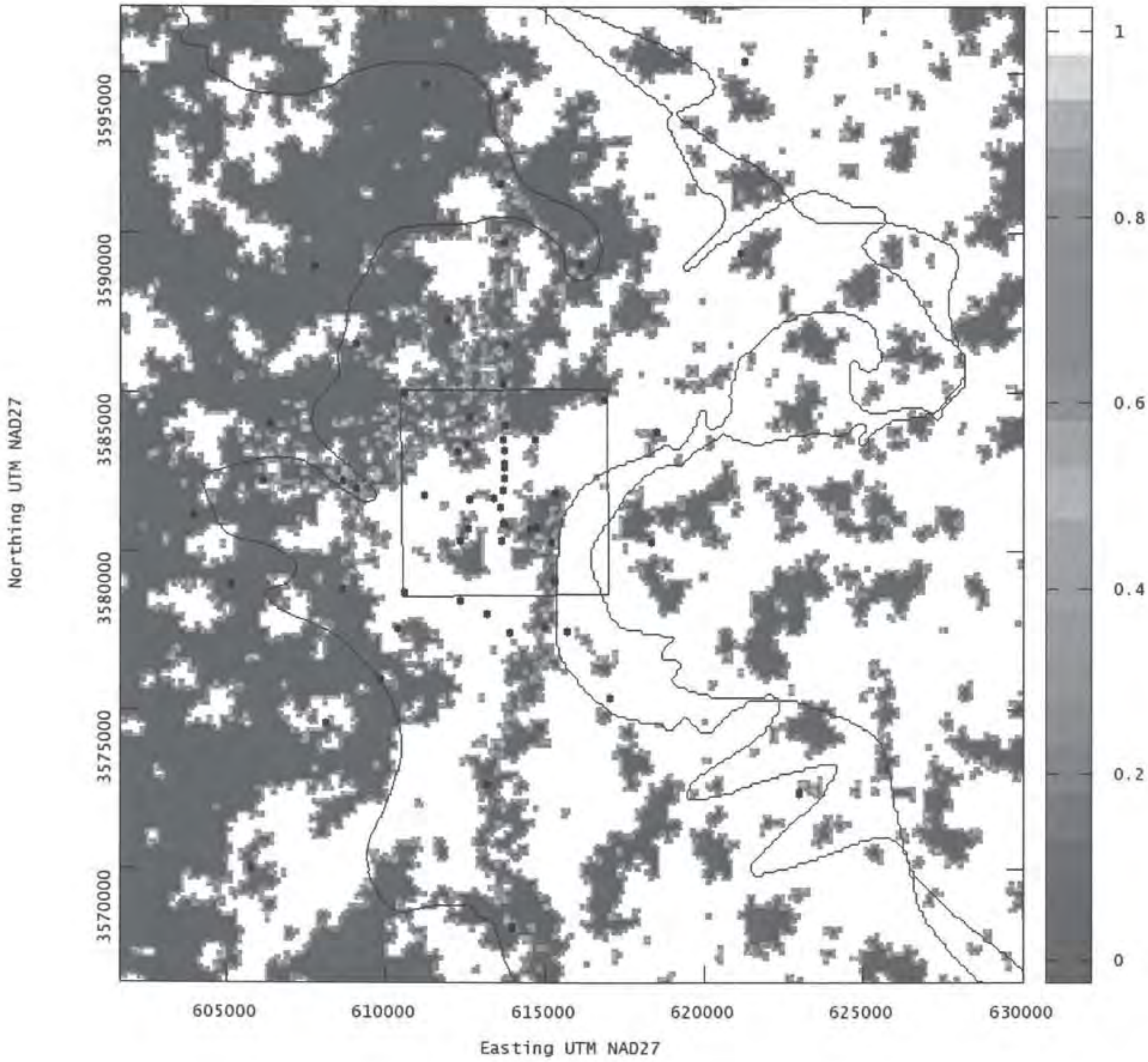

Figure 6-1: Sample indicator field for realization r123, where "1" indicates low T and "0" indicates high T.

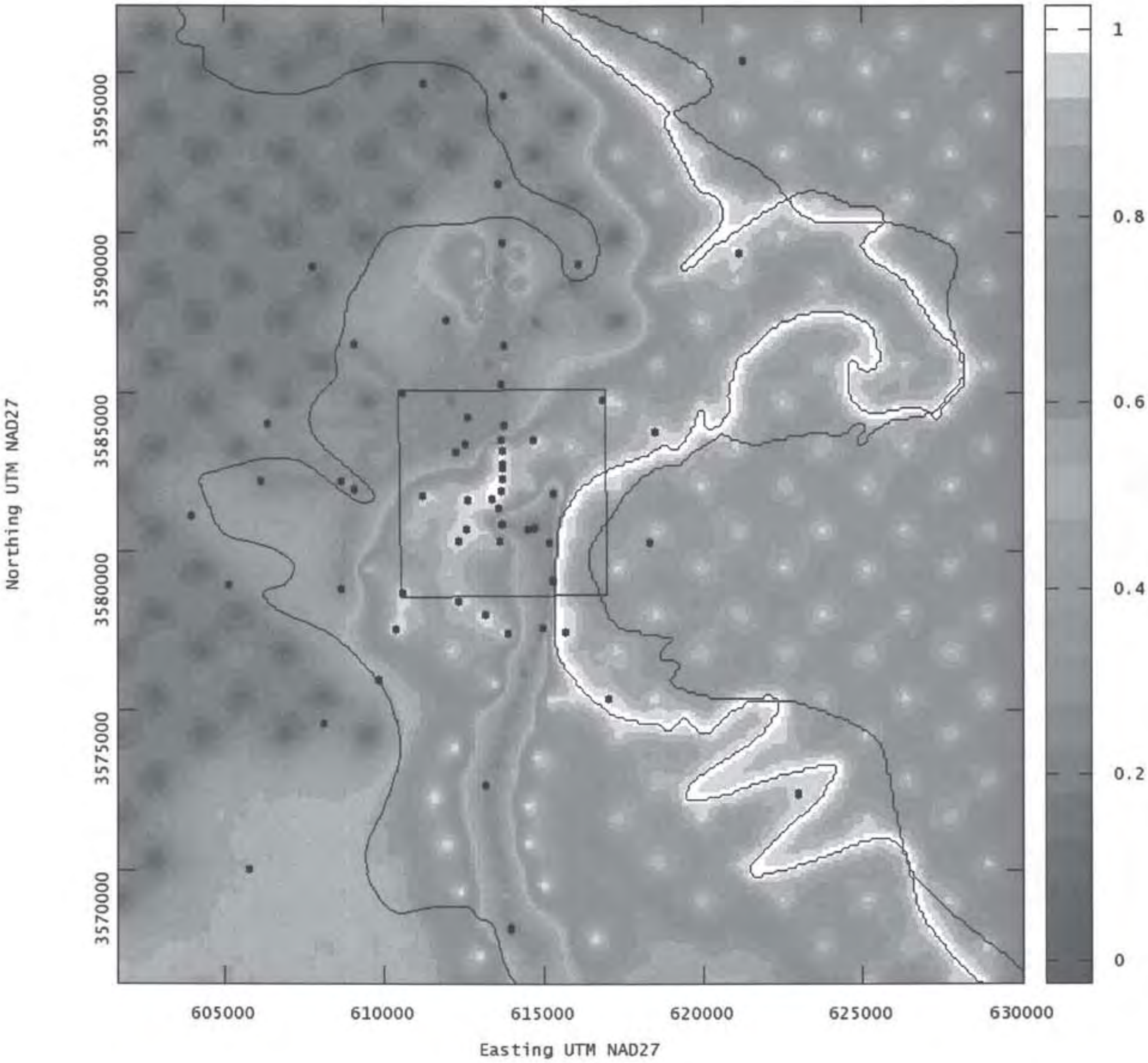

Figure 6-2: Average indicator values across all 1000 realizations.

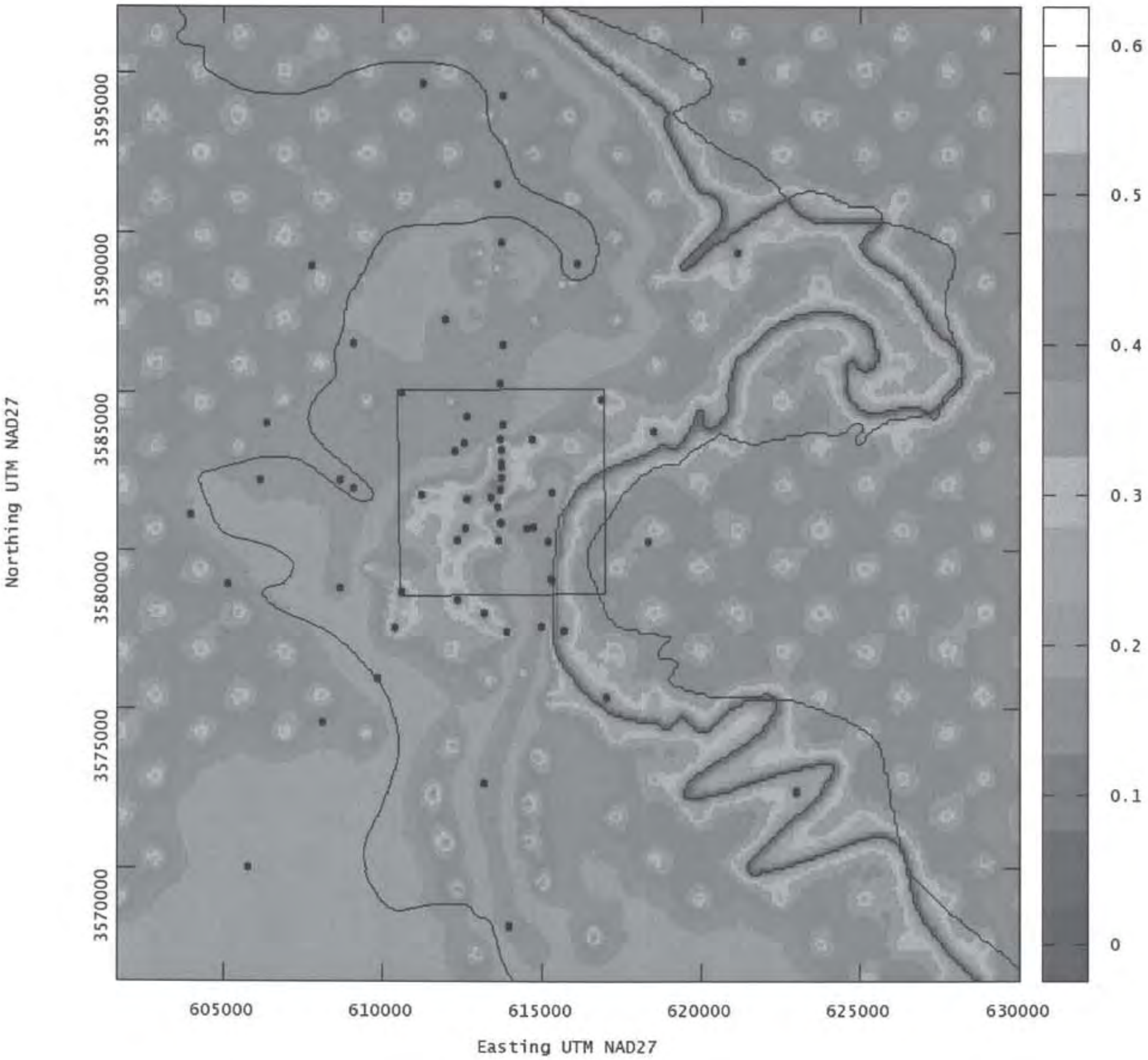

Figure 6-3: Standard deviation of indicator values across all 1000 realizations.

7 Subtask 5 – Construction of Transmissivity Fields

Once the indicator fields are created, the transmissivity values can be assigned by using the regression equation described in Subtask 1. A Perl script was written to accomplish this subtask, called GEO2FIELD. This script reads in GEO-EAS formatted data files and produces transmissivity values as output. This file contains a vector of T values organized column-major from the northwest corner of the domain. Following the inputs of these files, GEO2FIELD requests **a** and **b** values for each zone. These are used as shown in Equation 7.1 to calculate the transmissivity value at each cell.

$$\log_{10}(T_{x,y}) = \mathbf{b}(Z_{x,y}) + \mathbf{a}(Z_{x,y}) \cdot d_{x,y} \tag{7.1}$$

The **b** and **a** values represent combinations of the β values based on the zone the cell is in $Z_{x,y}$. Table 7-1 shows how the variables in the original equation were related to the GEO2FIELD equation variables. The map of the zones is reproduced in this chapter as Figure 7-1.

Table 7-1: Correlation of β and *I* values from Equation 3.1 to the a and b values in Equation 7.1.

	Zone 0 *Salado*	**Zone 1** *Halite 2*	**Zone 2** *Halite*	**Zone 3** *Central low T*	**Zone 4** *Central high T*
I_f	1	0	0	0	1
I_D	1	0	0	0	0
I_H	0	1	0	0	0
I_h	0	1	1	0	0
b	$\beta_1 + \beta_3 + \beta_4$	$\beta_1 + \beta_5$	β_1	β_1	$\beta_1 + \beta_3$
a	β_2	β_2	β_2	β_2	β_2

The GEO2FIELD program was executed on all realizations, completing this subtask. Source code and inputs used for this subtask are presented in Appendix E. A sample final base transmissivity field is presented in Figure 7-2. This is field number "r123." The mean $\log_{10} T$ field is presented in Figure 7-3. The standard deviation of $\log_{10} T$ is presented in Figure 7-4.

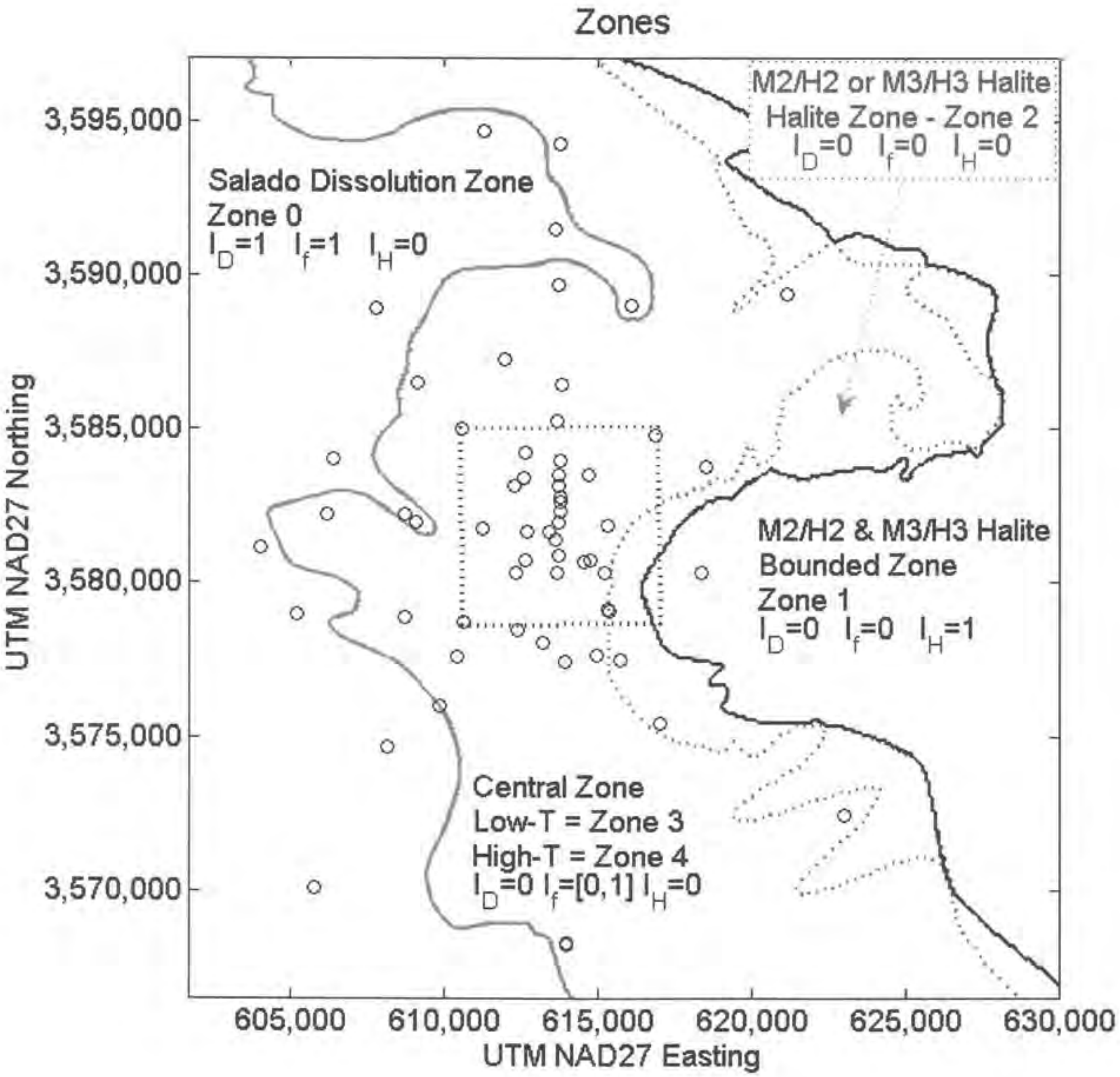

Figure 7-1: The final conceptual model zones, along with indicator values discussed in Section 3 and zone numbers discussed in Section 7.

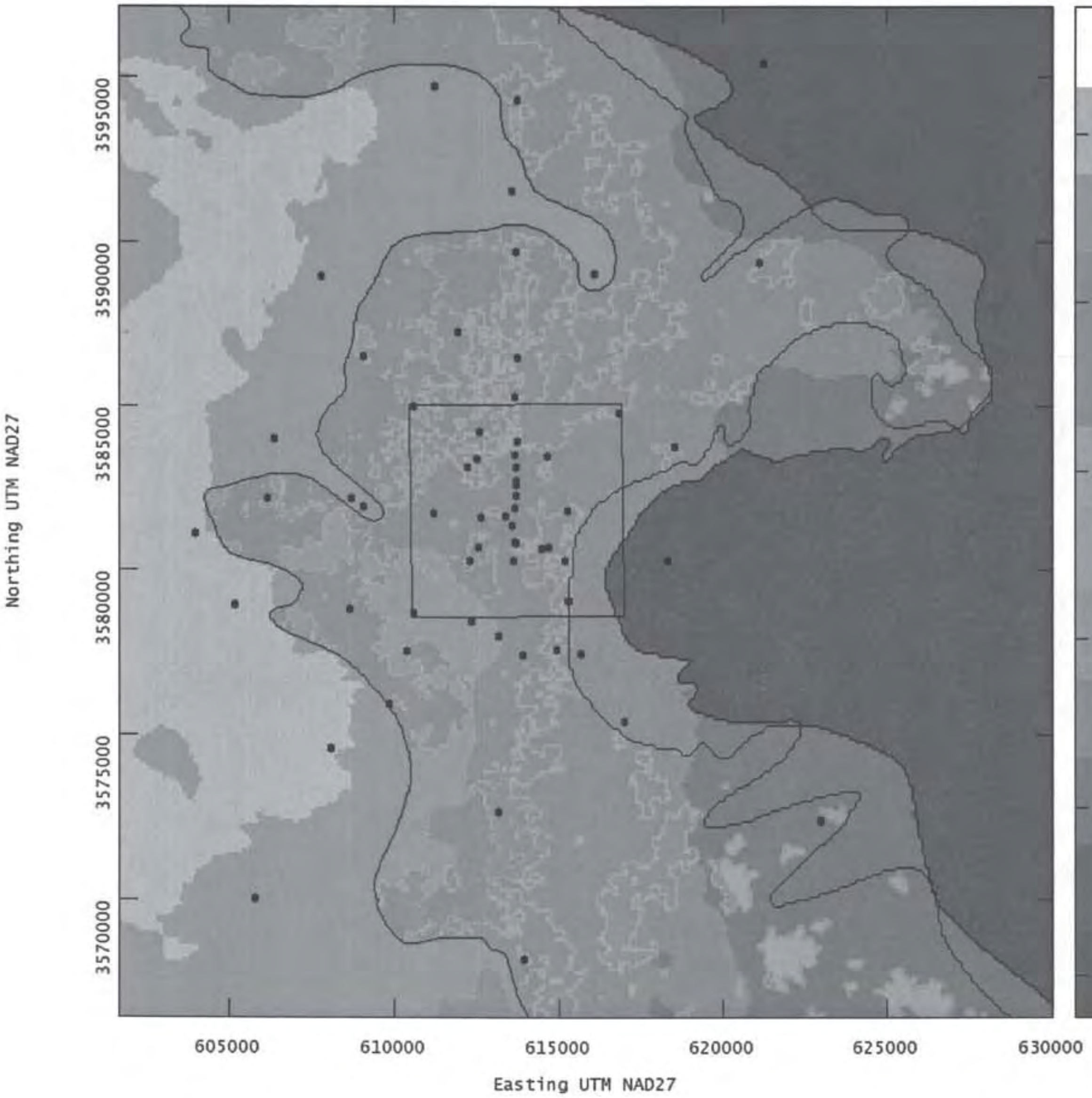

Figure 7-2: Sample $\log_{10}$ T base field realization: r123.

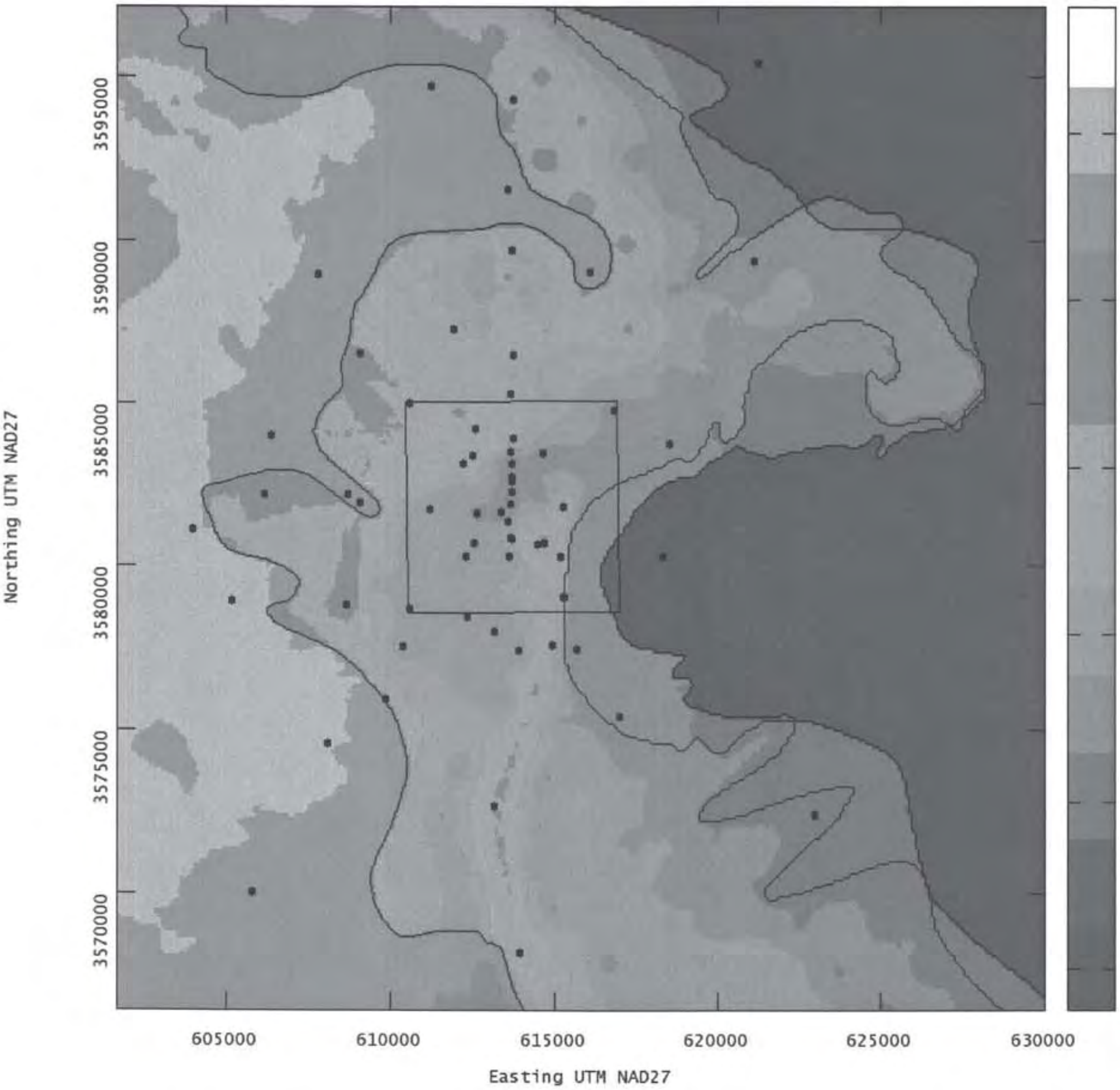

Figure 7-3: Mean $\log_{10}$ T values across all 1000 realizations.

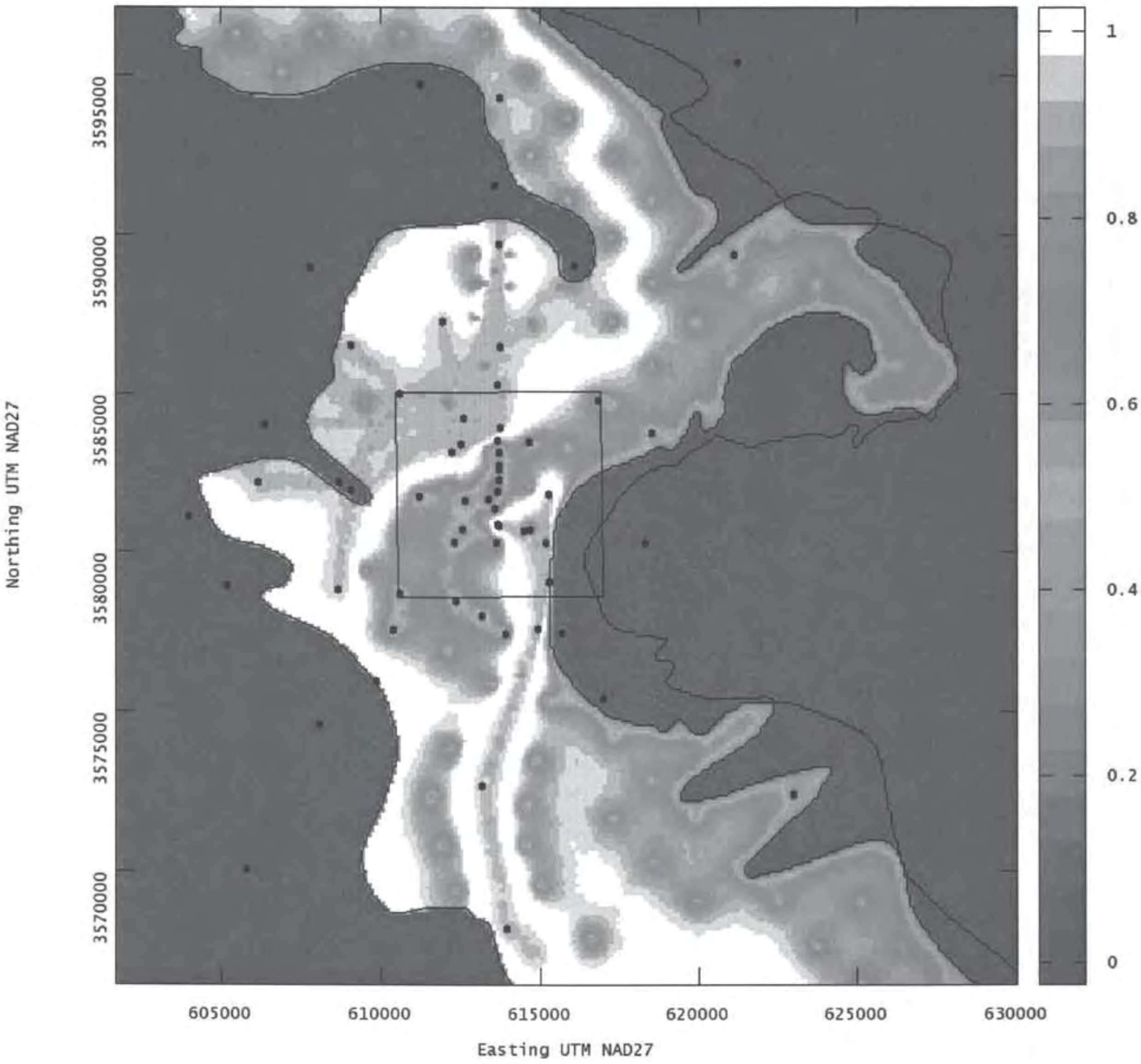

Figure 7-4: Standard deviation of $\log_{10}$ T values across all 1000 realizations.

8 Conclusions

The conclusion of subtask 5 completes Task 5 of AP-114. The end result of this task was the creation of 1000 base transmissivity fields which can be used as starting points for calibration in Task 7 of AP-114. Each field created consists of an indicator field, a transmissivity field, and several intermediate fields. The naming convention for these files is: **`t###coord.*`**, where the numbers go from 000 to 999. All output files were transferred to the CVS repository on **`elo.sandia.gov:/nfs/data/CVSLIB/AP114`** in the **`Task5`** module. The final base fields can be extracted from the repository by run control scripts during the calibration phase of Task 7.

We believe that the base fields created during this task are the best that can be produced given currently available methods and field data. They combine deterministic geologic data with measured hydraulic observations and still provide a strong stochastic method with regards to placement of high-T areas where strong indicators are otherwise unavailable. The large number of fields produced provides a large population against which calibrated fields can be compared in future tasks.

9 References

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Appendix A

Inputs, Outputs, and Code used in Subtask 1

The following files were used in the regression analysis:

`NewTs-wdiss h9 engle no diss.prn`	Well depth and T values
`WIPP T Regression.mcd`	Mathcad notebook to calculate multiline regression model

The input file and the Mathcad sheets will be presented in Listing A.1 and Figures A.1 to A.5. There is one continuous Mathcad notebook but the pages were given separate figure numbers due to formatting constraints. The Mathcad notebook is self documenting, and can be validated by examining the source code itself, or checking out the data files from the CVS repository:

CVS Root: `:ext:elo.sandia.gov:/data/CVSLIB/AP114`

Repository: `Task5/Outputs/runs/subtask1`

Column 1: well name

Column 2: UTM X coordinate, meters, NAD27, Zone 13

Column 3: UTM Y coordinate, meters, NAD27, Zone 13

Column 4: depth to Culebra (m)

Column 5: $\log_{10}$(T) (m^2/s)

Column 6: not used

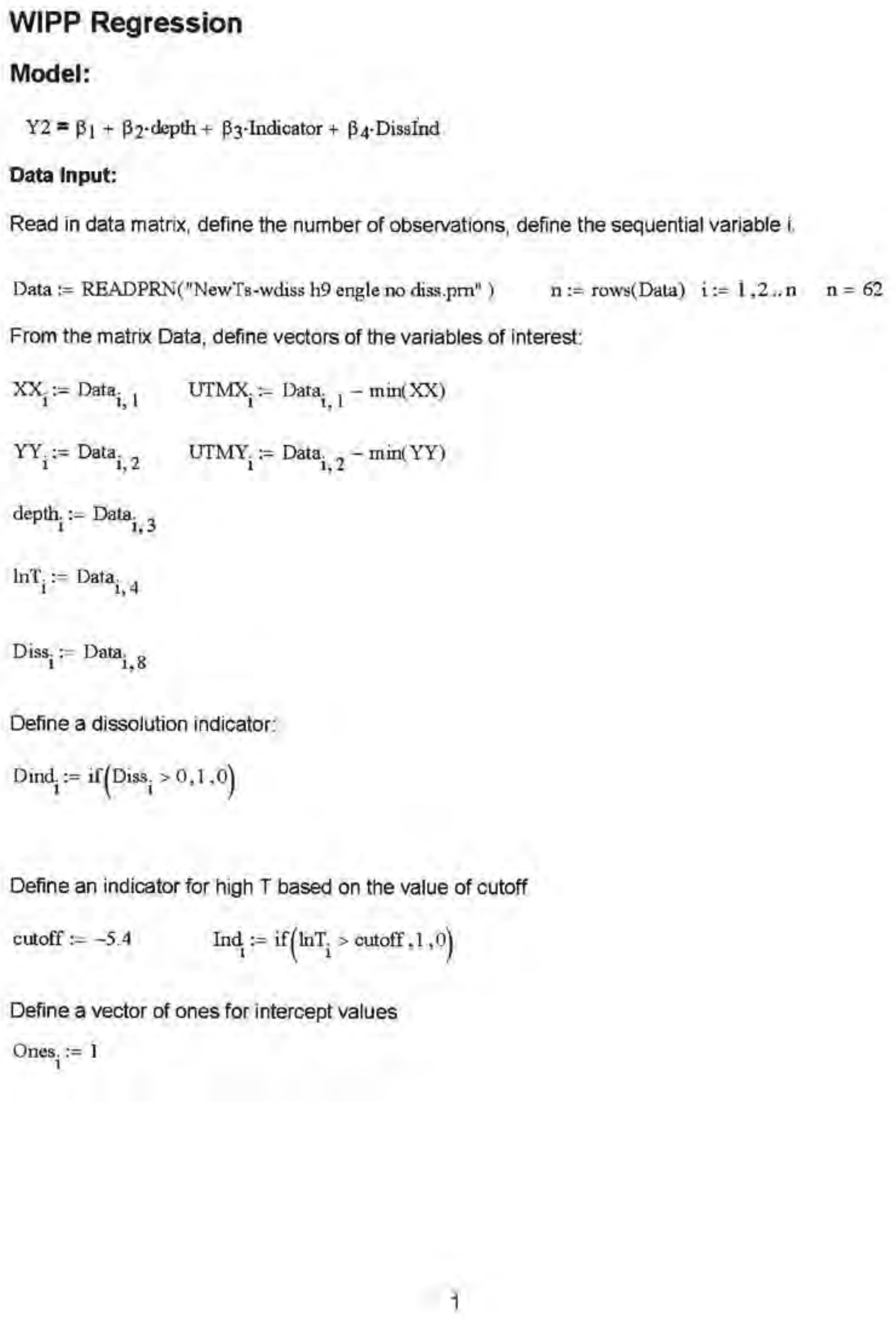
Column 7: not used

Column 8: dissolution index (if index > 0, the dissolution indicator $= 1$)

Listing A.1: Input file `NewTs-wdiss h9 engle no diss.prn` for subtask 1

```
"H-10b"      622975      3572473 419.25   -7.4    0       0       0       0
"P-15"       610624      3578747 129.24   -7      0       0       0       0
"WIPP-12"    613710      3583524 250.7    -7      0       0       0       0
"AEC-7"      621126      3589381 269.14   -6.8    0       0       0       0
"H-15"       615315      3581859 265.79   -6.8    0       0       0       0
"WQSP-3"     614686      3583518 260.38   -6.8    0       0       0       0
"H-12"       617023      3575452 254.97   -6.7    0       0       0       0
"H-5c"       616903      3584802 277.82   -6.7    0       0       0       0
"WIPP-30"    613721      3589701 195.69   -6.7    0       0       0       0
"H-17"       615718      3577513 219.03   -6.6    0       0       0       0
"SNL-8"      618523      3583783 291.5    -6.6    0       0       0       0
"WIPP-21"    613743      3582319 225.85   -6.6    0       0       0       0
"WQSP-6"     612605      3580736 180.31   -6.6    0       0       0       0
"CB-1"       613191      3578049 157.27   -6.5    0       0       0       0
"H-14"       612341      3580354 170.23   -6.5    0       0       0       0
"SNL-10"     611217      3581777 182.58   -6.5    0       0       0       0
"WIPP-18"    613735      3583179 243.08   -6.5    0       0       0       0
"SNL-13"     610394      3577600 118.26   -6.4    0       0       0       0
"WIPP-22"    613739      3582653 229.51   -6.4    0       0       0       0
"ERDA-9"     613696      3581958 218.08   -6.3    0       0       0       0
```

21	"C–2737"	613597	3581401	205.74	−6.2	0	0	0	0
22	"H–2c"	612666	3581668	192.94	−6.2	0	0	0	0
23	"WIPP–19"	613739	3582782	233.93	−6.2	0	0	0	0
24	"H–16"	613369	3582212	217.46	−6.1	0	0	0	0
25	"H–4c"	612406	3578499	153.31	−6.1	0	0	0	0
26	"H–1"	613423	3581684	209.55	−6	0	0	0	0
27	"P–17"	613926	3577466	173.89	−6	0	0	0	0
28	"WQSP–5"	613668	3580353	200.67	−5.9	0	0	0	0
29	"D–268"	608702	3578877	115.98	−5.7	0	0	0	0
30	"H–18"	612264	3583166	213.57	−5.7	0	0	0	0
31	"SNL–5"	611970	3587285	194.16	−5.3	0	1	1	0
32	"H–19b0"	614514	3580716	229.2	−5.2	0	1	1	0
33	"DOE–1"	615203	3580333	253.44	−4.9	0	1	1	0
34	"WQSP–4"	614728	3580766	236.42	−4.9	0	1	1	0
35	"H–3b1"	613729	3580895	207.87	−4.7	0	1	1	0
36	"WQSP–2"	613776	3583973	249.72	−4.7	0	1	1	0
37	"WQSP–1"	612561	3583427	215.79	−4.5	0	1	1	0
38	"H–6c"	610610	3584983	187.61	−4.4	0	1	1	0
39	"SNL–9"	608705	3582238	167.64	−4.4	1	1	0	1
40	"Engle"	614953	3567454	204.22	−4.3	0	1	1	0
41	"H–11b4"	615301	3579131	223.93	−4.3	0	1	1	0
42	"SNL–14"	614973	3577643	198.12	−4.3	0	1	1	0
43	"WIPP–13"	612644	3584247	217.17	−4.1	0	1	1	0
44	"DOE–2"	613683	3585294	254.51	−4	0	1	1	0
45	"H–9c"	613974	3568234	201.78	−4	0	1	1	0
46	"SNL–18"	613606	3591536	163.98	−3.9	1	1	0	20
47	"SNL–2"	609113	3586529	138.99	−3.8	1	1	0	1
48	"WIPP–25"	606385	3584028	140.06	−3.6	1	1	0	48
49	"WIPP–28"	611266	3594680	131.98	−3.6	1	1	0	45
50	"P–14"	609084	3581976	178	−3.5	1	1	0	14
51	"SNL–17"	609863	3576016	101.19	−3.5	1	1	0	15
52	"SNL–19"	607816	3588931	103.94	−3.4	1	1	0	50
53	"WIPP–11"	613791	3586475	256.95	−3.4	0	1	1	0
54	"SNL–12"	613210	3572728	166.73	−3.3	0	1	1	0
55	"USGS–1"	606462	3569459	162.44	−3.3	1	1	0	37
56	"WIPP–27"	604426	3593079	92.97	−3.3	1	1	0	70
57	"SNL–1"	613781	3594299	181.66	−3.2	1	1	0	5
58	"SNL–3"	616103	3589047	229.51	−3	1	1	0	15
59	"WIPP–29"	596981	3578694	8.23	−3	1	1	0	115
60	"SNL–16"	605265	3579037	58.83	−2.9	1	1	0	40
61	"WIPP–26"	604014	3581162	60.2	−2.9	1	1	0	52
62	"H–7c"	608095	3574640	77.88	−2.8	1	1	0	30



WIPP Regression

Model:

$Y2 = \beta_1 + \beta_2 \cdot depth + \beta_3 \cdot Indicator + \beta_4 \cdot DissInd$

Data Input:

Read in data matrix, define the number of observations, define the sequential variable i.

Data := READPRN("NewTs-wdiss h9 engle no diss.prn") $n := rows(Data)$ $i := 1, 2 .. n$ $n = 62$

From the matrix Data, define vectors of the variables of interest:

$XX_i := Data_{i,1}$ $UTMX_i := Data_{i,1} - min(XX)$

$YY_i := Data_{i,2}$ $UTMY_i := Data_{i,2} - min(YY)$

$depth_i := Data_{i,3}$

$lnT_i := Data_{i,4}$

$Diss_i := Data_{i,8}$

Define a dissolution indicator:

$Dind_i := if\left(Diss_i > 0, 1, 0\right)$

Define an indicator for high T based on the value of cutoff

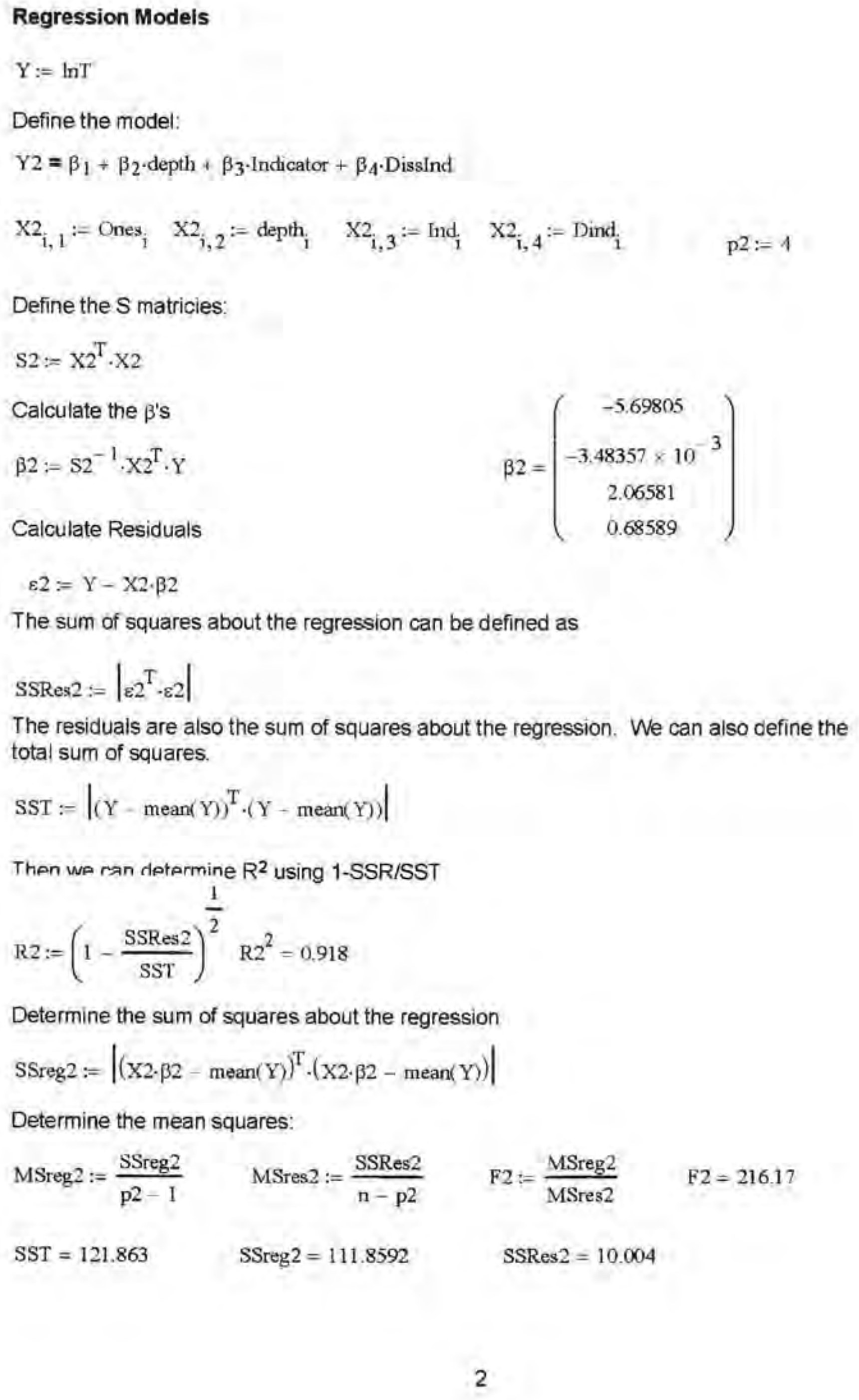
$cutoff := -5.4$ $Ind_i := if\left(lnT_i > cutoff, 1, 0\right)$

Define a vector of ones for intercept values

$Ones_i := 1$

1

Figure A.1: Mathcad source for regression model



Regression Models

$Y := \ln T$

Define the model:

$Y2 \equiv \beta_1 + \beta_2 \cdot \text{depth} + \beta_3 \cdot \text{Indicator} + \beta_4 \cdot \text{DissInd}$

$X2_{i,1} := \text{Ones}_i \quad X2_{i,2} := \text{depth}_i \quad X2_{i,3} := \text{Ind}_i \quad X2_{i,4} := \text{Dind}_i \qquad p2 := 4$

Define the S matricies:

$S2 := X2^T \cdot X2$

Calculate the β's

$\beta 2 := S2^{-1} \cdot X2^T \cdot Y$

$$\beta 2 = \begin{pmatrix} -5.69805 \\ -3.48357 \times 10^{-3} \\ 2.06581 \\ 0.68589 \end{pmatrix}$$

Calculate Residuals

$\varepsilon 2 := Y - X2 \cdot \beta 2$

The sum of squares about the regression can be defined as

$SSRes2 := \left| \varepsilon 2^T \cdot \varepsilon 2 \right|$

The residuals are also the sum of squares about the regression. We can also define the total sum of squares.

$SST := \left| (Y - \text{mean}(Y))^T \cdot (Y - \text{mean}(Y)) \right|$

Then we can determine R^2 using 1-SSR/SST

$R2 := \left(1 - \frac{SSRes2}{SST} \right)^{\frac{1}{2}} \quad R2^2 = 0.918$

Determine the sum of squares about the regression

$SSreg2 := \left| (X2 \cdot \beta 2 - \text{mean}(Y))^T \cdot (X2 \cdot \beta 2 - \text{mean}(Y)) \right|$

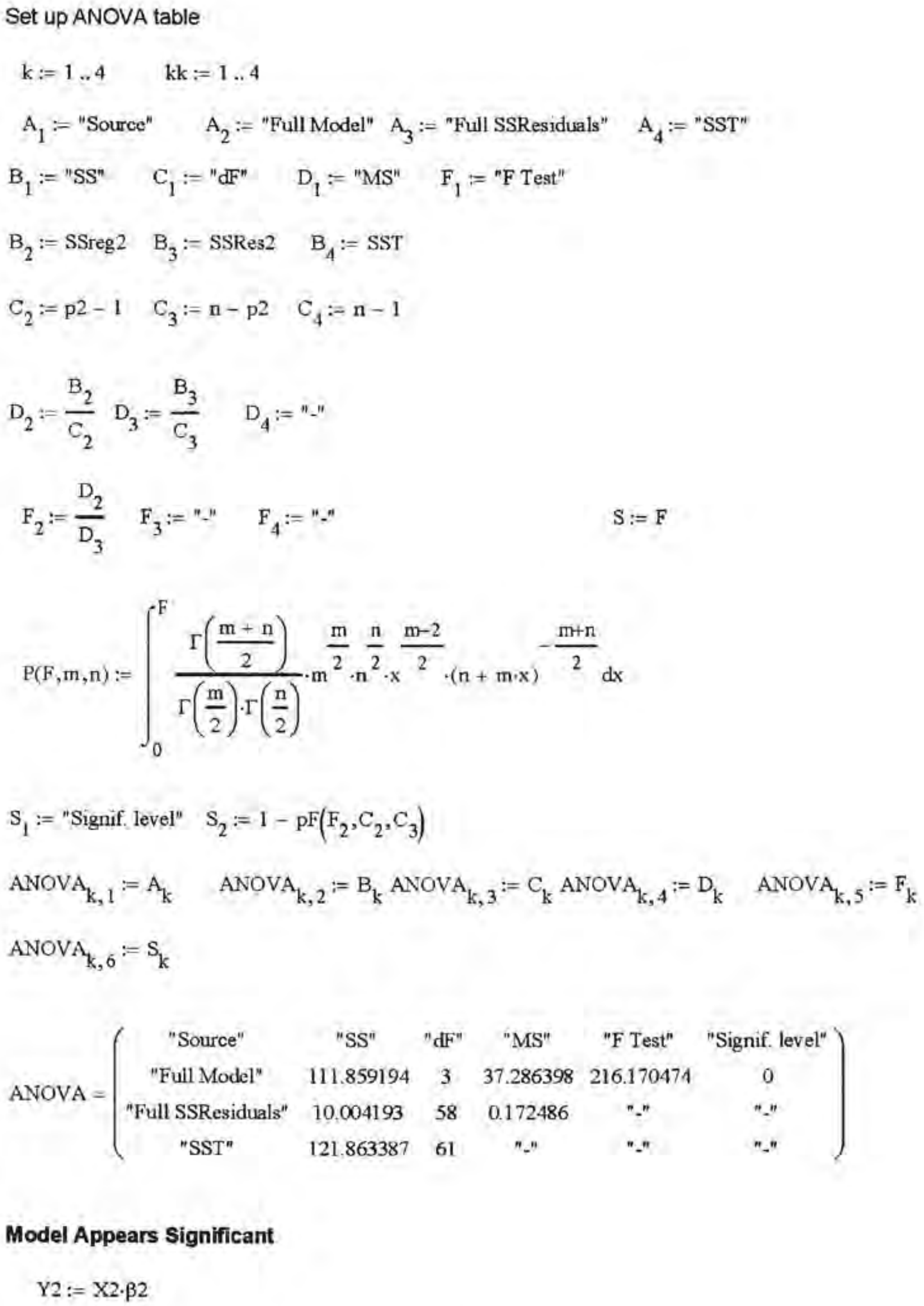
Determine the mean squares:

$MSreg2 := \frac{SSreg2}{p2 - 1} \qquad MSres2 := \frac{SSRes2}{n - p2} \qquad F2 := \frac{MSreg2}{MSres2} \qquad F2 = 216.17$

$SST = 121.863 \qquad SSreg2 = 111.8592 \qquad SSRes2 = 10.004$

2

Figure A.2: Mathcad source for regression model, ctd.



Set up ANOVA table

$k := 1 .. 4 \qquad kk := 1 .. 4$

$A_1 :=$ "Source" $\quad A_2 :=$ "Full Model" $\quad A_3 :=$ "Full SSResiduals" $\quad A_4 :=$ "SST"

$B_1 :=$ "SS" $\quad C_1 :=$ "dF" $\quad D_1 :=$ "MS" $\quad F_1 :=$ "F Test"

$B_2 := SSreg2 \quad B_3 := SSRes2 \quad B_4 := SST$

$C_2 := p2 - 1 \quad C_3 := n - p2 \quad C_4 := n - 1$

$D_2 := \frac{B_2}{C_2} \quad D_3 := \frac{B_3}{C_3} \quad D_4 :=$ "-"

$F_2 := \frac{D_2}{D_3} \quad F_3 :=$ "-" $\quad F_4 :=$ "-" $\qquad S := F$

$$P(F,m,n) := \int_0^F \frac{\Gamma\left(\frac{m+n}{2}\right)}{\Gamma\left(\frac{m}{2}\right)\cdot\Gamma\left(\frac{n}{2}\right)}\cdot m^{\frac{m}{2}}\cdot n^{\frac{n}{2}}\cdot x^{\frac{m-2}{2}}\cdot(n+m\cdot x)^{-\frac{m+n}{2}}\,dx$$

$S_1 :=$ "Signif. level" $\quad S_2 := 1 - pF(F_2, C_2, C_3)$

$ANOVA_{k,1} := A_k \quad ANOVA_{k,2} := B_k \quad ANOVA_{k,3} := C_k \quad ANOVA_{k,4} := D_k \quad ANOVA_{k,5} := F_k$

$ANOVA_{k,6} := S_k$

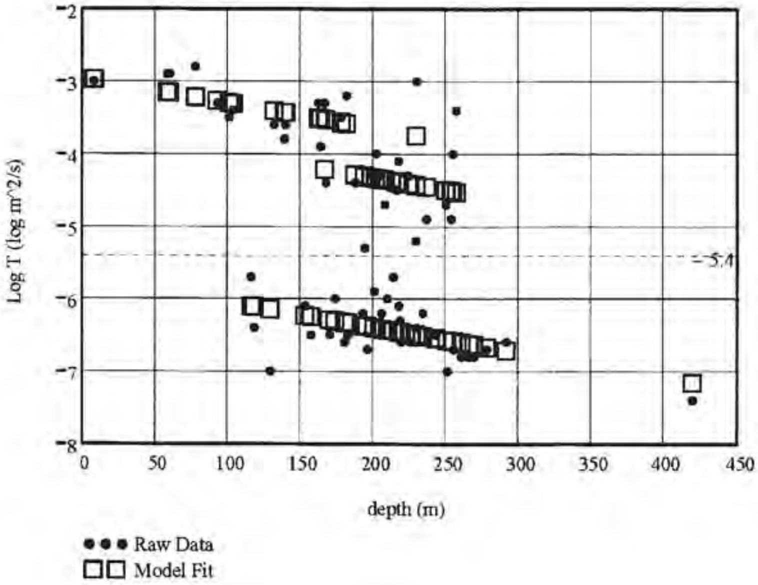
$$ANOVA = \begin{pmatrix} \text{"Source"} & \text{"SS"} & \text{"dF"} & \text{"MS"} & \text{"F Test"} & \text{"Signif. level"} \\ \text{"Full Model"} & 111.859194 & 3 & 37.286398 & 216.170474 & 0 \\ \text{"Full SSResiduals"} & 10.004193 & 58 & 0.172486 & \text{"-"} & \text{"-"} \\ \text{"SST"} & 121.863387 & 61 & \text{"-"} & \text{"-"} & \text{"-"} \end{pmatrix}$$

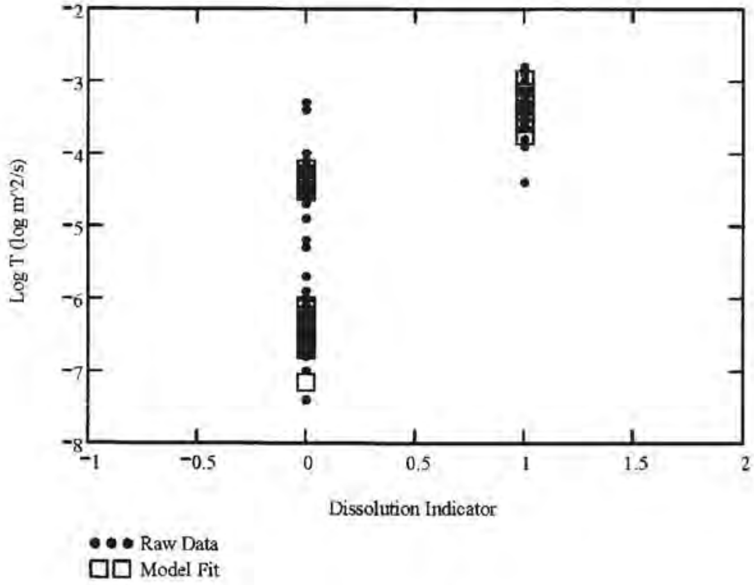
Model Appears Significant

$Y2 := X2\cdot\beta2$

Figure A.3: Mathcad source for regression model, ctd.

Let's look at the fits





4

Figure A.4: Mathcad source for regression model, ctd.

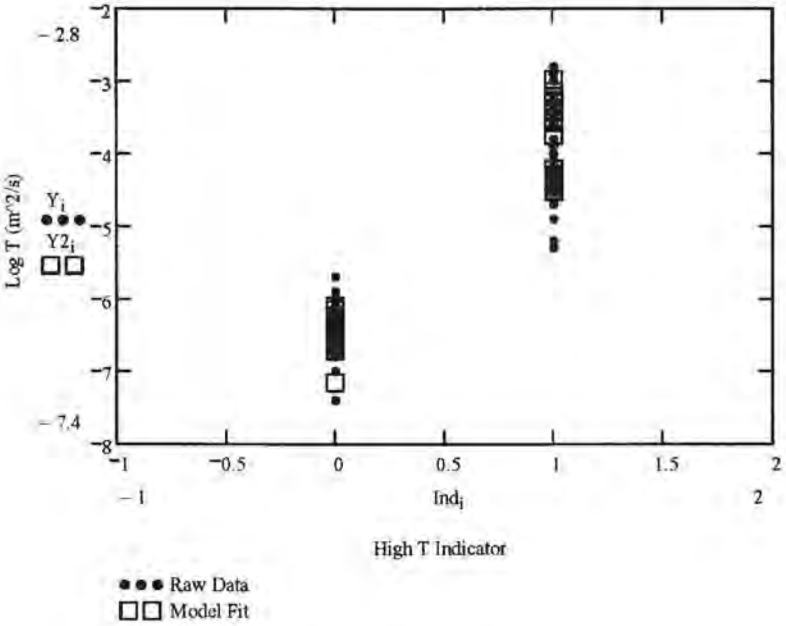


Figure A.5: Mathcad source for regression model, ctd.

Appendix B

Inputs, Outputs, and Scripts used in Subtask 2

The following files were used or created during the compilation of soft data.

CVS Root: `:ext:elo.sandia.gov:/data/CVSLIB/AP114`

Script Files Repository: `Task5/Inputs/scripts`

Data Files Repository: `Task5/Inputs/config`

Outputs Repository: `Task5/Outputs/runs/subtask2`

`createSoftData.sh`	Script to create all the soft data. Listing B.1.
`makeGypsum.m`	Matlab script to create gypsum soft data. Listing B.3.
`makeHalite.m`	Matlab script to create halite soft data. Listing B.2.
`makeConnect.m`	Matlab script to create diffusivity based soft data. Listing B.4.
`createSoftDataGrfx.sh`	Script to create graphics from the outputs. Listing B.5
`h2_200711.csv`	Halite margin M2/H2 (input). Not listed here due to length. From Powers (2007)
`h3_200711.csv`	Halite margin M3/H3 (input). Not listed here due to length. From Powers (2007)
`header.dat`	GEO-EAS header information (input). See first 9 lines of Listing B.9
`low_gypsum.txt`	Areas of low gypsum content (input). Not listed here due to length. Digitized from maps in Appendix F.
`no_gypsum.txt`	Areas of no gypsum content (input). Not listed here due to length. Digitized from maps in Appendix F.
`wellcoords.txt`	UTM NAD27 X and Y coordinates for each well (input). Listing B.6. Wells are in alphabetical order.
`connections.txt`	Matrix of high diffusivity connections between wells (input). Listing B.7. This file provides the indices into `wellcoords.txt`.
`ndlogTe.dat`	Well T measurements and high/low indicator values (input). Listing B.8.
`softdata.dat`	GEO-EAS formatted file with probabilities calculated at each soft data location (output). Truncated due to length, Listing B.9. This file is the combined, final output of `createSoftData.sh`.

The source code can be validated by examining the code itself, and the results double checked by examining the figure presented in B.1.

Listing B.1: Source code for the subtask 2 control shell script `createSoftData.sh`

```
#!/bin/bash
#$Id: createSoftData.sh,v 1.1 2008/06/16 20:35:07 dbhart Exp $
#
# This script executes AP-114 Task 5 Subtask 2 - create soft data from
# geological data

echo "This␣is␣AP-114␣TASK-5␣SUBTASK-2:␣`date`"
```

```
echo "RCS-Info:␣\$Id\$"

# Copy necessary input files and scripts
SCRIPTS="makeHalite.m␣makeGypsum.m␣makeConnect.m␣createSoftDataGrfx.sh"
CONFIGS="h2_200711.csv␣h3_200711.csv␣header.dat␣low_gypsum.txt␣no_gypsum.txt␣wellcoords.txt␣LucidaTypewriterRegular.ttf␣ndlogTe.dat"
SAVEFILES="softdata.dat"
GRAPHICS="softdata.png"

[ -d graphics ] || { mkdir graphics; }
[ -d subtask2 ] || { mkdir subtask2; }

# Verify MATLAB(R) intallation
MATLABPATH=`which matlab`
if [ -z "$MATLABPATH" ] ; then
    echo 'MATLAB(R) is not installed!'
    echo 'MATLAB is required to execute Subtask 2 — please try again'
else
    # Create the soft data pieces
    matlab -nodesktop <<EOF
disp('Mapping no-gypsum...');
makeGypsum;
disp('Mapping halite...');
makeHalite;
disp('Making connections...');
makeConnect;
quit;
EOF
    # Create the softdata input file
    cat header.dat halite.dat no_gypsum.dat low_gypsum.dat connections.dat> softdata.dat
    tail -n +9 ndlogTe.dat | awk '{print $1,$2,$3,$4,$6}' >> softdata.dat
    echo
fi

# Create graphics
bash createSoftDataGrfx.sh

cp $SAVEFILES subtask2
cp $GRAPHICS graphics

echo "AP-114␣Task-5␣Subtask-2␣Finished:␣`date`"
```

Listing B.2: Create soft data for the halite bounding area

```
% MAKEHALITE creates the Halite margin soft data for the base field
% creation
%
%$Id: makeHalite.m,v 1.4 2008/07/23 19:19:04 dbhart Exp $
```

```

warning('off','all');

% Create the model domain grid and read in the data files
[X,Y] = meshgrid([601700:100:630000],[3566500:100:3597100]);
[h2] = textread('h2_200711.csv','','delimiter',',','headerlines',1);
[h3] = textread('h3_200711.csv','','delimiter',',','headerlines',1);

% Clean up the halite margin data from the CSV files
h2 = h2(1:338,:);
h2(end+1,:) = [h2(end,1),h2(1,2)];
h2(end,:) = [h2(1,1),h2(end-1,2)];
h2(end+1,:) = [h2(end,1),h2(1,2)];
h3(end+1,:) = [h3(end,1),h3(1,2)];

% Map the areas within the two halite margins onto the X and Y grid
H2G = inpolygon(X,Y,h2(:,1),h2(:,2));
H3G = inpolygon(X,Y,h3(:,1),h3(:,2));
haliteDbl = H2G & H3G;
haliteSng = H2G | H3G;

% Downsample the grid so that not every cell has data in it, keep contour
chanelPts = haliteDbl;
chanelPts(:,:) = 0;
CPX = [115,102,96,100,104,110,132,128,125,125,130,146];
CPY = [95,75,60,45,30,10,90,72,57,45,32,15];
CPC = [CPX',CPY'];
for iC = 1:size(CPC,1)
  chanelPts(CPC(iC,2),CPC(iC,1)+4) = 1;
end
XX = X(1:3:end,1:3:end);
YY = Y(1:3:end,1:3:end);
CC = contour(X,Y,haliteSng,[1 1])';
HH = haliteSng(1:3:end,1:3:end);
edge = [CC(2:end,:),ones(CC(1,2),1),zeros(CC(1,2),1),ones(CC(1,2),1) ];
CP = chanelPts;
ll = size(CP,1)*size(CP,2);
line = [X(1:end)',Y(1:end)',CP(1:end)',zeros(ll,1),ones(ll,1)];
line = line(line(:,3)==1,:);
edge = [line;edge];

% Create the Geo-EAS formatted data and select only those we want (HH==1)
ll = size(HH,1)*size(HH,2);
line = [XX(1:end)',YY(1:end)',HH(1:end)',zeros(ll,1),ones(ll,1)];
line = line(line(:,3)==1,:);
% line = [line ; edge]; line = edge;
% Save the data
save('halite.dat','line','-ASCII');
```

Listing B.3: Create soft data for the no-gypsum bounded area

```
% MAKEGYPSUM creates the Gypsum soft data for the base field creation
%
%$Id: makeGypsum.m,v 1.8 2008/07/23 19:19:04 dbhart Exp $

warning('off','all');

[gyp] = textread('no_gypsum.txt','','headerlines',0);
X = reshape(gyp(:,1),284,307)';
Y = reshape(gyp(:,2),284,307)';
G = reshape(gyp(:,3),284,307)';
nNoGyp = sum(gyp(:,3));

XX =[ X(1:26:end,1:26:end); X(13:26:end,13:26:end);];
YY =[ Y(1:26:end,1:26:end); Y(13:26:end,13:26:end);];
GG =[ G(1:26:end,1:26:end); G(13:26:end,13:26:end);];

no_gypsum = [XX(1:end);YY(1:end);GG(1:end);0.95*ones(size(XX,1)*size(XX,2),1)';0.05*ones(size(XX,1)*size(XX,2),1)']';
no_gypsum = no_gypsum(no_gypsum(:,3)==1,:);
save('no_gypsum.dat','no_gypsum','-ASCII');

[gyp] = textread('low_gypsum.txt','','headerlines',0);
X = reshape(gyp(:,1),284,307)';
Y = reshape(gyp(:,2),284,307)';
G = reshape(gyp(:,3),284,307)';
nLowG = sum(gyp(:,3)==0);

XX =[ X(1:26:end,1:26:end); X(13:26:end,13:26:end);];
YY =[ Y(1:26:end,1:26:end); Y(13:26:end,13:26:end);];
GG =[ G(1:26:end,1:26:end); G(13:26:end,13:26:end);];
low_gypsum = [XX(1:end);YY(1:end);1-GG(1:end);0.05*ones(size(XX,1)*size(XX,2),1)';0.95*ones(size(XX,1)*size(XX,2),1)']';
XX =X(210:10:260,84:10:130);
YY =Y(210:10:260,84:10:130);
GG =G(210:10:260,84:10:130);
low_gypsum = [low_gypsum; [XX(1:end);YY(1:end);1-GG(1:end);0.05*ones(size(XX,1)*size(XX,2),1)';0.95*ones(size(XX,1)*size(XX,2),1)']'];
low_gypsum = low_gypsum(low_gypsum(:,3)==1,:);
save('low_gypsum.dat','low_gypsum','-ASCII');

highToLow = nNoGyp / nLowG;
```

Listing B.4: Create soft data for the high diffusivity well connections

```
% MAKECONNECT creates the diffusivity soft data for the base field creation
%
%$Id: makeConnect.m,v 1.4 2008/07/23 19:19:04 dbhart Exp $
```

```

warning('off','all');

spacing = 100;

connections = load('connections.txt');
wellcoords = load('wellcoords.txt');
CC = [];
for i = 1:length(connections);
  Start = connections(i,1);
  Stop = connections(i,2);
  X1 = wellcoords(Start,1);
  Y1 = wellcoords(Start,2);
  X2 = wellcoords(Stop,1);
  Y2 = wellcoords(Stop,2);
  if X2 == X1,
    X1 = X1 - 50.0;
  end
  m = ( Y2 - Y1 ) / (X2 - X1);
  b = Y1 - m * X1;
  XX = min(X1,X2):10:max(X1,X2);
  YY = m .* XX + b;
  YY2 = min(Y1,Y2):10:max(Y1,Y2);
  XX2 = ( YY2 - b ) ./ m;
  CC = [ CC ; XX', YY' ; XX2', YY2'];
end
CC = unique(round(CC/spacing)*spacing,'rows');
CC(1:end,3) = 1;
CC(1:end,4) = 0.75;
CC(1:end,5) = 0.25;
CC = sortrows(CC);
CC = [ CC(mod(CC(:,1),100)==0,:) ; CC(mod(CC(:,2),100)==0,:) ];

save('connections.dat','CC','-ASCII');
```

Listing B.5: Source code for the subtask 2 graphics generation script `createSoftDataGrfx.sh`

```
#!/bin/bash
#$Id: createSoftDataGrfx.sh,v 1.1 2008/06/16 20:35:07 dbhart Exp $
#
# This script executes AP-114 Task 5 Subtask 2 graphics creation

# Get hard data for comparison
cat ndlogTe.dat | awk '{if ( $4 == 1 ) print; }' > highT.gp
cat ndlogTe.dat | awk '{if ( $6 == 1 ) print; }' > lowT.gp

# Create a graph of soft data locations
gnuplot <<EOF
set terminal png font "./LucidaTypewriterRegular.ttf" 20 size 1800,1800
```

```
    nocrop enhanced
set size ratio -1
set view map

set xlabel "Easting␣UTM␣NAD27"
set ylabel "Northing␣UTM␣NAD27"
set palette maxcolors 256
set format x "%.0f"
set format y "%.0f"
set ytics rotate
set xtics
set xrange [601700:630000]
set yrange [3566500:3597100]
set key tmargin horizontal

set palette model CMY negative maxcolors 256
set output 'softdata.png'
plot 'halite.dat' u 1:2 w p lc rgb "blue" pt 6 ps 1.5 title "Halite",\
 'no_gypsum.dat' u 1:2 w p lc rgb "red" pt 8 ps 1.5 title "No␣Gypsum",\
 'low_gypsum.dat' u 1:2 w p lc rgb "blue" pt 10 ps 1.5 title "High␣Gypsum",\
 'connections.dat' u 1:2 w p lc rgb "dark-red" pt 10 ps 1.5 title "Connections",\
 'highT.gp' u 1:2 w p lc rgb "light-red" pt 13 ps 2 title "High␣T␣Well", \
 'lowT.gp' u 1:2 w p lc rgb "light-blue" pt 13 ps 2 title "Low␣T␣Well"

EOF

echo "\$Id\$" >> softdata.png
```

Listing B.6: `wellcoords.txt` – this file has UTM NAD27 X and Y coordinates of each well in alphabetical order.

```
  6.2112600e+005   3.5893810e+006
  6.1359700e+005   3.5814010e+006
  6.1319100e+005   3.5780490e+006
  6.0870200e+005   3.5788770e+006
  6.1520300e+005   3.5803330e+006
  6.1368300e+005   3.5852940e+006
  6.1495300e+005   3.5674540e+006
  6.1369600e+005   3.5819580e+006
  6.1342300e+005   3.5816840e+006
  6.2297500e+005   3.5724730e+006
  6.1530100e+005   3.5791310e+006
  6.1702300e+005   3.5754520e+006
  6.1234100e+005   3.5803540e+006
  6.1531500e+005   3.5818590e+006
  6.1336900e+005   3.5822120e+006
  6.1571800e+005   3.5775130e+006
```

17	6.1226400e+005	3.5831660e+006
18	6.1451400e+005	3.5807160e+006
19	6.1266600e+005	3.5816680e+006
20	6.1372900e+005	3.5808950e+006
21	6.1240600e+005	3.5784990e+006
22	6.1690300e+005	3.5848020e+006
23	6.1061000e+005	3.5849830e+006
24	6.0809500e+005	3.5746400e+006
25	6.1397400e+005	3.5682340e+006
26	6.0618000e+005	3.5822400e+006
27	6.0908400e+005	3.5819760e+006
28	6.1062400e+005	3.5787470e+006
29	6.1392600e+005	3.5774660e+006
30	6.1378100e+005	3.5942990e+006
31	6.1121700e+005	3.5817770e+006
32	6.1321000e+005	3.5727280e+006
33	6.1039400e+005	3.5776000e+006
34	6.1497300e+005	3.5776430e+006
35	6.1835300e+005	3.5803360e+006
36	6.0526500e+005	3.5790370e+006
37	6.0986300e+005	3.5760160e+006
38	6.1360600e+005	3.5915360e+006
39	6.0781600e+005	3.5889310e+006
40	6.0911300e+005	3.5865290e+006
41	6.1610300e+005	3.5890470e+006
42	6.1197000e+005	3.5872850e+006
43	6.2124400e+005	3.5953900e+006
44	6.1852300e+005	3.5837830e+006
45	6.0870500e+005	3.5822380e+006
46	6.0646200e+005	3.5694590e+006
47	6.1379100e+005	3.5864750e+006
48	6.1371000e+005	3.5835240e+006
49	6.1264400e+005	3.5842470e+006
50	6.1373500e+005	3.5831790e+006
51	6.1373900e+005	3.5827820e+006
52	6.1374300e+005	3.5823190e+006
53	6.1373900e+005	3.5826530e+006
54	6.0638500e+005	3.5840280e+006
55	6.0401400e+005	3.5811620e+006
56	6.0442600e+005	3.5930790e+006
57	6.1126600e+005	3.5946800e+006
58	6.1372100e+005	3.5897010e+006
59	6.1256100e+005	3.5834270e+006
60	6.1377600e+005	3.5839730e+006
61	6.1468600e+005	3.5835180e+006
62	6.1472800e+005	3.5807660e+006
63	6.1366800e+005	3.5803530e+006
64	6.1260500e+005	3.5807360e+006

Listing B.7: `connections.txt` – this file show the indices into `wellcoords.txt`, with starting and ending index on each line.

```
27  4
11  5
18  5
49  6
60  6
25  7
34  11
11  14
34  14
47  17
11  18
18  20
5  20
6  23
27  23
40  23
45  23
47  23
49  23
45  26
54  26
25  32
34  32
38  41
30  47
41  47
58  47
27  49
42  49
47  49
54  49
58  49
59  49
27  54
45  54
17  60
47  60
49  60
59  60
```

Listing B.8: `ndlogTe.dat` – column headings are given on lines 3-9.

```
Culebra log T data and indicators
6
UTMX
UTMY
```

```
ZDUM
HTI
logT
LTI
621126   3589381  1       0       -6.8    1
613597   3581401  1       0       -6.2    1
613191   3578049  1       0       -6.5    1
608702   3578877  1       0       -5.7    1
615203   3580333  1       1       -4.9    0
613683   3585294  1       1       -4      0
613696   3581958  1       0       -6.3    1
613423   3581684  1       0       -6      1
622975   3572473  1       0       -7.4    1
615301   3579131  1       1       -4.3    0
617023   3575452  1       0       -6.7    1
612341   3580354  1       0       -6.5    1
615315   3581859  1       0       -6.8    1
613369   3582212  1       0       -6.1    1
615718   3577513  1       0       -6.6    1
612264   3583166  1       0       -5.7    1
614514   3580716  1       1       -5.2    0
612666   3581668  1       0       -6.2    1
613729   3580895  1       1       -4.7    0
612406   3578499  1       0       -6.1    1
616903   3584802  1       0       -6.7    1
610610   3584983  1       1       -4.4    0
610624   3578747  1       0       -7      1
613926   3577466  1       0       -6      1
611217   3581777  1       0       -6.5    1
613210   3572728  1       1       -3.3    0
610394   3577599  1       0       -6.4    1
614973   3577643  1       1       -4.3    0
611969   3587284  1       1       -5.3    0
618523   3583783  1       0       -6.6    1
613791   3586475  1       1       -3.4    0
613710   3583524  1       0       -7      1
612644   3584247  1       1       -4.1    0
613735   3583179  1       0       -6.5    1
613739   3582782  1       0       -6.2    1
613743   3582319  1       0       -6.6    1
613739   3582653  1       0       -6.4    1
613721   3589701  1       0       -6.7    1
612561   3583427  1       1       -4.5    0
613776   3583973  1       1       -4.7    0
614686   3583518  1       0       -6.8    1
614728   3580766  1       1       -4.9    0
613668   3580353  1       0       -5.9    1
612605   3580736  1       0       -6.6    1
614953   3567454  1       1       -4.3    0
613974   3568234  1       1       -4.0    0
```

Listing B.9: `softdata.dat` truncated to 200 lines. Please see B.1 for a graphical representation of this file.

```
Culebra log T data and indicators
5
UTMX
UTMY
ZDUM
HTI
LTI
    6.1160000e+05   3.5724000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1200000e+05   3.5709000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1220000e+05   3.5739000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1240000e+05   3.5694000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1300000e+05   3.5674000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1350000e+05   3.5759000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1450000e+05   3.5709000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1450000e+05   3.5721000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1480000e+05   3.5736000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1500000e+05   3.5696000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1520000e+05   3.5754000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1660000e+05   3.5679000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1480000e+05   3.5971000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1480000e+05   3.5971000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1490000e+05   3.5971000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1500000e+05   3.5970000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1500000e+05   3.5970000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1510000e+05   3.5969000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1510000e+05   3.5969000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1520000e+05   3.5968000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
    6.1520000e+05   3.5968000e+06   1.0000000e+00   0.0000000e+00   1.0000000e+00
```

29	6.1530000e+05 +00	3.5967000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
30	6.1530000e+05 +00	3.5967000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
31	6.1540000e+05 +00	3.5966000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
32	6.1540000e+05 +00	3.5966000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
33	6.1550000e+05 +00	3.5966000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
34	6.1560000e+05 +00	3.5965000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
35	6.1560000e+05 +00	3.5965000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
36	6.1570000e+05 +00	3.5964000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
37	6.1570000e+05 +00	3.5964000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
38	6.1580000e+05 +00	3.5963000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
39	6.1580000e+05 +00	3.5963000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
40	6.1590000e+05 +00	3.5962000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
41	6.1590000e+05 +00	3.5962000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
42	6.1600000e+05 +00	3.5961000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
43	6.1600000e+05 +00	3.5961000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
44	6.1610000e+05 +00	3.5961000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
45	6.1620000e+05 +00	3.5960000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
46	6.1620000e+05 +00	3.5960000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
47	6.1630000e+05 +00	3.5959000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
48	6.1630000e+05 +00	3.5959000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
49	6.1640000e+05 +00	3.5958000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
50	6.1640000e+05 +00	3.5958000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
51	6.1650000e+05 +00	3.5957000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
52	6.1650000e+05 +00	3.5957000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
53	6.1660000e+05 +00	3.5956000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
54	6.1660000e+05	3.5956000e+06	1.0000000e+00	0.0000000e+00	1.0000000e

+00

55	6.1670000e+05	3.5956000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
56	6.1680000e+05	3.5955000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
57	6.1680000e+05	3.5955000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
58	6.1690000e+05	3.5954000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
59	6.1690000e+05	3.5954000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
60	6.1700000e+05	3.5953000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
61	6.1700000e+05	3.5953000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
62	6.1710000e+05	3.5953000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
63	6.1720000e+05	3.5952000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
64	6.1720000e+05	3.5952000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
65	6.1730000e+05	3.5951000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
66	6.1730000e+05	3.5951000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
67	6.1740000e+05	3.5950000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
68	6.1740000e+05	3.5950000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
69	6.1750000e+05	3.5950000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
70	6.1760000e+05	3.5949000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
71	6.1760000e+05	3.5949000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
72	6.1770000e+05	3.5948000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
73	6.1770000e+05	3.5948000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
74	6.1780000e+05	3.5947000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
75	6.1780000e+05	3.5947000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
76	6.1790000e+05	3.5947000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
77	6.1800000e+05	3.5946000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
78	6.1800000e+05	3.5946000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
79	6.1810000e+05	3.5945000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00

80	6.1810000e+05 +00	3.5945000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
81	6.1820000e+05 +00	3.5944000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
82	6.1820000e+05 +00	3.5944000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
83	6.1830000e+05 +00	3.5944000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
84	6.1840000e+05 +00	3.5943000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
85	6.1840000e+05 +00	3.5943000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
86	6.1850000e+05 +00	3.5942000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
87	6.1850000e+05 +00	3.5942000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
88	6.1860000e+05 +00	3.5941000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
89	6.1860000e+05 +00	3.5941000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
90	6.1870000e+05 +00	3.5941000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
91	6.1880000e+05 +00	3.5940000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
92	6.1880000e+05 +00	3.5940000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
93	6.1890000e+05 +00	3.5939000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
94	6.1890000e+05 +00	3.5939000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
95	6.1900000e+05 +00	3.5938000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
96	6.1900000e+05 +00	3.5937000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
97	6.1890000e+05 +00	3.5936000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
98	6.1890000e+05 +00	3.5936000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
99	6.1890000e+05 +00	3.5935000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
100	6.1890000e+05 +00	3.5934000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
101	6.1890000e+05 +00	3.5933000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
102	6.1890000e+05 +00	3.5933000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
103	6.1900000e+05 +00	3.5932000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
104	6.1900000e+05 +00	3.5931000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
105	6.1900000e+05	3.5931000e+06	1.0000000e+00	0.0000000e+00	1.0000000e

					+00
106	6.1910000e+05	3.5930000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
107	6.1910000e+05	3.5929000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
108	6.1910000e+05	3.5929000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
109	6.1920000e+05	3.5928000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
110	6.1920000e+05	3.5927000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
111	6.1920000e+05	3.5927000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
112	6.1930000e+05	3.5926000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
113	6.1930000e+05	3.5925000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
114	6.1930000e+05	3.5925000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
115	6.1940000e+05	3.5924000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
116	6.1940000e+05	3.5923000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
117	6.1940000e+05	3.5923000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
118	6.1950000e+05	3.5922000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
119	6.1950000e+05	3.5921000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
120	6.1950000e+05	3.5921000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
121	6.1960000e+05	3.5920000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
122	6.1960000e+05	3.5919000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
123	6.1960000e+05	3.5919000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
124	6.1970000e+05	3.5918000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
125	6.1970000e+05	3.5917000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
126	6.1970000e+05	3.5917000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
127	6.1980000e+05	3.5916000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
128	6.1980000e+05	3.5915000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
129	6.1980000e+05	3.5915000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
130	6.1990000e+05	3.5914000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00

131	6.1990000e+05 +00	3.5914000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
132	6.2000000e+05 +00	3.5913000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
133	6.2000000e+05 +00	3.5913000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
134	6.2010000e+05 +00	3.5913000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
135	6.2020000e+05 +00	3.5913000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
136	6.2030000e+05 +00	3.5912000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
137	6.2030000e+05 +00	3.5912000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
138	6.2040000e+05 +00	3.5912000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
139	6.2050000e+05 +00	3.5911000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
140	6.2050000e+05 +00	3.5911000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
141	6.2060000e+05 +00	3.5910000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
142	6.2060000e+05 +00	3.5909000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
143	6.2060000e+05 +00	3.5909000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
144	6.2070000e+05 +00	3.5908000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
145	6.2070000e+05 +00	3.5907000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
146	6.2070000e+05 +00	3.5906000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
147	6.2070000e+05 +00	3.5905000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
148	6.2070000e+05 +00	3.5904000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
149	6.2060000e+05 +00	3.5903000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
150	6.2060000e+05 +00	3.5903000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
151	6.2060000e+05 +00	3.5902000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
152	6.2050000e+05 +00	3.5901000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
153	6.2050000e+05 +00	3.5901000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
154	6.2040000e+05 +00	3.5900000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
155	6.2040000e+05 +00	3.5900000e+06	1.0000000e+00	0.0000000e+00	1.0000000e
156	6.2030000e+05	3.5899000e+06	1.0000000e+00	0.0000000e+00	1.0000000e

	+00				
157	6.2030000e+05	3.5899000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
158	6.2020000e+05	3.5898000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
159	6.2020000e+05	3.5898000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
160	6.2010000e+05	3.5897000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
161	6.2010000e+05	3.5897000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
162	6.2000000e+05	3.5896000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
163	6.2000000e+05	3.5896000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
164	6.1990000e+05	3.5895000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
165	6.1990000e+05	3.5895000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
166	6.1980000e+05	3.5894000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
167	6.1980000e+05	3.5894000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
168	6.1970000e+05	3.5893000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
169	6.1970000e+05	3.5893000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
170	6.1960000e+05	3.5892000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
171	6.1960000e+05	3.5892000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
172	6.1950000e+05	3.5891000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
173	6.1950000e+05	3.5891000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
174	6.1940000e+05	3.5890000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
175	6.1940000e+05	3.5890000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
176	6.1940000e+05	3.5889000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
177	6.1940000e+05	3.5889000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
178	6.1950000e+05	3.5889000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
179	6.1950000e+05	3.5889000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
180	6.1960000e+05	3.5890000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
181	6.1970000e+05	3.5890000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00

182	6.1970000e+05	3.5890000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
183	6.1980000e+05	3.5891000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
184	6.1980000e+05	3.5891000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
185	6.1990000e+05	3.5892000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
186	6.1990000e+05	3.5892000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
187	6.2000000e+05	3.5893000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
188	6.2000000e+05	3.5893000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
189	6.2010000e+05	3.5894000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
190	6.2010000e+05	3.5894000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
191	6.2020000e+05	3.5895000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
192	6.2020000e+05	3.5895000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
193	6.2030000e+05	3.5896000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
194	6.2030000e+05	3.5896000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
195	6.2040000e+05	3.5897000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
196	6.2050000e+05	3.5897000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
197	6.2050000e+05	3.5897000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
198	6.2060000e+05	3.5898000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
199	6.2070000e+05	3.5898000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00
200	6.2070000e+05	3.5898000e+06	1.0000000e+00	0.0000000e+00	1.0000000e+00

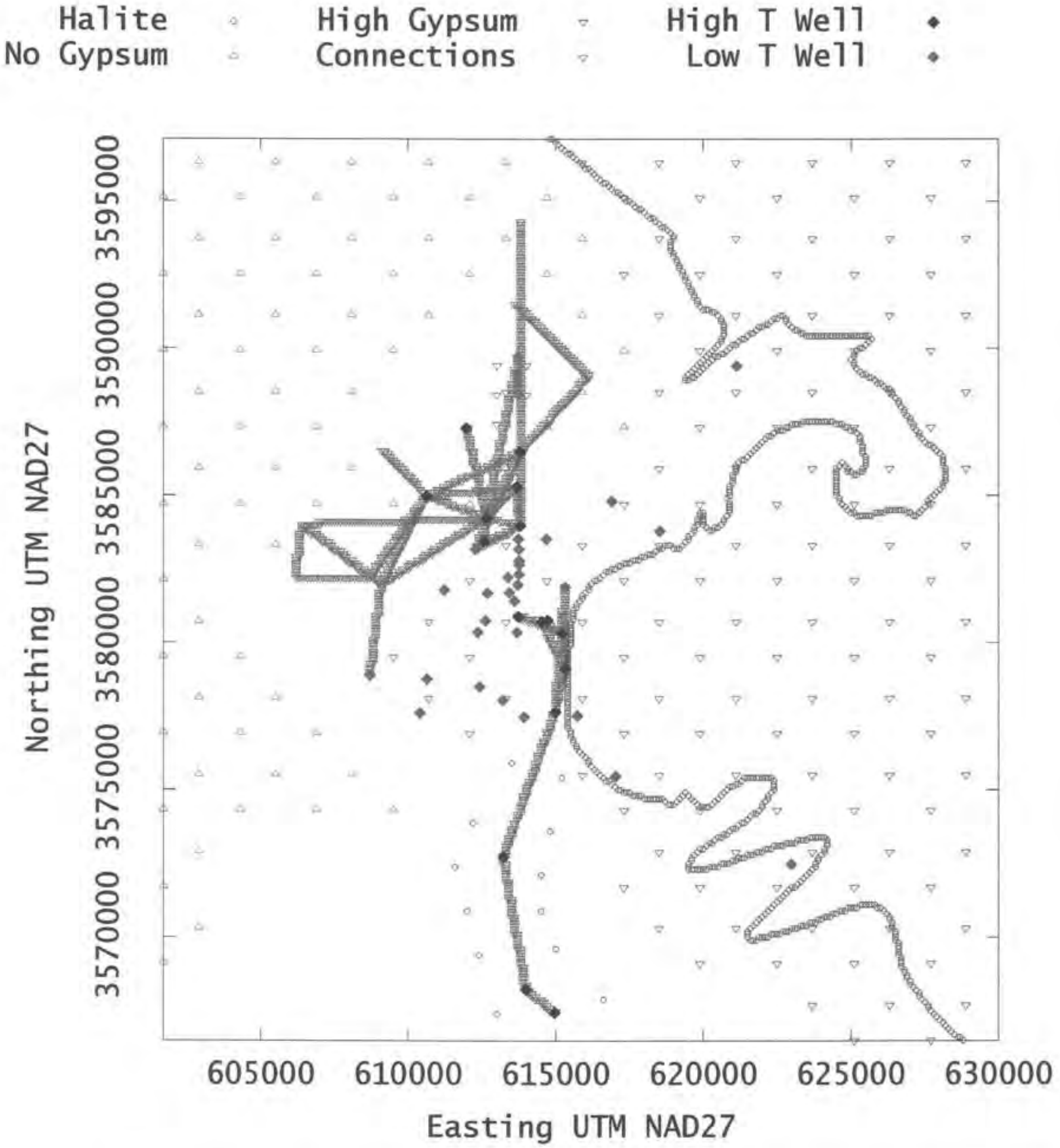


Figure B.1: Soft data points generated during subtask 2. Hard data points (indicator values at wells) are included for reference.

References

Powers, D. W. (2007). Analysis Report for Task 1A of AP-114: Refinement of Rustler Halite Margins Within the Culebra Modeling Domain. ERMS 547559, Sandia National Laboratories, Carlsbad, NM. WIPP Records Center.

Appendix C

Indicator Variography Inputs and Outputs Used in Subtask 3

These calculations were done on a laptop PC (Dell D620, SNL Property ID: S889688) in the directory: C:\projects\WIPP\FY08\T_Vario.

The input data are held and organized in the file: *T_Wells_UTMNAD27.xls* The data used in these calculations are shown in Table C-1. These are taken from the "Indicator" tab in the spreadsheet. Note that the UTMX and UTMY coordinates have been translated by subtracting 600,000 from the UTMX values and 3,500,000 from the UTMY values. This translation is done to facilitate calculations in the VarioWin software that does not handle numbers with > 6 digits.

The Translated UTM X and Translated UTM Y columns along with the indicator column are pasted into the *T_ind.dat* file and this file is used as input to the VarioWin program. The *T_ind.dat* file is listed at the end of this appendix. The final results of fitting the variogram model in the VarioWin program are the model parameters. There is no output file created or needed for any further applications. The variogram model parameters are copied from the graphical interface in the VarioWin "Model" application.

The first step in indicator variogram analysis is to identify any anisotropy in the spatial correlation of the data. The variogram surface is shown in (Figure C-1). This surface is created by grouping all indicator values into bins that define the distances and orientations by which they are separated. Each cell in the surface (Figure C-1) is 2000 by 2000 meters – the "lag" spacing used here. Therefore, all indicator values separated by +/- 1000 m or less, in any direction, are used in the variogram calculation to produce the variogram value assigned to the surface cell centered at coordinates (0.0,0.0). From Figure C-1, 156 pairs of indicator values fall within this central cell. Similarly, all indicator values separated by 6000 m (+/- 1000 m) in the E-W (X) direction and +/- 1000 m in the north-south (Y) direction are grouped and used to calculate the variogram value assigned to the cells centered at (6000.0,0.0) and (-6000.0,0.0). Six pairs of indicator data are separated by these distances (see Figure C-1). Figure C-1 shows indication of stronger correlation in the NE-SW direction at low values, near 0.10, of the variogram function.

Further analyses with directional variograms calculated in the NE-SW and NW-SE directions to identify this anisotropy are inconclusive (Figure C-2). While there is no doubt some anisotropy in the indicator data, the data set is not large enough to calculate and model this. When the variogram search neighborhood is limited with a bandwidth and angular-tolerance for the directional calculations shown in Figure C-2, the number of pairs of points available at each lag spacing for the calculations is reduced and the resulting variograms are quite variable. Note that the number of data pairs compared at each point is less than 20. In these variogram calculations, we require a minimum of 30 pairs for each lag spacing to produce a reliable estimate of the variogram function. Therefore, the directional variograms are not pursued and an omnidirectional variogram is calculated using a lag spacing of 500 m and the variogram model is fit to these results.

Table C-1. Culebra indicator transmissivity data listing.

Translated UTM X	Translated UTM Y	log T (m²/s)	Indicator (-5.4)	Well ID
22975.0	72473.0	-7.4	1.0	(H-10b)
10624.0	78747.0	-7	1.0	(P-15)
13710.0	83524.0	-7	1.0	(WIPP-12)
21126.0	89381.0	-6.8	1.0	(AEC-7)
15315.0	81859.0	-6.8	1.0	(H-15)
14686.0	83518.0	-6.8	1.0	(WQSP-3)
17023.0	75452.0	-6.7	1.0	(H-12)
16903.0	84802.0	-6.7	1.0	(H-5c)
13721.0	89701.0	-6.7	1.0	(WIPP-30)
15718.0	77513.0	-6.6	1.0	(H-17)
18522.5	83783.2	-6.6	1.0	(SNL-8)
13743.0	82319.0	-6.6	1.0	(WIPP-21)
12605.0	80736.0	-6.6	1.0	(WQSP-6)
13191.0	78049.0	-6.5	1.0	(CB-1)
12341.0	80354.0	-6.5	1.0	(H-14)
11217.0	81777.0	-6.5	1.0	(SNL-10)
13735.0	83179.0	-6.5	1.0	(WIPP-18)
10394.0	77599.6	-6.4	1.0	(SNL-13)
13739.0	82653.0	-6.4	1.0	(WIPP-22)
13696.0	81958.0	-6.3	1.0	(ERDA-9)
13597.0	81401.0	-6.2	1.0	(C-2737)
12666.0	81668.0	-6.2	1.0	(H-2c)
13739.0	82782.0	-6.2	1.0	(WIPP-19)
13369.0	82212.0	-6.1	1.0	(H-16)
12406.0	78499.0	-6.1	1.0	(H-4c)
13423.0	81684.0	-6	1.0	(H-1)
13926.0	77466.0	-6	1.0	(P-17)
13668.0	80353.0	-5.9	1.0	(WQSP-5)
8702.0	78877.0	-5.7	1.0	(D-268)
12264.0	83166.0	-5.7	1.0	(H-18)
11970.0	87284.7	-5.3	0.0	(SNL-5)
14514.0	80716.0	-5.2	0.0	(H-19b0)
15203.0	80333.0	-4.9	0.0	(DOE-1)
14728.0	80766.0	-4.9	0.0	(WQSP-4)
13729.0	80895.0	-4.7	0.0	(H-3b1)
13776.0	83973.0	-4.7	0.0	(WQSP-2)
12561.0	83427.0	-4.5	0.0	(WQSP-1)
10610.0	84983.0	-4.4	0.0	(H-6c)
14953.0	67454.0	-4.3	0.0	(Engle)
15301.0	79131.0	-4.3	0.0	(H-11b4)
14972.8	77643.4	-4.3	0.0	(SNL-14)
12644.0	84247.0	-4.1	0.0	(WIPP-13)
13683.0	85294.0	-4	0.0	(DOE-2)
13974.0	68234.0	-4	0.0	(H-9c)
13791.0	86475.0	-3.4	0.0	(WIPP-11)
13210.0	72728.0	-3.3	0.0	(SNL-12)

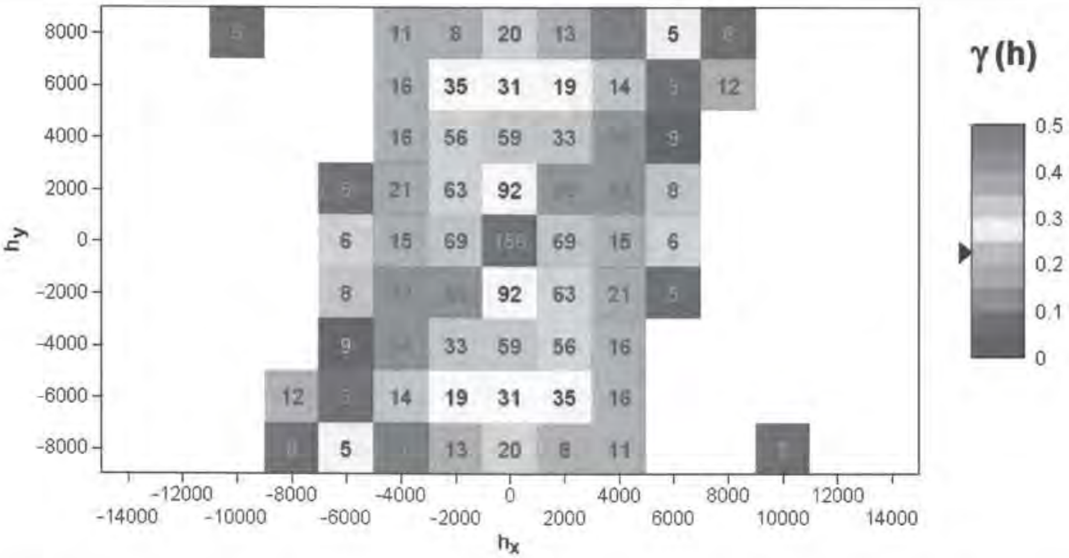


Figure C-1: Indicator variogram surface showing the dependence of the indicator variogram values on the orientation and lag distance. The color scale indicates the variogram value (unitless) and the black triangle identifies the theoretical sill (variance of the data set). The number in each cell denotes the number of pair comparisons used in the calculation for that cell location. The X and Y axis units are meters.

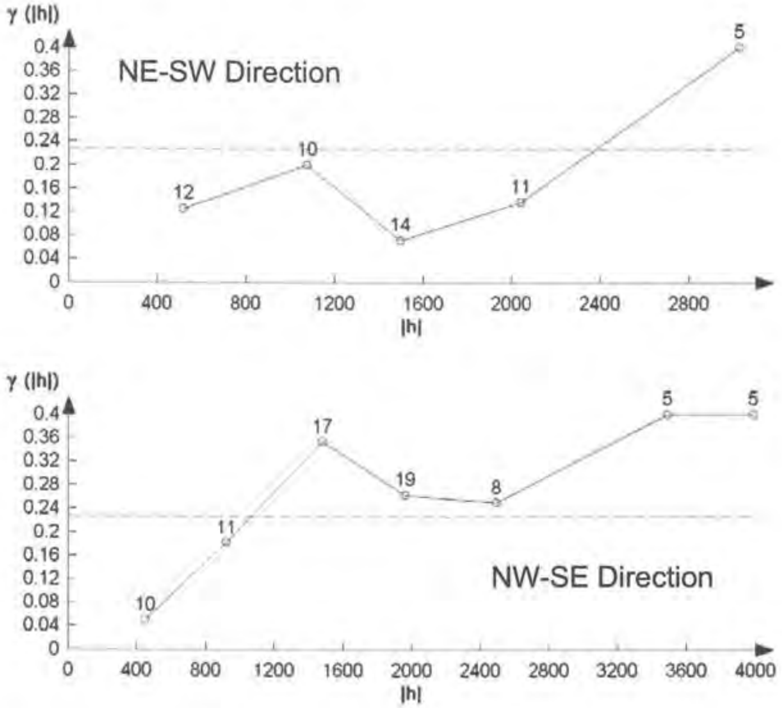


Figure C-2: Directional experimental variograms calculated in the NE-SW and NW-SE directions. The X-axis is the separation, or lag, distance, in meters and the variogram function is shown on the Y axis (unitless).

Listing C.1: T_ind.dat

```
Culebra log 10 T Indicator data, July 2008
3
Trans_X
Trans_Y
Ind
14686.0     83518.0     1.0
17023.0     75452.0     1.0
16903.0     84802.0     1.0
13721.0     89701.0     1.0
15718.0     77513.0     1.0
18522.5     83783.2     1.0
11970.0     87284.7     0.0
14514.0     80716.0     0.0
15203.0     80333.0     0.0
14728.0     80766.0     0.0
13729.0     80895.0     0.0
13735.0     83179.0     1.0
10394.0     77599.6     1.0
13974.0     68234.0     0.0
13791.0     86475.0     0.0
13210.0     72728.0     0.0
13739.0     82653.0     1.0
13696.0     81958.0     1.0
13597.0     81401.0     1.0
12666.0     81668.0     1.0
13739.0     82782.0     1.0
13369.0     82212.0     1.0
12406.0     78499.0     1.0
13423.0     81684.0     1.0
13926.0     77466.0     1.0
13668.0     80353.0     1.0
8702.0      78877.0     1.0
12264.0     83166.0     1.0
13776.0     83973.0     0.0
12561.0     83427.0     0.0
10610.0     84983.0     0.0
22975.0     72473.0     1.0
10624.0     78747.0     1.0
13710.0     83524.0     1.0
21126.0     89381.0     1.0
15315.0     81859.0     1.0
14953.0     67454.0     0.0
15301.0     79131.0     0.0
14972.8     77643.4     0.0
13743.0     82319.0     1.0
12605.0     80736.0     1.0
13191.0     78049.0     1.0
12341.0     80354.0     1.0
11217.0     81777.0     1.0
12644.0     84247.0     0.0
13683.0     85294.0     0.0
```

Appendix D

Inputs, Outputs, and Scripts used in Subtask 4

ADDCOORDS is easily validated by creating a graphic from outputs of a single realization, since any errror in adding coordinates would produce: 1) a graphic that would have no form and 2) the combined halite boundary line would be incorrectly placed. The sample indicator field presented in Figure D.1 shows that the combined M2/H2 and M3/H3 margins are placed correctly, which means that ADDCOORDS is working correctly.

The Figures D.2 and D.3 show that where a data point has a P value of 1.0 or 0.0, the standard deviation at that point is zero. Places where the P value is between zero and one have slightly higher standard deviations, and have an average value that is close to the set P value. By examining the source code, available in Deutsch & Journel (1998) and kept with the data files in CVS, and by verifying that the mean field effectively reproduces the soft data with a satisfactory variance (shown by the standard deviation field) verifies that the SISIM code is performing properly.

The input and output files used are presented in the table below. The sample field for which inputs and outputs are provided is field r123 which is presented again in Figure D.1.

CVS Root: `:ext:elo.sandia.gov:/data/CVSLIB/AP114`

Script Files Repository: `Task5/Inputs/scripts`

Sourcecode Repository: `Task5/Inputs/source`

Data Files Repository: `Task5/Inputs/config`

Outputs Repository: `Task5/Outputs/runs/subtask4`

`createReals.sh`	Script that runs SISIM and ADDCOORDS, modifying the input files as necessary to change file names and produce 1000 different outputs. See Listing D.1
`createRealsGrfx.sh`	Script that creates graphics from outputs. See Listing D.2
`doIndicatorStats.m`	Matlab script that reads in all 1000 base fields and outputs min, max, mean and standard devation files. See Listing D.3.
`ndlogTe.dat`	Input to SISIM with hard indicator data (input) See Listing B.8.
`softdata.dat`	Input to SISIM with soft indicator data (input) See Listing B.9
`sisim??.par`	SISIM parameter files `sisim00.par` to `sisim99.par` modified for each of 100 SISIM realizations (input). Listing D.4
`sisim??.out`	SISIM output files used as input to ADDCOORDS (output). Not shown due to size.
`r???.par`	ADDCOORDS parameter files used to generate the 1000 base field maps (input) See Listing D.5
`r???coord.map`	ADDCOORDS output files, the final indicator maps of stochastic high and low T for the base fields (output) See Listing D.6 and Figure D.1
`gw-util_wells.crd`	Well coordinates file for adding well locations to field graphics. Not used in calculations.
`observed_margins.xyz`	Halite and Salado Dissolution margins for graphics files. Not used in calculations.

Listing D.1: Source code for the subtask 4 control shell script: `createReals.sh`

```
#!/bin/bash
#$Id: createReals.sh,v 1.2 2008/07/18 22:26:01 dbhart Exp $
#
# This script executes AP-114 Task 5 Subtask 4 - create stochastic
# high T / low T indicator maps based on geologic and soft data

echo "This␣is␣AP-114␣TASK-5␣SUBTASK-4:␣`date`"
echo "RCS-Info:␣\$Id\$"

SCRIPTS="doIndicatorStats.m"
BINARIES="sisim.exe␣addcoord.exe"
CONFIGS="sisim.par␣ndlogTe.dat␣gw-util_wells.crd␣observed_margins.xyz␣LucidaTypewriterRegular.ttf"
PREVFILES="softdata.dat"
SAVEFILES="aveInd.mod␣maxInd.mod␣minInd.mod␣stdInd.mod␣r???.par␣r???coord.map␣sisim??.par␣sisim??.out"
GRAPHICS="aveInd.png␣minInd.png␣maxInd.png␣stdInd.png␣sampleI.png"

[ -d graphics ] || { mkdir graphics; }
[ -d subtask4 ] || { mkdir subtask4; }
[ -s softdata.dat ] || {
    echo 'Data file form Subtask 2 not present!'
    echo 'Missing: softdata.dat'
}

# Create the indicator fields
KS="0␣1␣2␣3␣4␣5␣6␣7␣8␣9"
for K in $KS
do
JS="0␣1␣2␣3␣4␣5␣6␣7␣8␣9"
for J in $JS
  do
  # Resent random seed and output filename
  N=$((69069+J+100*K))
  cat sisim.par | sed -e "s/69069/$N/" | sed -e "s/sisim.out/sisim${K}${J}.out/" > sisim${K}${J}.par
  # Run SISIM to create 10 realizations
  ./sisim.exe <<EOF
sisim${K}${J}.par
EOF

  # Create 10 fields from SISIM realization
  IS="0␣1␣2␣3␣4␣5␣6␣7␣8␣9"
  for I in $IS
    do
    # Create parameter file
    cat -> r${K}${J}${I}.par <<EOF
START OF PARAMETERS:
sisim${K}${J}.out
r${K}${J}${I}coord.map
$((I + 1))
```

```
284 601700.0 100.0
307 3566500.0 100.0
1 1.0 1.0
EOF
        # Run ADDCOORD to extract 1 realization
        ./addcoord.exe <<EOF
r${K}${J}${I}.par
EOF
    done
done
done

# Calculate statistics and generate graphics if MATLAB installed
MATLABPATH=`which matlab`
if [ -z "$MATLABPATH" ]; then
        echo "MATLAB(R)␣is␣NOT␣installed␣--␣statistics␣will␣have␣to␣be"
        echo "created␣and␣analyzed␣at␣a␣later␣date.␣Data␣files␣will␣still"
        echo "be␣saved␣in␣CVS␣-␣check␣them␣out␣to␣process␣them"
else
        matlab -nodesktop <<EOF
warning off all;
doIndicatorStats;
quit;
EOF

fi

bash createRealsGrfx.sh

cp $SAVEFILES subtask4;
cp $GRAPHICS graphics

echo "AP-114␣Task-5␣Subtask-4␣Finished:␣`date`"
```

Listing D.2: Source code for the subtask 4 graphics creation script `createRealsGrfx.sh`

```
#!/bin/bash
#$Id: createRealsGrfx.sh,v 1.2 2008/07/18 22:26:06 dbhart Exp $
#
# This script executes AP-114 Task 5 Subtask 4 graphics creation

# Create the necessary gnuplot input files (silently)
./mod2xyz.pl aveInd.mod 1>/dev/null 2>/dev/null
./mod2xyz.pl minInd.mod 1>/dev/null 2>/dev/null
./mod2xyz.pl maxInd.mod 1>/dev/null 2>/dev/null
./mod2xyz.pl stdInd.mod 1>/dev/null 2>/dev/null
./mod2xyz.pl sample.mod 1>/dev/null 2>/dev/null

# Run gnuplot to create graphics
gnuplot <<EOF
```

```
set terminal png  font "./LucidaTypewriterRegular.ttf" 10 size 900,900 nocrop enhanced
set size ratio -1
set view map
set pm3d

set xlabel "Easting␣UTM␣NAD27"
set ylabel "Northing␣UTM␣NAD27"
set palette maxcolors 256
set format x "%.0f"
set format y "%.0f"
set ytics rotate
set xtics
set xrange [601700:630000]
set yrange [3566500:3597100]

set colorbox
set palette model CMY negative maxcolors 21
set cbrange [-0.025:1.025]
set title "$FIELD"
set origin -.1,-.1
set size 1.2,1.2

set output 'aveInd.png'
splot  "aveInd.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

set output 'minInd.png'
splot  "minInd.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

set output 'maxInd.png'
splot  "maxInd.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

set output 'sampleI.png'
splot  "sample.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

set palette model CMY negative maxcolors 13
set cbrange [-0.025:0.625]
set output 'stdInd.png'
splot  "stdInd.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

EOF
echo "\$Id\$" >> aveInd.png
echo "\$Id\$" >> minInd.png
```

```
echo "\$Id\$" >> maxInd.png
echo "\$Id\$" >> stdInd.png
echo "\$Id\$" >> sampleI.png

# Clean up spurrious files and copy graphics to directory
rm *.mod.xyz
```

Listing D.3: Source code for the subtask 4 statistics generation code `doIndicatorStats.m`

```
% DOSTATS calculates statistics for the 100 realizations of
% transmissivity calculated by GEO2FIELD
%$Id: doIndicatorStats.m,v 1.4 2008/07/23 19:19:04 dbhart Exp $

% Read in each of the 100 realizations
FileIDs=[0:99];
for i = 1:100;
  [ II ] = textread(['sisim',num2str(FileIDs(i),'%.2d'),'.out'], '', ...
                    'headerlines', 3);
  I = reshape(II,284,307,10);
  x = (10*i);
  IFS(:,:,x-9:x) = I;
end

% Calculate the statistics on log10(T)
stdIF = std(IFS,0,3)';
minIF = min(IFS,[],3)';
maxIF = max(IFS,[],3)';
aveIF = mean(IFS,3)';
nLow = sum(sum(sum(IFS)));
nHigh = (size(IFS,1)*size(IFS,2)*size(IFS,3)) - nLow;

% Create the X,Y coordinates grid
[X,Y] = meshgrid([601700:100:630000],[3566500:100:3597100]);

% Save the σ2(log10(T)) values
dataOut = stdIF(end:-1:1,:);
save('stdInd.mod','dataOut','-ASCII');

% Save the MIN(log10(T)) values
dataOut = minIF(end:-1:1,:);
save('minInd.mod','dataOut','-ASCII');

% Save the MAX(log10(T)) values
dataOut = maxIF(end:-1:1,:);
save('maxInd.mod','dataOut','-ASCII');

% Save the MEAN(log10(T)) values
dataOut = aveIF(end:-1:1,:);
save('aveInd.mod','dataOut','-ASCII');

```

```
dataOut = IFS(:,:,124);
dataOut = dataOut(end:-1:1,:);
save('sample.mod','dataOut','-ASCII');

disp('Number␣of␣low␣indicator␣cells:␣')
disp(nLow);
disp('Number␣of␣high␣indicator␣cells:␣')
disp(nHigh);
```

Listing D.4: Configuration file for SISIM realization `sisim12.par`. This is the input file that creates data for the **r123** sample field.

```
                         Parameters for SISIM
                         ********************
$Id: sisim12.par,v 1.1 2008/07/24 18:51:42 dbhart Exp $

START OF PARAMETERS:
0                                       – 1=continuous(cdf), 0=categorical(pdf)
2                                       – number thresholds/categories
0 1                                     –  thresholds / categories
0.500 0.500                             –  global cdf / pdf
ndlogTe.dat                             – file with data
1   2   3   6                           –  columns for X,Y,Z, and variable
softdata.dat                            – file with soft indicator input
1   2   3   4 5                         –  columns for X,Y,Z, and indicators
0                                       –  Markov-Bayes simulation (0=no,1=yes)
0.00   0.00                             –  calibration B(z) values
-1.0e-4   2.0e0                         – trimming limits
0.0      1.0                            – minimum and maximum data value
1        0.0                            –  lower tail option and parameter
1        1.0                            –  middle option and parameter
1       30.0                            –  upper tail option and parameter
ndlogTe.dat                             –  file with tabulated values – unused
6   3                                   –  columns for variable, weight
0                                       – debugging level: 0,1,2,3
sisim.dbg                               – file for debugging output
sisim12.out                               – file for simulation output – modified for each simulation
10                                      – number of realizations
284   601700.0   100.0                  – nx,x0,Δx
307   3566500.   100.0                  – ny,y0,Δy
1     1.0     10.0                      – nz,z0,Δz
69171                                   – random number seed – modified for each simulation
8                                       – maximum original data for each kriging
3                                       – maximum previous nodes for each kriging
16                                      – maximum soft indicator nodes for kriging
1                                       – assign data to nodes? (0=no,1=yes)
0       3                               – multiple grid search? (0=no,1=yes),num
0                                       – maximum per octant (0=not used)
200000.0   200000.0   200000.0          – maximum search radii
 0.0    0.0     0.0                     – angles for search ellipsoid
```

```
0     0.5                                     - 0=full IK, 1=median approx. (cutoff)
0                                             - 0=SK, 1=OK
1     0.00                                    - One nst, nugget effect
1     0.226843 0.0     0.0     0.0 -  it,cc,ang1,ang2,ang3
        2195.0  2195.0   01.0         -  a_hmax, a_hmin, a_vert
1     0.0                                     - Two nst, nugget effect
1     0.226843 0.0     0.0     0.0 -  it,cc,ang1,ang2,ang3
        2195.0  2195.0   01.0         -  a_hmax, a_hmin, a_vert
```

Listing D.5: Sample configuration file for ADDCOORD; file is for realization **r123**, which is used as the sample field in all relevant figures.

```
START OF PARAMETERS:
sisim12.out
r123coord.map
4
284 601700.0 100.0
307 3566500.0 100.0
1 1.0 1.0
```

Listing D.6: Sample output indicator map, `r123coord.map`. Listing is truncated at 256 lines.

```
With Coordinates
  4
X
Y
Z
Simulated Value
  601700.0    3566500.   1.0000000    1.0000
  601800.0    3566500.   1.0000000    1.0000
  601900.0    3566500.   1.0000000    1.0000
  602000.0    3566500.   1.0000000    1.0000
  602100.0    3566500.   1.0000000    1.0000
  602200.0    3566500.   1.0000000    1.0000
  602300.0    3566500.   1.0000000    1.0000
  602400.0    3566500.   1.0000000    1.0000
  602500.0    3566500.   1.0000000    0.0000
  602600.0    3566500.   1.0000000    0.0000
  602700.0    3566500.   1.0000000    0.0000
  602800.0    3566500.   1.0000000    0.0000
  602900.0    3566500.   1.0000000    0.0000
  603000.0    3566500.   1.0000000    0.0000
  603100.0    3566500.   1.0000000    0.0000
  603200.0    3566500.   1.0000000    0.0000
  603300.0    3566500.   1.0000000    0.0000
  603400.0    3566500.   1.0000000    0.0000
  603500.0    3566500.   1.0000000    0.0000
  603600.0    3566500.   1.0000000    0.0000
```

27	603700.0	3566500.	1.0000000	0.0000
28	603800.0	3566500.	1.0000000	0.0000
29	603900.0	3566500.	1.0000000	0.0000
30	604000.0	3566500.	1.0000000	0.0000
31	604100.0	3566500.	1.0000000	0.0000
32	604200.0	3566500.	1.0000000	0.0000
33	604300.0	3566500.	1.0000000	0.0000
34	604400.0	3566500.	1.0000000	0.0000
35	604500.0	3566500.	1.0000000	0.0000
36	604600.0	3566500.	1.0000000	0.0000
37	604700.0	3566500.	1.0000000	0.0000
38	604800.0	3566500.	1.0000000	1.0000
39	604900.0	3566500.	1.0000000	1.0000
40	605000.0	3566500.	1.0000000	1.0000
41	605100.0	3566500.	1.0000000	1.0000
42	605200.0	3566500.	1.0000000	1.0000
43	605300.0	3566500.	1.0000000	1.0000
44	605400.0	3566500.	1.0000000	1.0000
45	605500.0	3566500.	1.0000000	1.0000
46	605600.0	3566500.	1.0000000	1.0000
47	605700.0	3566500.	1.0000000	1.0000
48	605800.0	3566500.	1.0000000	1.0000
49	605900.0	3566500.	1.0000000	1.0000
50	606000.0	3566500.	1.0000000	1.0000
51	606100.0	3566500.	1.0000000	1.0000
52	606200.0	3566500.	1.0000000	1.0000
53	606300.0	3566500.	1.0000000	0.0000
54	606400.0	3566500.	1.0000000	0.0000
55	606500.0	3566500.	1.0000000	0.0000
56	606600.0	3566500.	1.0000000	0.0000
57	606700.0	3566500.	1.0000000	0.0000
58	606800.0	3566500.	1.0000000	0.0000
59	606900.0	3566500.	1.0000000	0.0000
60	607000.0	3566500.	1.0000000	0.0000
61	607100.0	3566500.	1.0000000	0.0000
62	607200.0	3566500.	1.0000000	1.0000
63	607300.0	3566500.	1.0000000	1.0000
64	607400.0	3566500.	1.0000000	1.0000
65	607500.0	3566500.	1.0000000	1.0000
66	607600.0	3566500.	1.0000000	1.0000
67	607700.0	3566500.	1.0000000	1.0000
68	607800.0	3566500.	1.0000000	0.0000
69	607900.0	3566500.	1.0000000	0.0000
70	608000.0	3566500.	1.0000000	0.0000
71	608100.0	3566500.	1.0000000	0.0000
72	608200.0	3566500.	1.0000000	0.0000
73	608300.0	3566500.	1.0000000	0.0000
74	608400.0	3566500.	1.0000000	0.0000
75	608500.0	3566500.	1.0000000	0.0000
76	608600.0	3566500.	1.0000000	0.0000
77	608700.0	3566500.	1.0000000	0.0000
78	608800.0	3566500.	1.0000000	0.0000
79	608900.0	3566500.	1.0000000	0.0000

80	609000.0	3566500.	1.0000000	0.0000
81	609100.0	3566500.	1.0000000	0.0000
82	609200.0	3566500.	1.0000000	0.0000
83	609300.0	3566500.	1.0000000	0.0000
84	609400.0	3566500.	1.0000000	0.0000
85	609500.0	3566500.	1.0000000	0.0000
86	609600.0	3566500.	1.0000000	0.0000
87	609700.0	3566500.	1.0000000	0.0000
88	609800.0	3566500.	1.0000000	0.0000
89	609900.0	3566500.	1.0000000	0.0000
90	610000.0	3566500.	1.0000000	0.0000
91	610100.0	3566500.	1.0000000	0.0000
92	610200.0	3566500.	1.0000000	0.0000
93	610300.0	3566500.	1.0000000	0.0000
94	610400.0	3566500.	1.0000000	0.0000
95	610500.0	3566500.	1.0000000	0.0000
96	610600.0	3566500.	1.0000000	0.0000
97	610700.0	3566500.	1.0000000	0.0000
98	610800.0	3566500.	1.0000000	0.0000
99	610900.0	3566500.	1.0000000	0.0000
100	611000.0	3566500.	1.0000000	0.0000
101	611100.0	3566500.	1.0000000	0.0000
102	611200.0	3566500.	1.0000000	0.0000
103	611300.0	3566500.	1.0000000	0.0000
104	611400.0	3566500.	1.0000000	0.0000
105	611500.0	3566500.	1.0000000	0.0000
106	611600.0	3566500.	1.0000000	0.0000
107	611700.0	3566500.	1.0000000	0.0000
108	611800.0	3566500.	1.0000000	0.0000
109	611900.0	3566500.	1.0000000	1.0000
110	612000.0	3566500.	1.0000000	1.0000
111	612100.0	3566500.	1.0000000	1.0000
112	612200.0	3566500.	1.0000000	1.0000
113	612300.0	3566500.	1.0000000	1.0000
114	612400.0	3566500.	1.0000000	1.0000
115	612500.0	3566500.	1.0000000	1.0000
116	612600.0	3566500.	1.0000000	1.0000
117	612700.0	3566500.	1.0000000	1.0000
118	612800.0	3566500.	1.0000000	1.0000
119	612900.0	3566500.	1.0000000	1.0000
120	613000.0	3566500.	1.0000000	1.0000
121	613100.0	3566500.	1.0000000	1.0000
122	613200.0	3566500.	1.0000000	1.0000
123	613300.0	3566500.	1.0000000	1.0000
124	613400.0	3566500.	1.0000000	1.0000
125	613500.0	3566500.	1.0000000	1.0000
126	613600.0	3566500.	1.0000000	1.0000
127	613700.0	3566500.	1.0000000	0.0000
128	613800.0	3566500.	1.0000000	0.0000
129	613900.0	3566500.	1.0000000	0.0000
130	614000.0	3566500.	1.0000000	0.0000
131	614100.0	3566500.	1.0000000	0.0000
132	614200.0	3566500.	1.0000000	0.0000

133	614300.0	3566500.	1.0000000	1.0000
134	614400.0	3566500.	1.0000000	1.0000
135	614500.0	3566500.	1.0000000	1.0000
136	614600.0	3566500.	1.0000000	1.0000
137	614700.0	3566500.	1.0000000	0.0000
138	614800.0	3566500.	1.0000000	0.0000
139	614900.0	3566500.	1.0000000	0.0000
140	615000.0	3566500.	1.0000000	0.0000
141	615100.0	3566500.	1.0000000	0.0000
142	615200.0	3566500.	1.0000000	0.0000
143	615300.0	3566500.	1.0000000	0.0000
144	615400.0	3566500.	1.0000000	0.0000
145	615500.0	3566500.	1.0000000	1.0000
146	615600.0	3566500.	1.0000000	1.0000
147	615700.0	3566500.	1.0000000	1.0000
148	615800.0	3566500.	1.0000000	1.0000
149	615900.0	3566500.	1.0000000	1.0000
150	616000.0	3566500.	1.0000000	1.0000
151	616100.0	3566500.	1.0000000	1.0000
152	616200.0	3566500.	1.0000000	1.0000
153	616300.0	3566500.	1.0000000	1.0000
154	616400.0	3566500.	1.0000000	1.0000
155	616500.0	3566500.	1.0000000	1.0000
156	616600.0	3566500.	1.0000000	1.0000
157	616700.0	3566500.	1.0000000	1.0000
158	616800.0	3566500.	1.0000000	1.0000
159	616900.0	3566500.	1.0000000	1.0000
160	617000.0	3566500.	1.0000000	1.0000
161	617100.0	3566500.	1.0000000	1.0000
162	617200.0	3566500.	1.0000000	1.0000
163	617300.0	3566500.	1.0000000	1.0000
164	617400.0	3566500.	1.0000000	1.0000
165	617500.0	3566500.	1.0000000	1.0000
166	617600.0	3566500.	1.0000000	1.0000
167	617700.0	3566500.	1.0000000	1.0000
168	617800.0	3566500.	1.0000000	1.0000
169	617900.0	3566500.	1.0000000	1.0000
170	618000.0	3566500.	1.0000000	1.0000
171	618100.0	3566500.	1.0000000	1.0000
172	618200.0	3566500.	1.0000000	1.0000
173	618300.0	3566500.	1.0000000	1.0000
174	618400.0	3566500.	1.0000000	1.0000
175	618500.0	3566500.	1.0000000	1.0000
176	618600.0	3566500.	1.0000000	1.0000
177	618700.0	3566500.	1.0000000	0.0000
178	618800.0	3566500.	1.0000000	0.0000
179	618900.0	3566500.	1.0000000	0.0000
180	619000.0	3566500.	1.0000000	1.0000
181	619100.0	3566500.	1.0000000	1.0000
182	619200.0	3566500.	1.0000000	1.0000
183	619300.0	3566500.	1.0000000	1.0000
184	619400.0	3566500.	1.0000000	1.0000
185	619500.0	3566500.	1.0000000	1.0000

186	619600.0	3566500.	1.0000000	1.0000
187	619700.0	3566500.	1.0000000	1.0000
188	619800.0	3566500.	1.0000000	1.0000
189	619900.0	3566500.	1.0000000	1.0000
190	620000.0	3566500.	1.0000000	1.0000
191	620100.0	3566500.	1.0000000	1.0000
192	620200.0	3566500.	1.0000000	1.0000
193	620300.0	3566500.	1.0000000	1.0000
194	620400.0	3566500.	1.0000000	1.0000
195	620500.0	3566500.	1.0000000	1.0000
196	620600.0	3566500.	1.0000000	1.0000
197	620700.0	3566500.	1.0000000	1.0000
198	620800.0	3566500.	1.0000000	1.0000
199	620900.0	3566500.	1.0000000	1.0000
200	621000.0	3566500.	1.0000000	1.0000
201	621100.0	3566500.	1.0000000	1.0000
202	621200.0	3566500.	1.0000000	1.0000
203	621300.0	3566500.	1.0000000	1.0000
204	621400.0	3566500.	1.0000000	1.0000
205	621500.0	3566500.	1.0000000	1.0000
206	621600.0	3566500.	1.0000000	1.0000
207	621700.0	3566500.	1.0000000	1.0000
208	621800.0	3566500.	1.0000000	1.0000
209	621900.0	3566500.	1.0000000	1.0000
210	622000.0	3566500.	1.0000000	1.0000
211	622100.0	3566500.	1.0000000	1.0000
212	622200.0	3566500.	1.0000000	1.0000
213	622300.0	3566500.	1.0000000	1.0000
214	622400.0	3566500.	1.0000000	1.0000
215	622500.0	3566500.	1.0000000	1.0000
216	622600.0	3566500.	1.0000000	0.0000
217	622700.0	3566500.	1.0000000	0.0000
218	622800.0	3566500.	1.0000000	0.0000
219	622900.0	3566500.	1.0000000	0.0000
220	623000.0	3566500.	1.0000000	0.0000
221	623100.0	3566500.	1.0000000	1.0000
222	623200.0	3566500.	1.0000000	1.0000
223	623300.0	3566500.	1.0000000	1.0000
224	623400.0	3566500.	1.0000000	1.0000
225	623500.0	3566500.	1.0000000	1.0000
226	623600.0	3566500.	1.0000000	1.0000
227	623700.0	3566500.	1.0000000	1.0000
228	623800.0	3566500.	1.0000000	1.0000
229	623900.0	3566500.	1.0000000	1.0000
230	624000.0	3566500.	1.0000000	1.0000
231	624100.0	3566500.	1.0000000	1.0000
232	624200.0	3566500.	1.0000000	1.0000
233	624300.0	3566500.	1.0000000	1.0000
234	624400.0	3566500.	1.0000000	1.0000
235	624500.0	3566500.	1.0000000	1.0000
236	624600.0	3566500.	1.0000000	1.0000
237	624700.0	3566500.	1.0000000	1.0000
238	624800.0	3566500.	1.0000000	1.0000

239	624900.0	3566500.	1.0000000	1.0000
240	625000.0	3566500.	1.0000000	1.0000
241	625100.0	3566500.	1.0000000	1.0000
242	625200.0	3566500.	1.0000000	1.0000
243	625300.0	3566500.	1.0000000	0.0000
244	625400.0	3566500.	1.0000000	0.0000
245	625500.0	3566500.	1.0000000	1.0000
246	625600.0	3566500.	1.0000000	1.0000
247	625700.0	3566500.	1.0000000	1.0000
248	625800.0	3566500.	1.0000000	1.0000
249	625900.0	3566500.	1.0000000	1.0000
250	626000.0	3566500.	1.0000000	0.0000
251	626100.0	3566500.	1.0000000	0.0000
252	626200.0	3566500.	1.0000000	0.0000
253	626300.0	3566500.	1.0000000	0.0000
254	626400.0	3566500.	1.0000000	0.0000
255	626500.0	3566500.	1.0000000	0.0000
256	626600.0	3566500.	1.0000000	0.0000

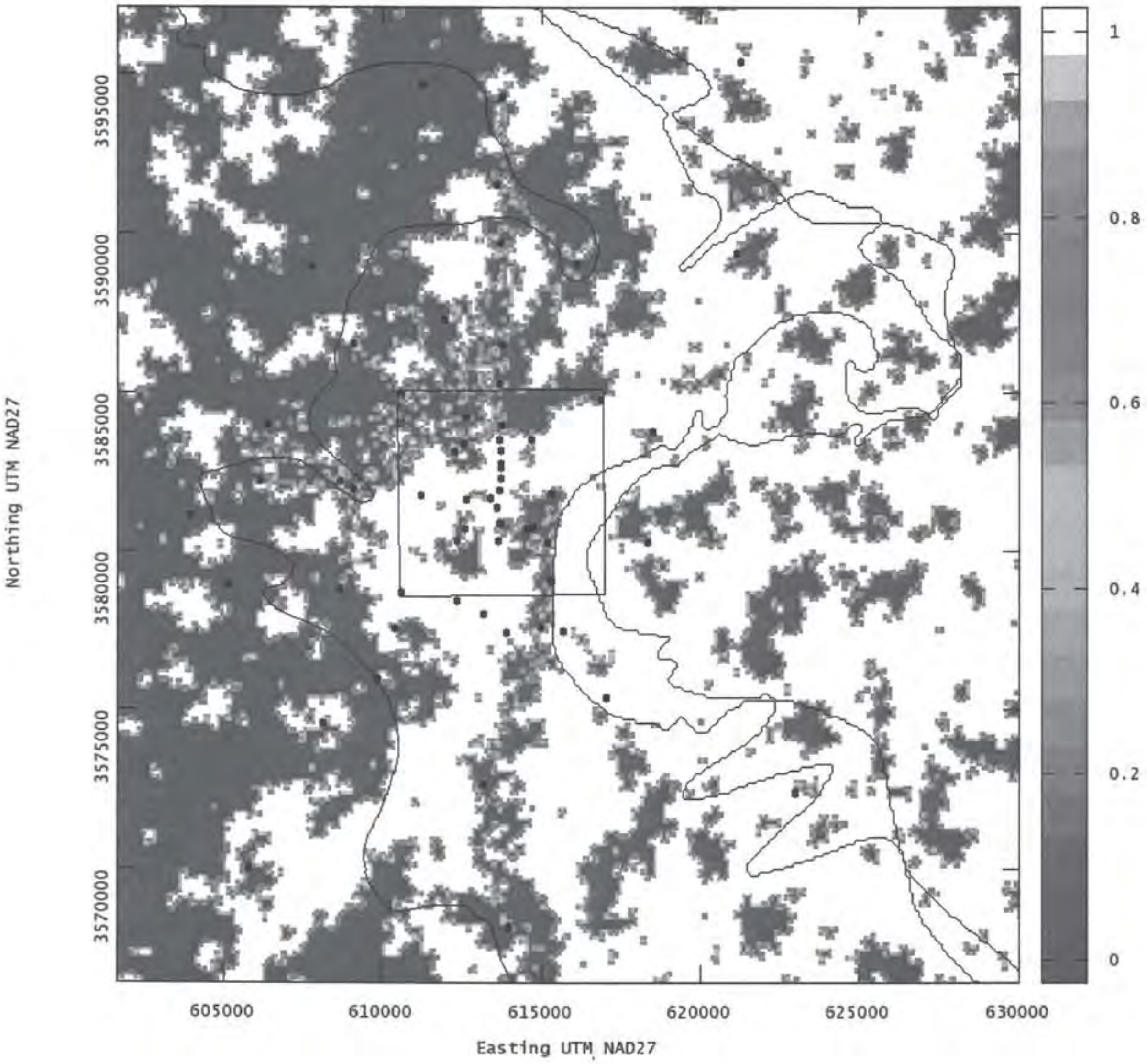


Figure D.1: Sample indicator field

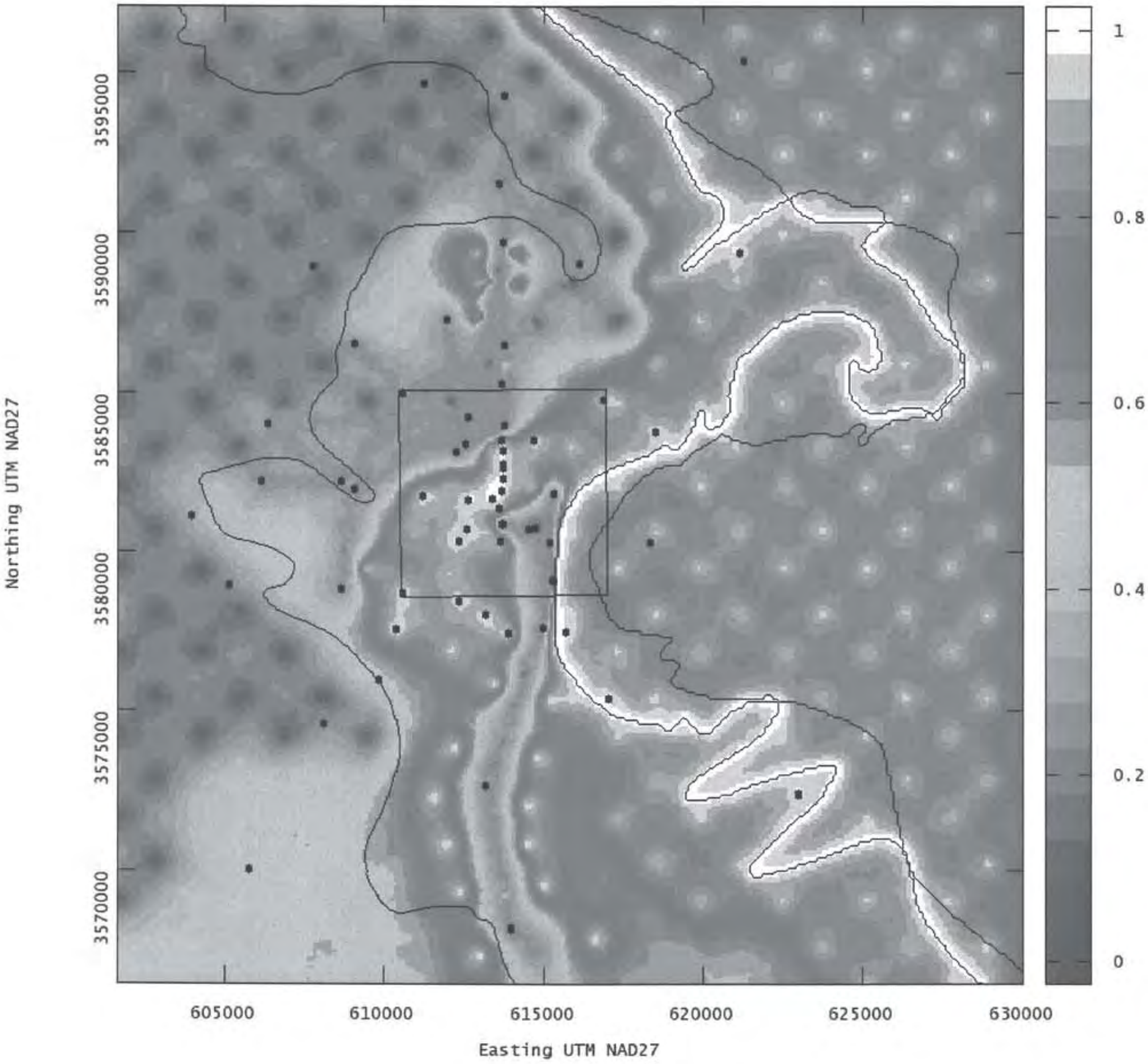


Figure D.2: Average indicator values across all 1000 realizations.

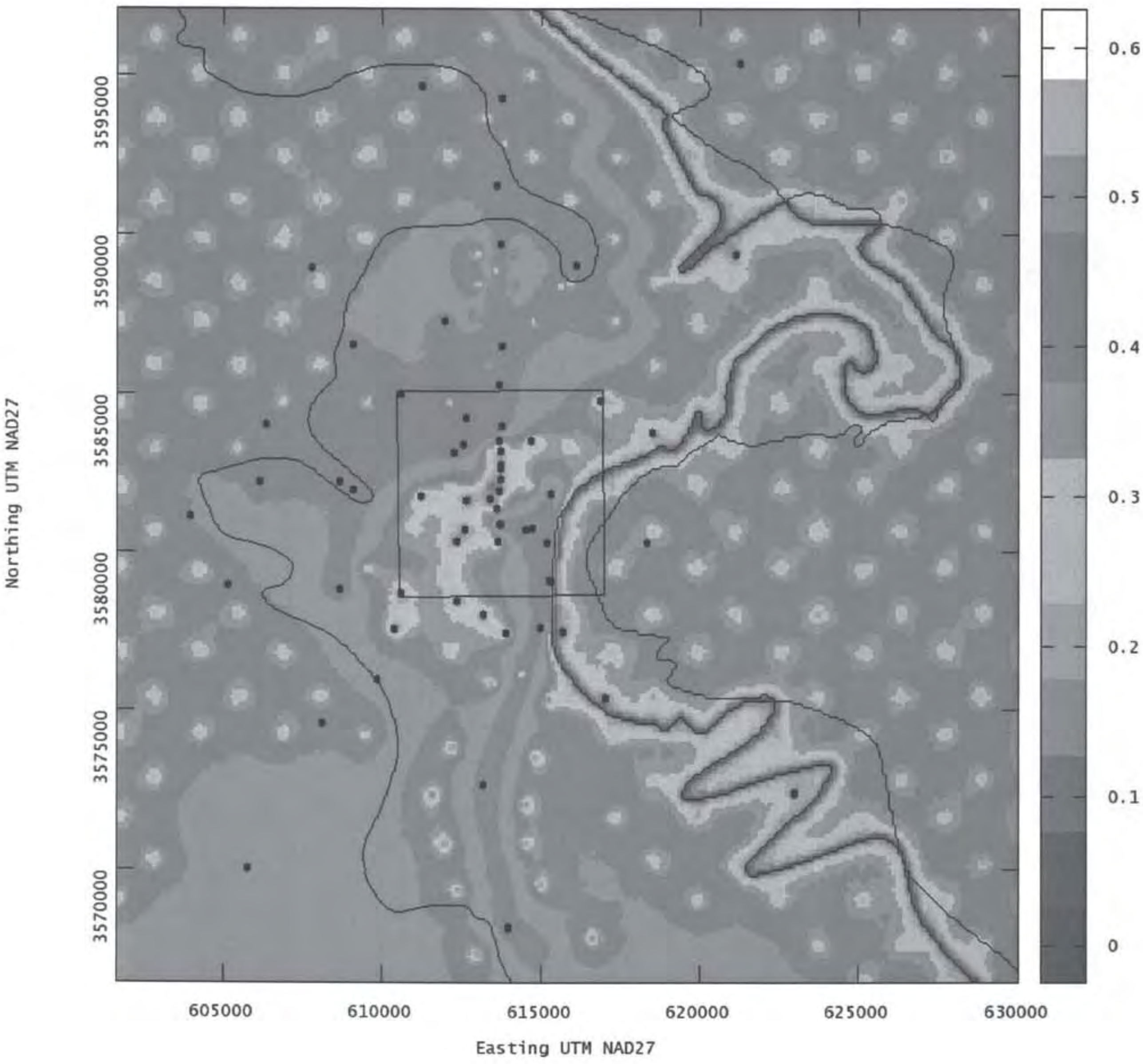


Figure D.3: Standard deviation of indicator values across all 1000 realizations.

References

Deutsch, C., & Journel, A. (1998). *GSLIB Geostatistical Software Library and User's Guide*. Oxford University Press, second ed.

Appendix E

Inputs, Outputs, and Scripts used in Subtask 5

The following files were used during the the final conversion of indicator fields to base T fields. The script GEO2FIELD was written specifically for this subtask, and can be validated through code analysis, and by verifying that the resulting T field graphic produces zones that match the Halite and Salado Dissolution

$$Y(\mathbf{x}) = \beta_1 + \beta_2 d(\mathbf{x}) + \beta_3 I_f(\mathbf{x}) + \beta_4 I_D(\mathbf{x}) + \beta_5 I_H + \epsilon \tag{E.1}$$

CVS Root: `:ext:elo.sandia.gov:/data/CVSLIB/AP114`

Script Files Repository: `Task5/Inputs/scripts`

Data Files Repository: `Task5/Inputs/config`

Outputs Repository: `Task5/Outputs/runs/subtask5`

`createTrans.sh`	Script that runs GEO2FIELD modifying the input files as necessary to change file names and produce 1000 different outputs. See Listing E.1
`createTransGrfx.sh`	Script that generates graphics for subtask 5. See Listing E.2
`doTFieldStats.m`	Reads in all 1000 fields and produces min, max, mean and standard deviation fields for all realizations of T. These can be used to create the graphics shown below. See Listing E.3.
`geo2field.pl`	Program that translates the various inputs, including ADDCOORDS outputs r???coord.map, into a final field. See Listing E.4.
`geo2field_points_K.in`	Configuration file for GEO2FIELD containing the combined β values from Equation (1). Listing E.5.
`observed_culebra.dat`	File containing all the elevation and zonation information for the culebra. Shown in Listing E.6, truncated to 200 lines.
`r???coord.map`	Output from ADDCOORDS that is used as input to GEO2FIELD. This file is renamed `modeled_basefield.map` prior to transformation.
`modeled_points_K.out`	This is the output field from GEO2FIELD. It is renamed `r???coord.mod` by the control script. See Figure E.1.

Listing E.1: Source code for the subtask 5 control shell script `createTrans.sh`

```
#!/bin/bash
#$Id: createTrans.sh,v 1.2 2008/07/18 22:26:09 dbhart Exp $
#
# This script executes AP-114 Task 5 Subtask 5 - create T fields from
# indicator data

echo "This␣is␣AP-114␣TASK-5␣SUBTASK-5:␣`date`"
echo "RCS-Info:␣\$Id\$"

# Copy necessary input files and scripts
```

```
SCRIPTS="doTFieldStats.m␣geo2field.pl␣mod2xyz.pl"
CONFIGS="LucidaTypewriterRegular.ttf␣geo2field_points_K.in␣observed_culebra.dat␣observed_margin.xyz␣gw-util_wells.crd"
PREVFILES="r???coord.map"
SAVEFILES="r???coord.mod␣aveLogT.mod␣minLogT.mod␣maxLogT.mod␣stdLogT.mod"
GRAPHICS="aveLogT.png␣minLogT.png␣maxLogT.png␣stdLogT.png␣sampleT.png␣histLogT.jpg"

[ -d graphics ] || { mkdir graphics; }
[ -d subtask5 ] || { mkdir subtask5; }

# Create the T fields
KS="0␣1␣2␣3␣4␣5␣6␣7␣8␣9"
for K in $KS
do
JS="0␣1␣2␣3␣4␣5␣6␣7␣8␣9"
for J in $JS
  do
  IS="0␣1␣2␣3␣4␣5␣6␣7␣8␣9"
  for I in $IS
    do
    # Copy file from ST-4, and convert it to a T field
    cp -v r${K}${J}${I}coord.map modeled_basefield.map
    ./geo2field.pl < geo2field_points_K.in
    mv -v modeled_points_K.mod r${K}${J}${I}coord.mod
  done
done
done

# Calculate statistics and generate graphics if MATLAB installed
MATLABPATH=`which matlab`
if [ -z "$MATLABPATH" ]; then
    echo "MATLAB(R)␣is␣NOT␣installed␣--␣statistics␣will␣have␣to␣be"
    echo "created␣and␣analyzed␣at␣a␣later␣date.␣Data␣files␣will␣still"
    echo "be␣saved␣in␣CVS␣-␣check␣them␣out␣to␣process␣them"
else
    matlab -nodesktop <<EOF
warning off all;
doTFieldStats;
quit;
EOF
fi

bash createTransGrfx.sh

cp $SAVEFILES subtask5
cp $GRAPHICS graphics

echo "AP-114␣Task-5␣Subtask-5␣Finished:␣`date`"
```

Listing E.2: Source code for the subtask 5 graphics creation script **createTransGrfx.sh**

```
#!/bin/bash
#$Id: createTransGrfx.sh,v 1.2 2008/07/18 22:26:13 dbhart Exp $
#
# This script executes AP-114 Task 5 Subtask 5 graphics creation

# Prepare files for gnuplot
./mod2xyz.pl aveLogT.mod
./mod2xyz.pl minLogT.mod
./mod2xyz.pl maxLogT.mod
./mod2xyz.pl stdLogT.mod
./mod2xyz.pl r123coord.mod

# Create the graphics
gnuplot <<EOF
set terminal png  font "./LucidaTypewriterRegular.ttf" 10 size 900,900 nocrop enhanced
set size ratio -1
set view map
set pm3d

set xlabel "Easting␣UTM␣NAD27"
set ylabel "Northing␣UTM␣NAD27"
set palette maxcolors 256
set format x "%.0f"
set format y "%.0f"
set ytics rotate
set xtics
set xrange [601700:630000]
set yrange [3566500:3597100]

set colorbox
set palette model CMY negative maxcolors 12
set cbrange [-8.25:-2.25]
set origin -.1,-.1
set size 1.2,1.2

set output 'aveLogT.png'
splot  "aveLogT.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

set output 'minLogT.png'
splot  "minLogT.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

set output 'maxLogT.png'
splot  "maxLogT.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""
```

```

set output 'sampleT.png'
splot  "r123coord.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

set palette model CMY negative maxcolors 21
set cbrange [-0.025:1.025]
set output 'stdLogT.png'
splot  "stdLogT.mod.xyz" with pm3d title "",\
 'gw-util_wells.crd' using 2:3:4 with points lt -1 pt 7 title "" ,\
 'observed_margins.xyz' with lines lt -1  title ""

EOF
echo "\$Id\$" >> aveLogT.png
echo "\$Id\$" >> minLogT.png
echo "\$Id\$" >> maxLogT.png
echo "\$Id\$" >> stdLogT.png
echo "\$Id\$" >> sampleT.png
echo "\$Id\$" >> histLogT.jpg

# Clean spurrious files and copy graphics to graphics directory
rm *.mod.xyz
```

Listing E.3: Source code for the subtask 5 statistics generation code `doTFieldStats.m`

```
% DOTFIELDSTATS calculates statistics for the 100 realizations of
% transmissivity calculated by GEO2FIELD
%$Id: doTFieldStats.m,v 1.3 2008/07/23 19:19:04 dbhart Exp $

% Read in each of the 100 realizations
FileIDs=[0:999];
for i = 1:1000;
  T = load(['r',num2str(FileIDs(i),'%.3d'),'coord.mod']);
  logT(:,i) = T;
end

% Calculate the statistics on log10(T)
meanLogT = mean(logT,2);
stdLogT = std(logT,0,2);
minLogT = min(logT,[],2);
maxLogT = max(logT,[],2);

% Create the X,Y coordinates grid
[X,Y] = meshgrid([601700:100:630000],[3597100:-100:3566500]);

% Save the MEAN(log10(T)) values
Z = reshape(meanLogT,284,307)';
dataOut =Z;
```

```
save('aveLogT.mod','dataOut','-ASCII');

% Save the MIN(log10(T)) values
Z = reshape(minLogT,284,307)';
dataOut =Z;
save('minLogT.mod','dataOut','-ASCII');

% Save the MAX(log10(T)) values
Z = reshape(maxLogT,284,307)';
dataOut =Z;
save('maxLogT.mod','dataOut','-ASCII');

% Save the σ^2(log10(T)) values
Z = reshape(stdLogT,284,307)';
dataOut =Z;
save('stdLogT.mod','dataOut','-ASCII');

% Lets get some histogram-style results
close all
hist(logT,100);
xlabel('log_{10}(T)␣m^2/s');
ylabel('Number␣of␣cells');
set(gcf,'PaperType','A5');
print(gcf,'-djpeg','histLogT');
close all;
```

Listing E.4: Source code for the GEO2FIELD Perl script

```
#!/usr/bin/perl
#$Id: geo2field.pl,v 1.1 2008/06/16 20:35:08 dbhart Exp $

use POSIX;
$Rev = '$Revision:␣1.1␣$';
$Rev =~ s/\$//g;
$Rev =~ s/Revision/version/;
print "␣␣This␣is␣GEO2FIELD␣$Rev␣\n";

print STDERR "Inputs␣to␣this␣program␣must␣be␣GEO-EAS␣formatted␣text␣files\n";
print STDERR "\n";
print STDERR "Please␣enter␣the␣main␣data␣table␣filename(X,Y,Ec,Es,I_D,I_H,I_h):␣";
chomp($filename = <STDIN>);
print STDERR "\n...␣the␣indicator␣kriging␣output␣file␣(X,Y,Z,I_f):␣";
chomp($basefilename = <STDIN>);
print STDERR "\n...␣the␣name␣of␣the␣output␣file␣stub␣(no␣extension):␣";
chomp($outputfile = <STDIN>);

open INPMAIN, "$filename" or die "Can't␣open␣input␣file␣'$filename'!";
open INPKRIG, "$basefilename" or die "Can't␣open␣input␣file␣'$basefilename'!";
```

```

@zoneNames[4] = "Nope";
# Read in the main data file with elevations and indicator values
chomp($text = <INPMAIN>);
$linein = <INPMAIN>;
( $dum, $ncol1 , $nx , $ny ,$nz ,$x0, $y0, $z0, $dx, $dy, $dz, $remain) =
      split /[\s]+/, $linein , 12;
if ( $dum ne "" ) {
    $dz = $dy; $dy = $dx; $dx = $z0; $z0 = $y0; $y0 = $x0; $x0 = $nz;
    $nz = $ny; $ny = $nx; $nx = $ncol1; $ncol1 = $dum;
}
for ( $i = 0; $i < $ncol1 ; $i++ )
{
    print $znCount;
    chomp($linein = <INPMAIN>);
    if ( $i > 3 ) {
        $node = $i - 4;
        @zoneNames[$node] = $linein . "==TRUE";
    }
}
# Read in the basefield kriged indicator map
chomp($text = <INPKRIG>);
$linein = <INPKRIG>;
( $dum, $ncol2 , $remain) = split /[\s]+/, $linein , 3;
if ( $dum ne "" ) {
    $ncol2 = $dum;
}
for ( $i = 0; $i < $ncol2 ; $i++ )
{
    print $znCount;
    chomp($linein = <INPKRIG>);
    if ( $i > 2) {
        @zoneNames[3] = $linein . "==TRUE";
        @zoneNames[4] = $linein . "==FALSE";
    }
}

# Now, get the alpha and beta values
for ( $i = 0; $i <= 4; $i++ ) {
    chomp($linein = @zoneNames[$i]);
    print STDERR "\n\nFor␣zone␣",$i,":␣",$linein,"\n";
    $b_answer = 0;
    print STDERR "␣␣given:␣log_{10}(V)␣=␣b␣+␣a␣*␣depth\n";
    printf STDERR "␣␣␣The␣value␣for␣'b'␣in␣zone␣%d:␣",$i;
    chomp($b = <STDIN>);
    printf STDERR "␣␣␣The␣value␣for␣'a'␣in␣zone␣%d:␣",$i;
    chomp($a = <STDIN>);
    @Beta[$i] = $b;
    @Alpha[$i] = $a;
    printf "␣Eqn.␣Zone-%s:␣\$log_{10}(V)␣=␣%.4f+%.4f␣\\cdot␣d\$\n",$i,$b,$a;
}
```

```

@I_HH[$nx*$ny] =0;
@I_HM[$nx*$ny] =0;
@I_SD[$nx*$ny] =0;
@I_KU[$nx*$ny] =0;
@I_KF[$nx*$ny] =0;
$VAL[1][$nx*$ny] = 0;


$lineinM = <INPMAIN>;
$lineinK = <INPKRIG>;
while ($lineinM ne "")
{
    chomp($lineinM);
    chomp($lineinK);
    ($dum, $x , $y, $eCul, $eSurf , $isd, $ihh , $ihs , $rem) = split /[\s]+/, $lineinM, 9;
    if ( $dum ne "" ) {
        $ihs = $ihh ; $ihh = $isd; $isd = $eSurf ; $eSurf = $eCul; $eCul = $y; $y = $x; $x = $dum;
    }
    $nodeM = (($y - $y0)/$dy) * $nx + (( $x - $x0 )/$dx);
    ($dum, $x , $y, $z, $ik, $rem ) = split /[\s]+/, $lineinK, 6;
    if ( $dum ne "" ) {
        $ik = $z; $z = $y; $y = $x ; $x = $dum;
    }
    $nodeK = (($y - $y0)/$dy) * $nx + (( $x - $x0 )/$dx);
    if ( $node >= 0 ) {
        @I_HH[$nodeM] = $ihh;
        @I_SD[$nodeM] = $isd;
        @I_HM[$nodeM] = $ihs;
        @D[$nodeM] = $eSurf - $eCul;
        @I_KU[$nodeK] = $ik;
        @I_KF[$nodeK] = 1-$ik;
    }
    $lineinM = <INPMAIN>;
    $lineinK = <INPKRIG>;
}
close INPMAIN;
close INPKRIG;
$v = 0;

$nofixed = 0;
$nFP = 0;
@FixedPtsX[0] = -1;
@FixedPtsY[0] = -1;
@FixedPtsV[0] = -1;
@FixedPtsN[0] = "";


$outmodfile = $outputfile . ".mod";
```

```
open OUTMOD, ">$outmodfile" or die "Can't␣open␣output␣file␣'$outmodfile'!";

$value = 0;
@myZn[$nx*$ny] = 0;
$log10T = 0;
for ($node = ($nx * $ny) - $nx ; $node >= 0; $node++)
{
    $d = @D[$node];
    $i_sd = @I_SD[$node];
    $i_hh = @I_HH[$node];
    $i_hm = @I_HM[$node];
    $i_kf = @I_KF[$node];
    $i_ku = @I_KU[$node];
    $zone = 3 if $i_ku == 1;
    $zone = 4 if $i_kf == 1;
    $zone = 2 if $i_hm == 1;
    $zone = 0 if $i_sd == 1;
    $zone = 1 if $i_hh == 1;
    $a = @Alpha[$zone];
    $b = @Beta[$zone];
    $t = @Type[$zone];
    $log10T = $b + ( $a * $d );
    @myZn[$node] = $zone;
    print OUTMOD "$log10T\n";
    if ( ($node + 1) % $nx == 0 )
    {
        $node -= 2 * $nx;
    }
}
close OUTMOD;
print "\n";
```

Listing E.5: Keyboard redirection file used for geo2field in Subtask 5

```
observed_culebra.dat
modeled_basefield.map
modeled_points_K
-2.94635
-3.48357e-3
-10.449
-3.48357e-3
-5.69805
-3.48357e-3
-5.69805
-3.48357e-3
-3.63224
-3.48357e-3
```

Listing E.6: `observed_culebra.dat`. Listing is truncated at 200 lines.

```
Elevation and Indicator Values for the Culebra
 7  284  307    1  601700.      3566500.     1.      100.      100.      1.   1
UTM X (NAD27)
UTM Y (NAD27)
Culebra Elevation (m)AMSL
Surface Elevation (m)AMSL
Salado Dissolution Indicator ( I_D )
Halite Sandwich Indicator ( I_H )
Halite Presence Indicator ( I_h )
    6.0170000e+05   3.5665000e+06   8.2944000e+02   9.7121000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0180000e+05   3.5665000e+06   8.2981000e+02   9.7146000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0190000e+05   3.5665000e+06   8.3036000e+02   9.7200000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0200000e+05   3.5665000e+06   8.3110000e+02   9.7304000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0210000e+05   3.5665000e+06   8.3202000e+02   9.7382000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0220000e+05   3.5665000e+06   8.3309000e+02   9.7563000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0230000e+05   3.5665000e+06   8.3433000e+02   9.7622000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0240000e+05   3.5665000e+06   8.3573000e+02   9.7628000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0250000e+05   3.5665000e+06   8.3728000e+02   9.7749000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0260000e+05   3.5665000e+06   8.3892000e+02   9.7910000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0270000e+05   3.5665000e+06   8.4062000e+02   9.7877000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0280000e+05   3.5665000e+06   8.4236000e+02   9.7994000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0290000e+05   3.5665000e+06   8.4410000e+02   9.8280000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0300000e+05   3.5665000e+06   8.4588000e+02   9.8394000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0310000e+05   3.5665000e+06   8.4765000e+02   9.8476000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0320000e+05   3.5665000e+06   8.4933000e+02   9.8716000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0330000e+05   3.5665000e+06   8.5090000e+02   9.8866000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0340000e+05   3.5665000e+06   8.5271000e+02   9.9066000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0350000e+05   3.5665000e+06   8.5524000e+02   9.9341000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
    6.0360000e+05   3.5665000e+06   8.5788000e+02   9.9522000e+02   1.0000000e+00   0.0000000e+00   0.0000000e+00
```

```
6.0370000e+05   3.5665000e+06   8.6007000e+02   9.9746000e+02   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0380000e+05   3.5665000e+06   8.6200000e+02   9.9975000e+02   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0390000e+05   3.5665000e+06   8.6421000e+02   1.0028800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0400000e+05   3.5665000e+06   8.6686000e+02   1.0046500e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0410000e+05   3.5665000e+06   8.6989000e+02   1.0064600e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0420000e+05   3.5665000e+06   8.7296000e+02   1.0098500e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0430000e+05   3.5665000e+06   8.7606000e+02   1.0140400e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0440000e+05   3.5665000e+06   8.7952000e+02   1.0156600e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0450000e+05   3.5665000e+06   8.8362000e+02   1.0163200e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0460000e+05   3.5665000e+06   8.8785000e+02   1.0124400e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0470000e+05   3.5665000e+06   8.9171000e+02   1.0122200e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0480000e+05   3.5665000e+06   8.9542000e+02   1.0143900e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0490000e+05   3.5665000e+06   8.9875000e+02   1.0179200e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0500000e+05   3.5665000e+06   9.0119000e+02   1.0176300e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0510000e+05   3.5665000e+06   9.0272000e+02   1.0152300e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0520000e+05   3.5665000e+06   9.0356000e+02   1.0153700e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0530000e+05   3.5665000e+06   9.0386000e+02   1.0144800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0540000e+05   3.5665000e+06   9.0370000e+02   1.0139300e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0550000e+05   3.5665000e+06   9.0334000e+02   1.0150500e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0560000e+05   3.5665000e+06   9.0299000e+02   1.0179100e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0570000e+05   3.5665000e+06   9.0272000e+02   1.0200800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0580000e+05   3.5665000e+06   9.0258000e+02   1.0244700e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0590000e+05   3.5665000e+06   9.0257000e+02   1.0263000e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0600000e+05   3.5665000e+06   9.0261000e+02   1.0289900e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0610000e+05   3.5665000e+06   9.0265000e+02   1.0323800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0620000e+05   3.5665000e+06   9.0259000e+02   1.0359400e+03   1.0000000e
```

```
    +00   0.0000000e+00   0.0000000e+00
6.0630000e+05   3.5665000e+06   9.0242000e+02   1.0392200e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0640000e+05   3.5665000e+06   9.0215000e+02   1.0431300e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0650000e+05   3.5665000e+06   9.0173000e+02   1.0489200e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0660000e+05   3.5665000e+06   9.0120000e+02   1.0522100e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0670000e+05   3.5665000e+06   9.0062000e+02   1.0544800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0680000e+05   3.5665000e+06   8.9996000e+02   1.0543800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0690000e+05   3.5665000e+06   8.9902000e+02   1.0534500e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0700000e+05   3.5665000e+06   8.9758000e+02   1.0518000e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0710000e+05   3.5665000e+06   8.9595000e+02   1.0541300e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0720000e+05   3.5665000e+06   8.9418000e+02   1.0550400e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0730000e+05   3.5665000e+06   8.9236000e+02   1.0521300e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0740000e+05   3.5665000e+06   8.9071000e+02   1.0544800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0750000e+05   3.5665000e+06   8.8943000e+02   1.0596600e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0760000e+05   3.5665000e+06   8.8820000e+02   1.0637700e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0770000e+05   3.5665000e+06   8.8690000e+02   1.0627900e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0780000e+05   3.5665000e+06   8.8558000e+02   1.0612800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0790000e+05   3.5665000e+06   8.8421000e+02   1.0612900e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0800000e+05   3.5665000e+06   8.8278000e+02   1.0608600e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0810000e+05   3.5665000e+06   8.8133000e+02   1.0599100e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0820000e+05   3.5665000e+06   8.7986000e+02   1.0607300e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0830000e+05   3.5665000e+06   8.7830000e+02   1.0616100e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0840000e+05   3.5665000e+06   8.7659000e+02   1.0526200e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0850000e+05   3.5665000e+06   8.7479000e+02   1.0491900e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0860000e+05   3.5665000e+06   8.7308000e+02   1.0519800e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
6.0870000e+05   3.5665000e+06   8.7160000e+02   1.0556000e+03   1.0000000e
    +00   0.0000000e+00   0.0000000e+00
```

```
81     6.0880000e+05   3.5665000e+06   8.7042000e+02   1.0607300e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
82     6.0890000e+05   3.5665000e+06   8.6957000e+02   1.0681600e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
83     6.0900000e+05   3.5665000e+06   8.6856000e+02   1.0698200e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
84     6.0910000e+05   3.5665000e+06   8.6730000e+02   1.0713800e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
85     6.0920000e+05   3.5665000e+06   8.6592000e+02   1.0725200e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
86     6.0930000e+05   3.5665000e+06   8.6437000e+02   1.0720700e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
87     6.0940000e+05   3.5665000e+06   8.6273000e+02   1.0722500e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
88     6.0950000e+05   3.5665000e+06   8.6120000e+02   1.0727300e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
89     6.0960000e+05   3.5665000e+06   8.5990000e+02   1.0735200e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
90     6.0970000e+05   3.5665000e+06   8.5883000e+02   1.0740400e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
91     6.0980000e+05   3.5665000e+06   8.5774000e+02   1.0747200e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
92     6.0990000e+05   3.5665000e+06   8.5659000e+02   1.0755700e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
93     6.1000000e+05   3.5665000e+06   8.5545000e+02   1.0764200e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
94     6.1010000e+05   3.5665000e+06   8.5434000e+02   1.0764300e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
95     6.1020000e+05   3.5665000e+06   8.5317000e+02   1.0767700e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
96     6.1030000e+05   3.5665000e+06   8.5193000e+02   1.0770100e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
97     6.1040000e+05   3.5665000e+06   8.5076000e+02   1.0772400e+03   1.0000000e
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98     6.1050000e+05   3.5665000e+06   8.4986000e+02   1.0774500e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
99     6.1060000e+05   3.5665000e+06   8.4875000e+02   1.0790500e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
100    6.1070000e+05   3.5665000e+06   8.4759000e+02   1.0822500e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
101    6.1080000e+05   3.5665000e+06   8.4647000e+02   1.0779900e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
102    6.1090000e+05   3.5665000e+06   8.4552000e+02   1.0721500e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
103    6.1100000e+05   3.5665000e+06   8.4476000e+02   1.0702500e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
104    6.1110000e+05   3.5665000e+06   8.4398000e+02   1.0716600e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
105    6.1120000e+05   3.5665000e+06   8.4309000e+02   1.0730900e+03   1.0000000e
          +00   0.0000000e+00   0.0000000e+00
106    6.1130000e+05   3.5665000e+06   8.4213000e+02   1.0764000e+03   1.0000000e
```

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               +00    0.0000000e+00    0.0000000e+00
108        6.1150000e+05    3.5665000e+06    8.3914000e+02    1.0725600e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
109        6.1160000e+05    3.5665000e+06    8.3635000e+02    1.0702000e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
110        6.1170000e+05    3.5665000e+06    8.3352000e+02    1.0675500e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
111        6.1180000e+05    3.5665000e+06    8.3123000e+02    1.0645400e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
112        6.1190000e+05    3.5665000e+06    8.2937000e+02    1.0665500e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
113        6.1200000e+05    3.5665000e+06    8.2821000e+02    1.0709700e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
114        6.1210000e+05    3.5665000e+06    8.2824000e+02    1.0748400e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
115        6.1220000e+05    3.5665000e+06    8.2858000e+02    1.0789600e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
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               +00    0.0000000e+00    0.0000000e+00
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               +00    0.0000000e+00    0.0000000e+00
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               +00    0.0000000e+00    0.0000000e+00
119        6.1260000e+05    3.5665000e+06    8.2792000e+02    1.0807200e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
120        6.1270000e+05    3.5665000e+06    8.2718000e+02    1.0780100e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
121        6.1280000e+05    3.5665000e+06    8.2634000e+02    1.0771200e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
122        6.1290000e+05    3.5665000e+06    8.2563000e+02    1.0742400e+03    1.0000000e
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               +00    0.0000000e+00    0.0000000e+00
127        6.1340000e+05    3.5665000e+06    8.2666000e+02    1.0668400e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
128        6.1350000e+05    3.5665000e+06    8.2736000e+02    1.0655700e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
129        6.1360000e+05    3.5665000e+06    8.2807000e+02    1.0637600e+03    1.0000000e
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130        6.1370000e+05    3.5665000e+06    8.2877000e+02    1.0627000e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
131        6.1380000e+05    3.5665000e+06    8.2940000e+02    1.0625000e+03    1.0000000e
               +00    0.0000000e+00    0.0000000e+00
```

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          +00   0.0000000e+00   0.0000000e+00
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139    6.1460000e+05   3.5665000e+06   8.3285000e+02   1.0559300e+03   0.0000000e
          +00   0.0000000e+00   0.0000000e+00
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          +00   0.0000000e+00   0.0000000e+00
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          +00   0.0000000e+00   0.0000000e+00
146    6.1530000e+05   3.5665000e+06   8.3466000e+02   1.0545200e+03   0.0000000e
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156    6.1630000e+05   3.5665000e+06   8.2664000e+02   1.0617400e+03   0.0000000e
          +00   0.0000000e+00   0.0000000e+00
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         +00   0.0000000e+00   0.0000000e+00
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        +00   0.0000000e+00   0.0000000e+00
185   6.1920000e+05   3.5665000e+06   7.9313000e+02   1.0790200e+03   0.0000000e
        +00   0.0000000e+00   0.0000000e+00
186   6.1930000e+05   3.5665000e+06   7.9630000e+02   1.0794700e+03   0.0000000e
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        +00   0.0000000e+00   0.0000000e+00
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        +00   0.0000000e+00   0.0000000e+00
192   6.1990000e+05   3.5665000e+06   7.9695000e+02   1.0864800e+03   0.0000000e
        +00   0.0000000e+00   0.0000000e+00
193   6.2000000e+05   3.5665000e+06   7.9606000e+02   1.0873500e+03   0.0000000e
        +00   0.0000000e+00   0.0000000e+00
194   6.2010000e+05   3.5665000e+06   7.9504000e+02   1.0879200e+03   0.0000000e
        +00   0.0000000e+00   0.0000000e+00
195   6.2020000e+05   3.5665000e+06   7.9393000e+02   1.0889100e+03   0.0000000e
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196   6.2030000e+05   3.5665000e+06   7.9269000e+02   1.0893200e+03   0.0000000e
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197   6.2040000e+05   3.5665000e+06   7.9139000e+02   1.0906700e+03   0.0000000e
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198   6.2050000e+05   3.5665000e+06   7.8997000e+02   1.0911100e+03   0.0000000e
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        +00   0.0000000e+00   0.0000000e+00
200   6.2070000e+05   3.5665000e+06   7.8705000e+02   1.0906300e+03   0.0000000e
        +00   0.0000000e+00   0.0000000e+00
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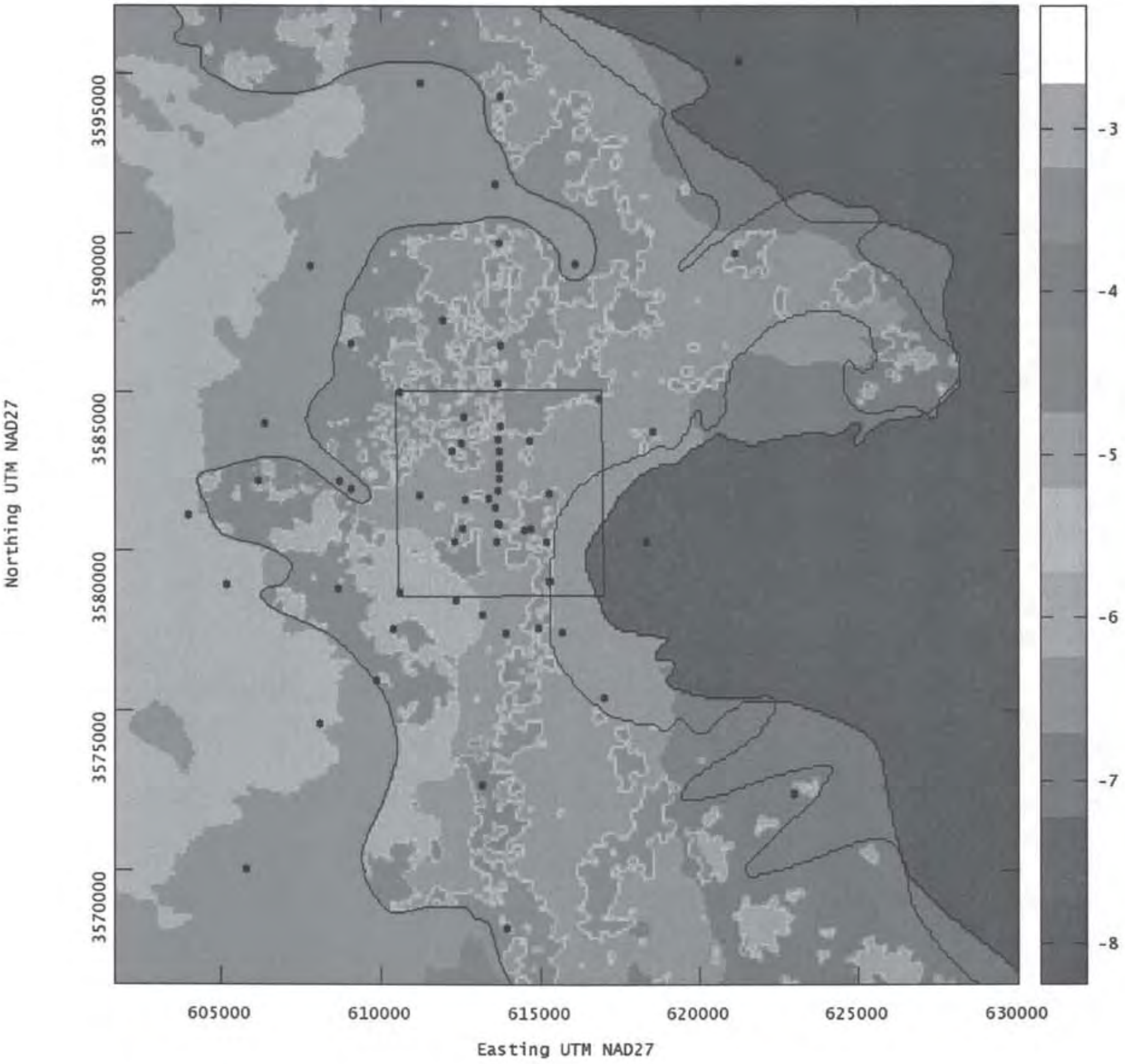

Figure E.1: Sample indicator field

Appendix F

The Gypsum-Transmissivity Relationship in the Culebra Dolomite Member of the Rustler Formation

Robert M. Holt and Dennis W. Powers

Introduction and Summary

Beauheim and Holt (1990) suggested that amount of gypsum cements in fractures and vuggy porosity within the Culebra Dolomite Member of the Rustler Formation showed an inverse relationship with Culebra transmissivity (T). They postulated that gypsum fracture fillings limited Culebra T by closing fracture apertures and filling critical fracture junctions. Beauheim and Holt illustrated a qualitative relationship but did not develop a quantitative model relating T to gypsum content because too few well locations had both measured T values and describable core. Since 1990, however, the Culebra has been cored and hydraulically tested at 24 additional locations, providing sufficient data to construct a quantitative model linking Culebra T with the presence of gypsum cements.

Here we construct a simple quantitative model relating Culebra gypsum content to T and develop maps showing the spatial occurrence of gypsum in the Culebra. We first review the stratigraphy of the Rustler and the hydrostratigraphy of the Culebra. We then develop a gypsum index for each WIPP borehole location where sufficient core exists to determine relative gypsum content in the Culebra units defined by Holt (1997). When the log of Culebra T is plotted against the gypsum index, a clear pattern emerges, and a critical value of the gypsum index can be defined. This critical gypsum index value can be used to infer the high-T/low-T status of Culebra well locations with an accuracy of greater than 97% for WIPP data. Maps showing the location of no gypsum and low gypsum in the Culebra are then created using the critical gypsum index value. These maps reveal that regions of no gypsum occur predominantly where Salado dissolution has affected the Culebra and that the low-gypsum region in the WIPP area is similar to the high-diffusivity region defined by Beauheim (2007).

Culebra Hydrostratigraphic Units

Holt (1997) subdivided the Culebra into four distinct units (Figure F-1), which can be identified in the subsurface across the entire WIPP area. 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 ~0.6 m) that bound large tabular blocks. The middle two Culebra units (CU-2 and CU-3) have a similar character, and are often not recovered during 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 open vugs (Holt, 1997). Because of their general similarity, CU-2 and CU-3 are treated as one unit here. The Culebra overlies a mudstone unit (M2 of Holt and Powers, 1988) across much of the WIPP area, and the lower contact undulates up to 1 m in WIPP shafts (Holt and Powers, 1990). The lowermost unit (CU-4) shows evidence of syndepositional and post-depositional deformation due to 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.

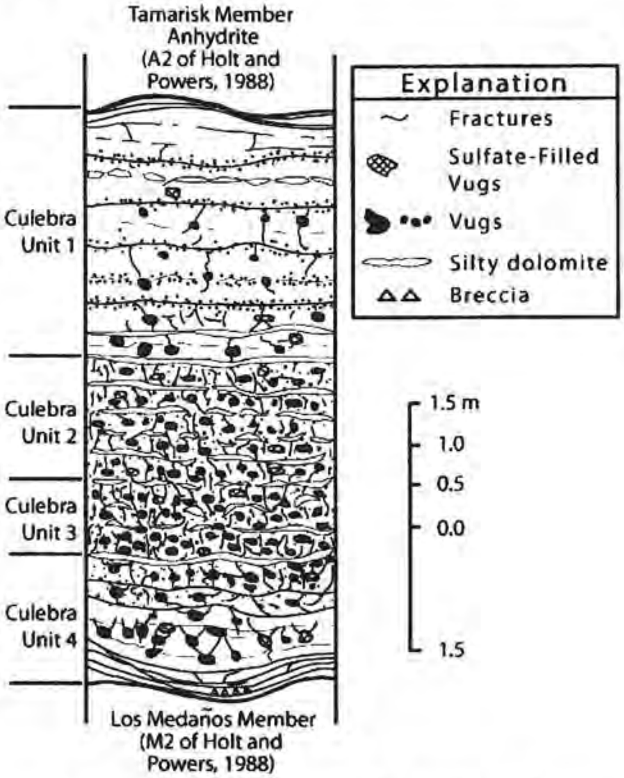

Figure F-1. Culebra hydrostratigraphy.

Gypsum Index

Published descriptions of Culebra core (e.g., Mercer et al., 1998) were combined with the authors' examination of cores to generate relative rankings of the gypsum content present in each of the Culebra units. These rankings included all reported occurrences of gypsum within the core description and were assigned to each unit using:

$$GR_{CUi} = \begin{cases} 1 & \text{No Gypsum} \\ 2 & \text{Some Gypsum} \\ 3 & \text{Moderately Abundant Gypsum} \\ 4 & \text{Abundant Gypsum (or Halite)} \end{cases} \qquad \text{(F-1)}$$

where *i* is 1, 23, or 4 for CU-1, CU-2 and CU-3, and CU-4, respectively. A gypsum rank was also assigned to describe the occurrence of large-scale gypsum-filled fractures (subvertical fractures greater than 0.3 m in length). This rank is given by:

$$GR_F = \begin{cases} 2 & \text{Gypsum Present} \\ 0 & \text{No Gypsum/No Fractures Observed} \end{cases} \qquad \text{(F-2)}$$

Gypsum rankings were collected at 51 core locations, including 46 locations with estimates of Culebra T (Table F-1).

At each core location, a gypsum index was determined from the gypsum ranking data using:

$$GI = \frac{1}{3}\left(GR_{CU1} + GR_{CU23} + GR_{CU4}\right) + GR_F \qquad \text{(F-3)}$$

where GR_{CU1}, GR_{CU23}, GR_{CU4}, and GR_F are the gypsum indices of CU-1, CU-2 and CU-3 combined, CU-4, and large-scale fractures, respectively. Table F-1 contains the gypsum index for all 51 core locations, along with T information from Holt and Yarbrough (2002), Roberts (2006; 2007), and Bowman and Roberts (2008).

A plot of Culebra log T against the gypsum index reveals a striking relationship (Figure F-2). Figure F-2 shows that all low-T ($\log_{10}$ T (m^2/s) < -5.4) wells have a gypsum index above 2.5, while nearly all high-T wells have a gypsum index below 2.5. The use of this critical gypsum index value to infer the high-T/low-T status of WIPP wells is correct for over 97% of the well data used here, with only a 1 in 46 chance (WQSP-4) of misclassification.

Table F-1. Gypsum rankings and gypsum indices for WIPP well locations with complete Culebra core (continued on next page).

Well ID	Log T [log(m²/s)]	Large-Scale Fractures[1]	CU 1[2]	CU 2&3[2]	CU 4[2]	Gypsum Index
H-11b4	-4.3	0	1	1	1	1.0
H-7c	-2.8	0	1	1	1	1.0
SNL-1	-3.2	0	1	1	1	1.0
SNL-14	-4.3	0	1	1	1	1.0
SNL-16	-2.9	0	1	1	1	1.0
SNL-17	-3.5	0	1	1	1	1.0
SNL-18	-3.8	0	1	1	1	1.0
SNL-19	-3.4	0	1	1	1	1.0
SNL-3	-3.0	0	1	1	1	1.0
WIPP-11	-3.4	0	1	1	1	1.0
WIPP-13	-4.1	0	1	1	1	1.0
WIPP-25	-3.6	0	1	1	1	1.0
WIPP-26	-2.9	0	1	1	1	1.0
WIPP-27	-3.3	0	1	1	1	1.0
WIPP-28	-3.6	0	1	1	1	1.0
WIPP-29	-3.0	0	1	1	1	1.0
WIPP-34	unknown	0	1	1	1	1.0
H-8c	unknown	0	1	1	1	1.0
WIPP-32	unknown	0	1	1	1	1.0
WIPP-33	unknown	0	1	1	1	1.0
H-3b1	-4.7	0	1	1	2	1.3
SNL-9	-4.4	0	2	1	1	1.3
WQSP-1	-4.5	0	2	1	1	1.3
WQSP-2	-4.7	0	2	1	1	1.3
SNL-12	-3.3	0	1	1	3	1.7
SNL-2	-3.8	0	2	1	2	1.7
H-9c	-4.0	0	1	1	4	2.0
AEC-8	unknown	0	1	1	4	2.0
SNL-5	-5.3	0	2	2	2	2.0
DOE-2	-4.0	0	2	1	4	2.3
H-19b0	-5.2	0	3	2	2	2.3
WIPP-30	-6.7	0	2	3	3	2.7
WQSP-5	-5.9	0	3	2	3	2.7
C-2737	-6.2	2	2	1	1	3.3
H-17	-6.6	0	4	2	4	3.3
H-18	-5.7	0	4	3	4	3.7
H-15	-6.8	0	4	3	4	3.7
H-14	-6.5	2	3	1	1	3.7

[1] Large-scale subvertical fractures are described as: 0 = open or not present and 2 = filled.

[2] Gypsum content estimated in core as: 1 = none, 2 = some, 3 = moderately abundant, and 4 = abundant. Note that when halite cements are present, they are treated as gypsum (e.g., SNL-6 and SNL-15).

Well ID	Log T [log(m^2/s)]	Large-Scale Fractures[1]	CU 1[2]	CU 2&3[2]	CU 4[2]	Gypsum Index
SNL-8	-6.6	2	2	2	2	4.0
SNL-6	-11.1	0	4	4	4	4.0
WQSP-4	-4.9	2	3	2	2	4.3
H-16	-6.1	2	2	3	3	4.7
SNL-13	-6.4	2	3	2	3	4.7
WIPP-19	-6.2	2	4	3	1	4.7
SNL-10	-6.5	2	3	3	3	5.0
H-5c	-6.7	2	3	3	4	5.3
WQSP-3	-6.8	2	3	3	4	5.3
WQSP-6	-6.6	2	4	3	3	5.3
H-12	-6.7	2	4	3	4	5.7
H-10b	-7.4	2	4	4	4	6.0
SNL-15	-12.9	2	4	4	4	6.0

[1] Large-scale subvertical fractures are described as: 0 = open or not present and 2 = filled.

[2] Gypsum content estimated in core as: 1 = none, 2 = some, 3 = moderately abundant, and 4 = abundant. Note that when halite cements are present, they are treated as gypsum (e.g., SNL-6 and SNL-15).

Spatial Relationships of Gypsum in the Culebra

Because of the strong relationship between the critical gypsum index value and the high-T or low-T designation of wells, maps showing the spatial occurrence of regions with no gypsum and low gypsum were created. In the interpretation of no- and low-gypsum regions, low-T locations (Figure F-3) were assumed to have a gypsum index greater than 2.5, an assumption supported by 100% of the low-T data shown in Figure F-2. It was also assumed that the Culebra displays low T where halite occurs within the M2/H2 or M3/H3 intervals, as defined by Holt and Powers (1988); halite distribution has been refined in these units by Powers (2007) as shown in Figures F-4 and F-5. The majority of the wells showing no gypsum occur within Nash Draw or within regions affected by Salado dissolution (Figure F-4). Figure F-5 shows the region where the gypsum index is less than the critical value of 2.5. Comparison of the low-gypsum line in Figure F-4 with the low-diffusivity line of Beauheim (2007; Figure F-6) reveals a striking similarity. This result is not surprising as regions of low diffusivity or T should correlate strongly with regions where the gypsum index is large.

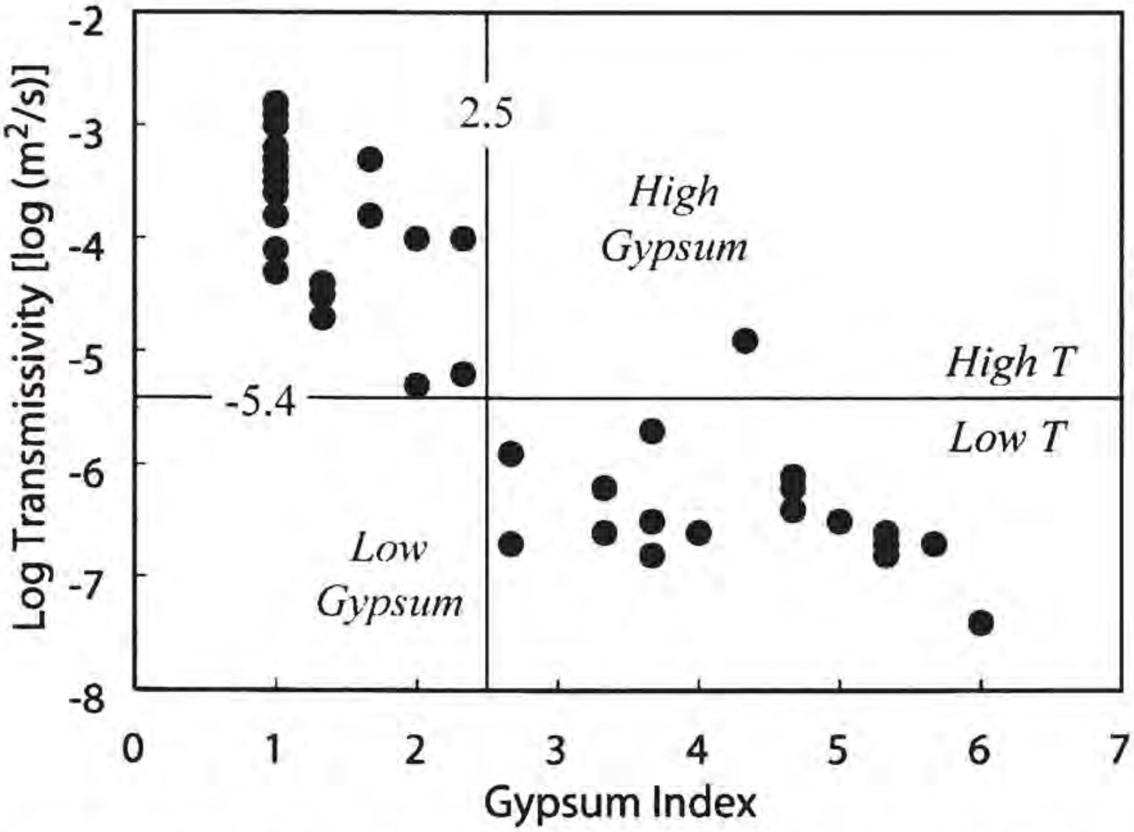

Figure F-2. Plot of Culebra log T versus the gypsum index. The blue line shows the high-T/low-T cutoff defined by Holt and Yarbrough (2002) and Holt et al. (2005). The red line shows the critical gypsum index value of 2.5.

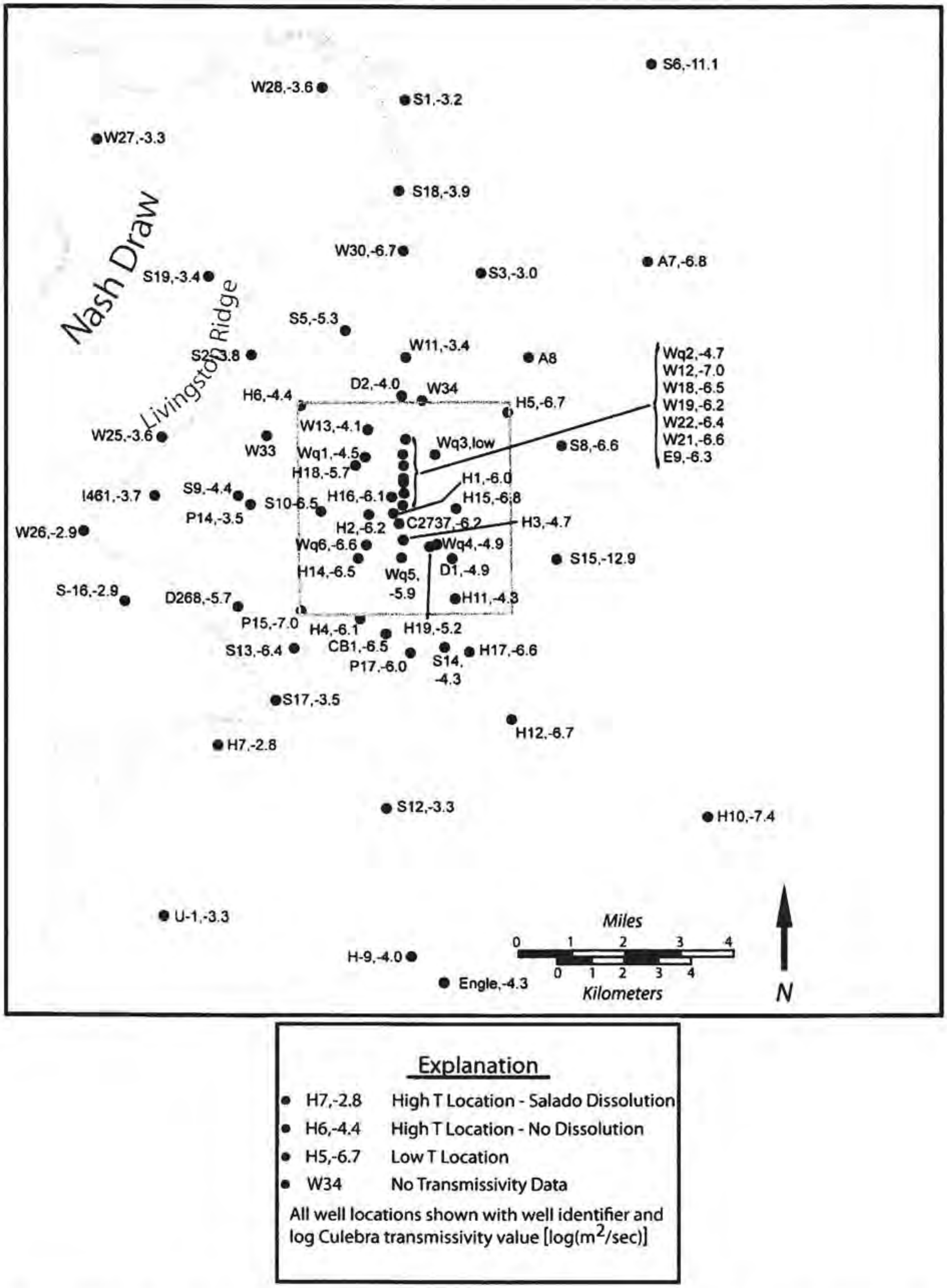

Figure F-3. Map showing the locations and log T values of Culebra wells used in this study.

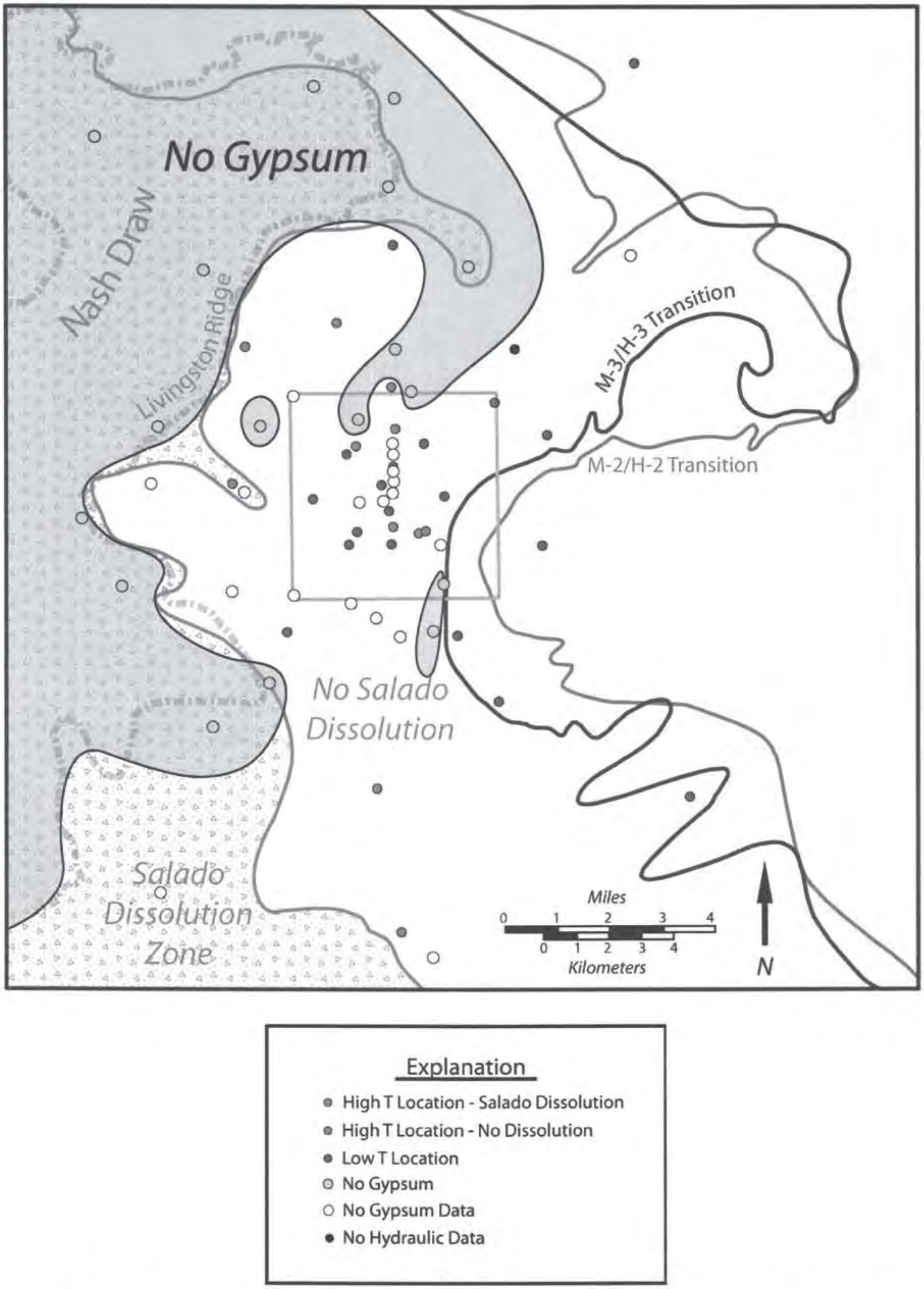

Figure F-4. Map of the no-gypsum region in the vicinity of the WIPP site. Halite occurs in the M-2/H-2 and M-3/H-3 intervals east of their respective transition lines.

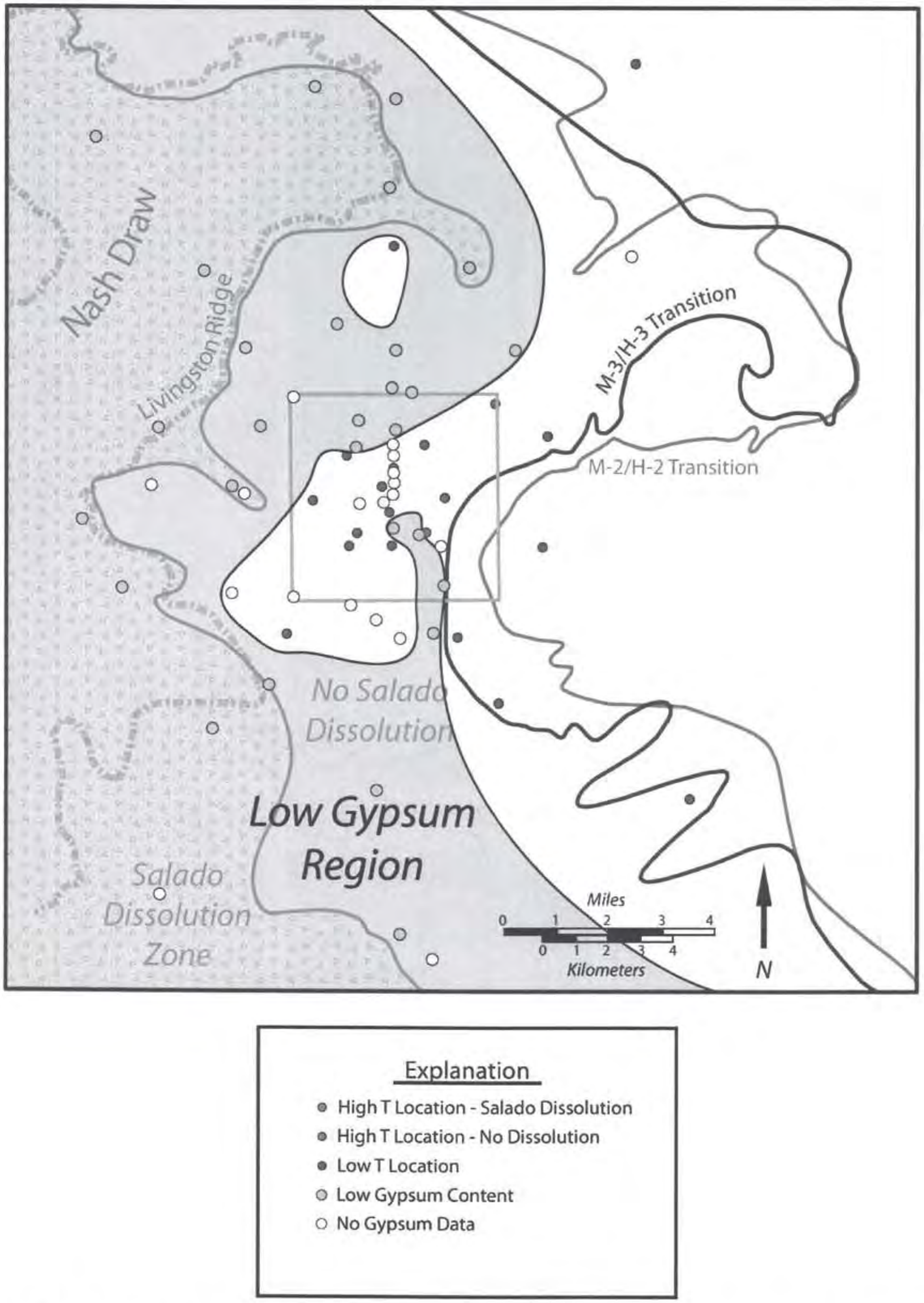

Figure F-5. Map of the low-gypsum region (including no gypsum) in the vicinity of the WIPP site. Area in white represents high-gypsum index (>2.5). Halite occurs in the M-2/H-2 and M-3/H-3 intervals east of their respective transition lines.

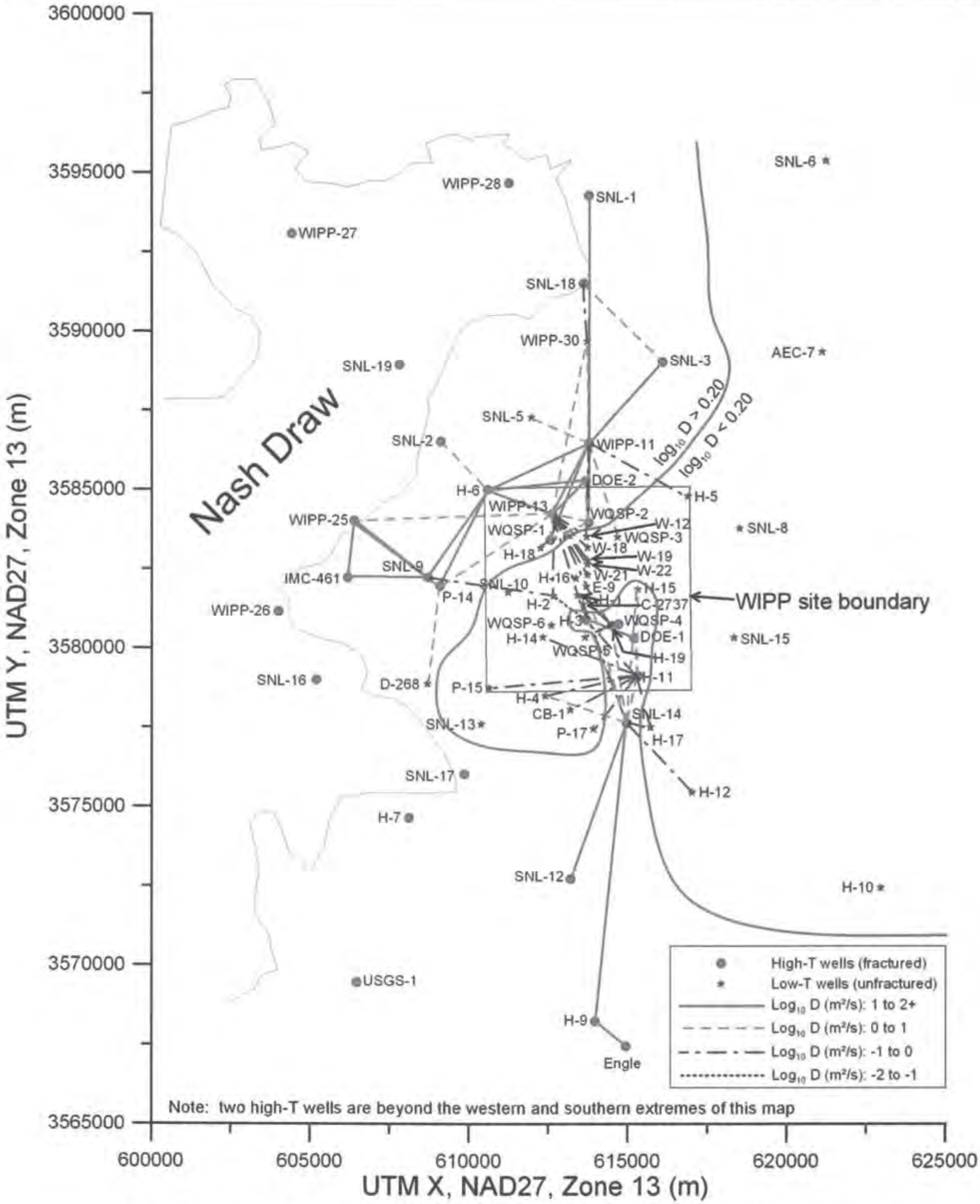

Figure F-6. Map from Beauheim (2007) showing regions of high and low diffusivity.

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Appendix G

Revision of Salado Dissolution Margin in the Vicinity of H-9

Richard L. Beauheim

The Salado dissolution margin used in generation of base Culebra T fields was defined by Powers (2003) on the basis of changes in the thickness of the interval from the Culebra to the Vaca Triste in the Salado Formation (Figure G-1). The data used by Powers (2003) are contained in his file *Task1 Source Data_Rev 01-03.xls*. In the vicinity of well H-9 south of the WIPP site, the inferred location of this margin was heavily influenced by an apparent sharp change in the thickness of this interval between two wells 141 m apart, Sundance Oil Company Betty Federal #1 (Powers ID# 1343) and El Paso Natural Gas Company Sundance Federal #1 (Powers ID# 1344). Powers (2003) had the Culebra to Vaca Triste thickness in 1343 as 215 m, and in 1344 as 187 m. All surrounding wells, however, had Culebra to Vaca Triste thicknesses closer to 215 m than to 187 m, making 1344 a sort of one-hole anomaly. At my request, Powers rechecked his stratigraphic picks for well 1344 and concluded that his earlier estimate was in error; he indicated the correct thickness should be 217 m (Powers, 2008).

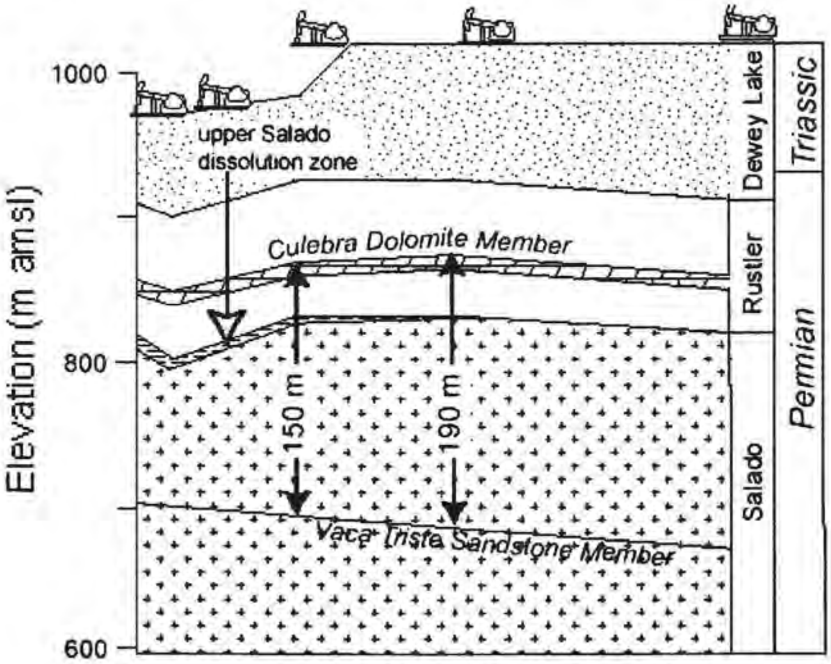

Figure G-1. Schematic drawing of thinning of Culebra to Vaca Triste interval due to Salado dissolution.

I extracted the information for 172 wells between approximately UTM X coordinates 610,000 and 620,000 m and UTM Y coordinates 3,562,500 and 3,572,000 m from *Task1 Source Data_Rev 01-03.xls*, creating file *H-9_dissolution_margin.xls*, with the wells ordered by increasing Culebra to Vaca Triste thickness (column K). I then plotted the locations of these wells in Grapher 7 as shown in Figure G-2, with the wells binned into 10-m thickness intervals. The Salado dissolution margin defined by Powers (2003) is shown on the figure, passing between wells 1343 and 1344, which are the two wells immediately ENE of H-9. Note that this line effectively puts all wells with a Culebra to Vaca Triste thickness >210 m in the area of no Salado dissolution, but leaves numerous wells with thicknesses in the 200-209 m range and one well with a thickness in the 190-199 m range also in the area of no Salado dissolution, while other wells with the same thicknesses are in the area of Salado dissolution.

I have drawn a new line on Figure G-2 that effectively defines the margin of Salado dissolution as corresponding to a Culebra to Vaca Triste thickness of 190 m. This is justified by the presence of wells with Culebra to Vaca Triste thicknesses in the 170-179 m and <170 m ranges occurring adjacent to wells with thicknesses in the 190-199 m range, indicating a significant change in thickness over a short distance. Powers (2003) generally attempted to place his dissolution line where the Culebra to Vaca Triste thickness began to show an abrupt decrease to the west. A digital representation of this line from Grapher 7 is stored in the file *H-9_dissolution_margin.txt* using UTM X and Y coordinates (m) in NAD27.

The revised dissolution line is not expected to impact any model results noticeably; it is simply a correction of an error discovered while reviewing data.

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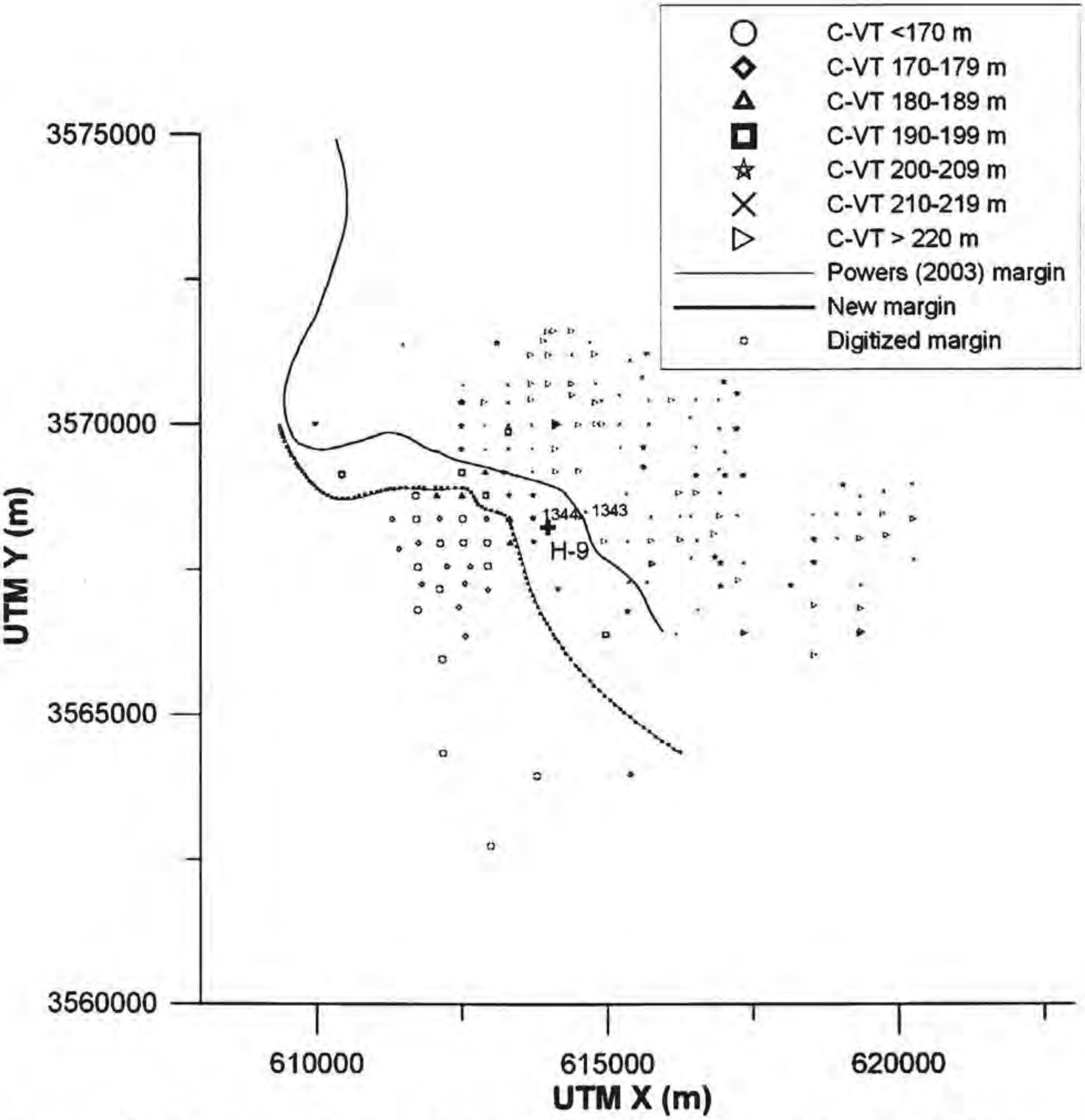

Figure G-2. Wells in the vicinity of H-9 showing Culebra to Vaca Triste (C-VT) thickness and old and new Salado dissolution margins.

Listing G.1: File *H-9_dissolution_margin.xls.*

ID Number	Drillhole/Event Name	Twp	Rge	Sec	Feet from the North/South Line	Feet from the East/West Line	UTMX (NAD 27)	UTMY (NAD 27)	Work Period	Thickness (m) between Top of Culebra and Base of Vaca Triste
1350	Charles B. Read, Ritchie Federal #1	24	31	18	660s	660e	612170	3564337	S02	153
1352	David Fasken, Poker Lake #40	24	31	20	660s	1980w	612990	3562733	S02	160
9302	ADELINE "ALN" FEDERAL #3	24	31	6	660n	1980e	611698	3568768	W03	160
9305	ADELINE "ALN" FEDERAL #9	24	31	6	1980s	660e	612121	3567956	W03	162
1346	Ambassador Oil Corporation, Federal Y #1	24	31	7	660s	660e	612152	3565948	S02	163
9376	SUNDANCE FEDERAL #13	24	31	5	1980s	1980w	612926	3567964	W03	163
9377	SUNDANCE FEDERAL #14	24	31	5	1980s	660w	612523	3567960	W03	163
1351	Pauley Petroleum Incorporated, Jennings Federal #1	24	31	20	660n	660e	613780	3563956	S02	165
9329	ADELINE "ALN" FEDERAL #15	24	31	6	660s	1980e	611729	3567549	W03	165
9381	SUNDANCE FEDERAL #15	24	31	5	660s	1980w	612936	3567564	W03	167
9372	SUNDANCE FEDERAL #7	24	31	5	1980n	660w	612513	3568373	W03	168
9487	PALLADIUM "7" FEDERAL #2	24	31	7	1800n	1980e	611740	3566800	W03	168
9303	ADELINE "ALN" FEDERAL #7	24	31	6	1980n	1980e	611708	3568366	W03	169
9636	PALLADIUM "7" FEDERAL #1	24	31	7	610n	760e	612108	3567166	W03	169
1353	Hill & Meeker, Carper Federal #1-21	24	31	21	660n	660e	615384	3563978	S02	170
9322	ADELINE "ALN" FEDERAL #17	24	31	5	660s	990w	612634	3567559	W03	170
9553	ADELINE "ALN" FEDERAL #11	24	31	6	1650s	2310w	611401	3567847	W03	170
9440	SQUIRES A L R #1	24	31	7	330n	1750e	611805	3567248	W03	171
9321	ADELINE "ALN" FEDERAL #16	24	31	6	660s	330e	612232	3567554	W03	173
9306	ADELINE "ALN" FEDERAL #10	24	31	6	1980s	1830e	611750	3567950	W03	174
9459	LOTOS FEDERAL #802	24	31	8	1980s	660w	612550	3566355	W03	174
9432	LOTOS FEDERAL #801	24	31	8	330n	660w	612540	3567256	W03	175
9293	SUNDANCE "8" FEDERAL #1	24	31	8	660n	1980w	612943	3567160	W03	176
9368	SUNDANCE FEDERAL #8	24	31	5	1980n	1980w	612915	3568377	W03	176
9294	SUNDANCE "8" FEDERAL #2	24	31	8	1650n	330w	612443	3566853	W03	177

9642	ADELINE "ALN" FEDERAL #1	24	31	6	1980n	1980w	611289	3568363	W03	177
9304	ADELINE "ALN" FEDERAL #8	24	31	6	1980n	660e	612111	3568370	W03	179
9375	SUNDANCE FEDERAL #12	24	31	5	1980s	1980e	613323	3567969	W03	180
9300	ADELINE "ALN" FEDERAL #2	24	31	6	660n	760e	612070	3568772	W03	183
9348	SUNDANCE FEDERAL #6	24	31	5	660n	660w	612503	3568775	W03	185
9255	PAULINE "ALB" STATE #5	23	31	32	660s	1980w	612897	3569181	W03	189
9359	SUNDANCE FEDERAL #9	24	31	5	1980n	1980e	613316	3568380	W03	189
9731	D-3S	23	30	36	417s	665e	610430	3569140	W03	192
9731	D-3S	23	30	36	417s	665e	610430	3569140	W03	192
9345	SUNDANCE FEDERAL #5	24	31	5	660n	1980w	612905	3568779	W03	194
9277	PAULINE "ALB" STATE #7	23	31	32	660s	660w	612495	3569178	W03	197
9737	I-342S	23	31	32	2500n	2000e	613290	3569890	W03	197
9239	LOTOS FEDERAL #1	24	31	9	1980s	1980e	614966	3566383	W03	198
9374	SUNDANCE FEDERAL #11	24	31	5	1980s	660e	613725	3567973	W03	200
9509	LOTOS "C" FEDERAL #903	24	31	9	1980n	760e	615335	3566786	W03	201
1339	Max Wilson, Jennings Federal No. 1	24	31	3	660s	660e	616940	3567612	S02	202
9341	SUNDANCE FEDERAL #4	24	31	5	660n	1980e	613309	3568782	W03	202
9373	SUNDANCE FEDERAL #10	24	31	5	1980n	660e	613718	3568383	W03	202
9479	TODD "2" STATE #4	24	31	2	1980s	660e	618543	3568027	W03	202
9480	TODD "2" STATE #3	24	31	2	660s	660e	618545	3567624	W03	202
9340	SUNDANCE FEDERAL #3	24	31	5	660n	660e	613711	3568786	W03	204
1347	Gulf Oil Corporation, Federal Littlefield CT #1	24	31	11	660n	1980e	618146	3567222	S02	205
9278	PAULINE "ALB" STATE #8	23	31	32	1980s	660w	612489	3569580	W03	205
9295	SUNDANCE "9" FEDERAL #3	24	31	9	660n	660w	614141	3567173	W03	205
9506	LOTOS "10" FEDERAL #3	24	31	10	660n	660e	616945	3567209	W03	205
9540	STERLING SILVER "34" FEDERAL #7	23	31	34	850s	330w	615616	3569274	W03	205
1258	J.A. Leonard, Continental State No. 1	23	31	32	660n	660w	612478	3570381	S02	206
9262	POKER LAKE "32" STATE #8	23	31	32	1980n	660w	612483	3569980	W03	206
9533	STERLING SILVER "34" FEDERAL #8	23	31	34	1980s	330w	615612	3569618	W03	206
9628	LITTLEFIELD FEDERAL WD#1	24	31	11	660n	1980e	618146	3567222	W03	206
9320	LILY ALY FEDERAL #8	24	31	3	990s	990e	616838	3567711	W03	207
9635	LILY ALY FEDERAL #8	24	31	3	990s	990e	616838	3567711	W03	207
9248	CAL-MON #6	23	31	35	330n	380w	617224	3570540	W03	208
9282	POKER LAKE "32" STATE #7	23	31	32	660n	760w	612508	3570382	W03	208

9292	SUNDANCE "1" FEDERAL #2	24	31	1	330n	990w	619041	3568956	W03	208
9774	L-1S	23	30	36	2150n	3090w	609970	3570010	W03	208
9253	PAULINE "ALB" STATE #3	23	31	32	660s	1980e	613220	3569184	W03	209
9267	TODD "27" FEDERAL #16	23	31	27	330s	330e	617006	3570739	W03	209
9269	CAL-MON #8	23	31	35	2310n	330w	617216	3569937	W03	209
9299	SAND DUNES "34" FEDERAL #3	23	31	34	330s	330e	617025	3569122	W03	209
9369	SAND DUNES "34" FEDERAL #8	23	31	34	330s	1980e	616522	3569122	W03	209
9547	CAL-MON #12	23	31	35	330s	660w	617326	3569130	W03	209
9785	PP-3	23	31	29	2620n	2655w	613100	3571410	W03	209
9235	FEDERALL "44" #1	23	31	34	660s	660e	616922	3569226	W03	210
9307	STERLING SILVER "34" FEDERAL #1	23	31	34	1980n	660w	615707	3570017	W03	210
9462	LOTOS "C" FEDERAL #901	24	31	9	330n	660e	615362	3567290	W03	210
9495	TODD "2" STATE #5	24	31	2	1980n	660e	618541	3568447	W03	210
9502	SUNDANCE "1" FEDERAL #8	24	31	1	1980s	660w	618945	3568031	W03	210
1341	Texaco, Incorporated, M.M. Stewart Federal #1	24	31	4	660n	660e	615323	3568810	S02	211
9254	PAULINE "ALB" STATE #4	23	31	32	1980s	1980w	612891	3569583	W03	211
9298	SAND DUNES "34" FEDERAL #2	23	31	34	2310n	660e	616915	3569933	W03	211
9308	SAND DUNES "34" FEDERAL #1	23	31	34	660n	660e	616909	3570435	W03	211
9309	LILY "ALY" FEDERAL #1	24	31	3	660n	660e	616928	3568824	W03	211
9313	FEDERAL "29" #8	23	31	29	330s	760w	612505	3570683	W03	211
9314	SAND DUNES "34" FEDERAL #4	23	31	34	1650s	330e	617020	3569528	W03	211
9489	STERLING SILVER "33" FEDERAL #15	23	31	33	1980n	990e	615204	3570012	W03	211
9646	STERLING SILVER "32" #1	23	31	32	1980s	1980w	613297	3569587	W03	211
9786	PP-4	23	31	30	2640s	2640e	611480	3571380	W03	211
9204	STEWART MM FEDERAL #1	24	31	4	660n	660e	615323	3568810	W03	212
9261	POKER LAKE "32" STATE #6	23	31	32	1980n	1980w	612886	3569985	W03	212
9361	SAND DUNES "34" FEDERAL #5	23	31	34	660n	1980e	616506	3570430	W03	212
9363	SAND DUNES "34" FEDERAL #7	23	31	34	1980s	1980e	616516	3569625	W03	212
9474	SOTOL FEDERAL #6	24	31	1	1980n	660w	618943	3568452	W03	212
9513	TODD "2" STATE #7	24	31	2	660s	660w	617342	3567616	W03	212
9532	STERLING SILVER "33" FEDERAL #16	23	31	33	1980s	990e	615209	3569613	W03	212
9252	PAULINE "ALB" STATE #2	23	31	32	660s	660e	613705	3569188	W03	213
9259	POKER LAKE "32" STATE #2	23	31	32	1980n	1980e	613293	3569991	W03	213
9362	SAND DUNES "34" FEDERAL #6	23	31	34	1650n	2310e	616415	3570127	W03	213

9424	STERLING SILVER "34" #2	23	31	34	660n	660w	615702	3570420	W03	213
9452	LOTOS "10" FEDERAL #1	24	31	10	1980n	1980e	616548	3566802	W03	213
9457	SOTOL FEDERAL #3	24	31	1	990n	1980w	619344	3568757	W03	213
9514	TODD "2" STATE #10	24	31	2	1980n	330w	617233	3568426	W03	213
1256	Patoil Corporation, Wright-Federal #1	23	31	27	1980s	660w	615691	3571224	S02	214
9251	PAULINE "ALB" STATE #1	23	31	32	1980s	660e	613700	3569590	W03	214
9318	LILY ALY FEDERAL #6	24	31	3	1980s	1980e	616534	3568009	W03	214
9319	LILY ALY FEDERAL #7	24	31	3	990s	2310e	616436	3567706	W03	214
9371	STERLING SILVER "33" FEDERAL #14	23	31	33	330n	990e	615198	3570515	W03	214
1343	Sundance Oil Company, Betty Federal #1	24	31	4	1659n	2310w	614621	3568495	S02	215
9219	POKER LAKE "32" STATE #1	23	31	32	660n	1980e	613288	3570393	W03	215
9325	MOBIL FEDERAL #8	23	31	29	330s	1980e	613284	3570695	W03	215
9391	STERLING SILVER "3" FEDERAL #6	24	31	3	1980n	2310w	616239	3568416	W03	215
9434	SUNDANCE "10" FEDERAL #1	24	31	10	330n	330w	615664	3567286	W03	215
9453	SOTOL "A" FEDERAL #3	24	31	12	660n	1980w	619353	3567232	W03	215
9458	SOTOL FEDERAL #5	24	31	1	330n	380e	620231	3568965	W03	215
9515	SUNDANCE "1" FEDERAL #5	24	31	1	660n	1980e	619742	3568857	W03	215
9201	WRIGHT-FEDERAL #1	23	31	27	1980s	660e	615691	3571224	W03	216
9211	SUNDANCE "1" FEDERAL #1	24	31	1	1980n	1945w	619335	3568455	W03	216
9260	POKER LAKE "32" STATE #3	23	31	32	1980n	660e	613695	3569997	W03	216
9437	STERLING SILVER "3" FEDERAL #1	24	31	3	1980n	660w	615736	3568412	W03	216
9486	SUNDANCE FEDERAL #21	24	31	4	1980s	660e	615345	3567993	W03	216
1344	El Paso Natural Gas Company, Sundance Federal #1	24	31	4	1980n	1980w	614522	3568395	S02	217
9428	PURE GOLD "D" FEDERAL #18	23	31	28	1650s	330e	615391	3571120	W03	217
9202	WRIGHT FEDERAL #3	23	31	33	660n	1980e	614897	3570411	W03	218
9246	LOTOS "B" FEDERAL #1	24	31	10	1980s	1980w	616173	3566397	W03	218
9290	PURE GOLD "D" FEDERAL #7	23	31	28	1980s	1650w	614387	3571211	W03	218
9311	LILLY "ALY" FEDERAL #3	24	31	3	1980n	2310e	616429	3568418	W03	218
9330	PURE GOLD "D" FEDERAL #12	23	31	28	330s	2310e	614793	3570712	W03	218
9416	TODD "27" FEDERAL #12	23	31	27	1980s	510w	615645	3571224	W03	218
9435	SUNDANCE "1" FEDERAL #4	24	31	1	740s	330e	620267	3567672	W03	218
9784	PP-2	23	31	28	2620n	2640w	614690	3571420	W03	218
9405	TODD "27" FEDERAL #13	23	31	27	660s	330w	615596	3570820	W03	219
9500	LOTOS "11D" FEDERAL #1	24	31	11	1980s	660w	617358	3566411	W03	219

9386	STERLING SILVER "33" FEDERAL #11	23	31	33	730n	2310e	614797	3570389	W03	220
9410	MOBIL FEDERAL #6	23	31	29	1980s	660e	613683	3571203	W03	220
9425	STERLING SILVER "34" FEDERAL #3	23	31	34	660n	1980w	616104	3570425	W03	220
9484	SUNDANCE FEDERAL #22	24	31	4	1980s	1980e	614943	3567988	W03	220
9281	POKER LAKE "32" STATE #5	23	31	32	660n	1980w	612880	3570387	W03	221
9510	SUNDANCE "1" FEDERAL #7	24	31	1	2130s	1830e	619801	3568089	W03	221
9645	BRAN-BETTIS FEDERA #1	24	31	11	660s	660e	618563	3566015	W03	221
9274	PURE GOLD "D" FEDERAL #3	23	31	28	1980s	330w	613985	3571207	W03	222
9289	PURE GOLD "D" FEDERAL #6	23	31	28	1980n	1650w	614383	3571612	W03	222
9355	STERLING SILVER "33" FEDERAL #5	23	31	33	330n	1650w	614393	3570507	W03	222
9406	STERLING SILVER "3" FEDERAL #7	24	31	3	1980s	2310w	616250	3568005	W03	222
9438	STERLING SILVER "3" FEDERAL #3	24	31	3	1980s	660w	615747	3567998	W03	222
1348	Coquina Oil Corporation, El Paso Federal No. 1	24	31	12	1980s	1980w	619362	3566428	S02	223
9272	PURE GOLD "D" FEDERAL #4	23	31	28	330s	330w	613988	3570704	W03	223
9280	POKER LAKE "32" STATE #4	23	31	32	560n	660e	613690	3570429	W03	223
9291	PURE GOLD "D" FEDERAL #8	23	31	28	330s	1650w	614391	3570708	W03	223
9384	PURE GOLD "D" FEDERAL #11	23	31	28	1980s	2310e	614786	3571215	W03	223
9390	STERLING SILVER "3" FEDERAL #5	24	31	3	660n	2310w	616228	3568818	W03	223
9441	STERLING SILVER "3" FEDERAL #4	24	31	3	660s	710w	615773	3567597	W03	223
9461	LOTOS "11" FEDERAL #1	24	31	11	330n	330w	617245	3567313	W03	223
9475	SOTOL FEDERAL #7	24	31	1	1980n	1980e	619742	3568459	W03	223
9216	JONES RANCH "3" #1	24	31	3	660s	660w	615758	3567596	W03	224
9383	STERLING SILVER "33" FEDERAL #8	23	31	33	660s	660w	614107	3569193	W03	224
9501	HEAVY METAL "12" FEDERAL #1	24	31	12	1900s	1900w	619338	3566398	W03	224
9270	MOBIL FEDERAL #7	23	31	29	330s	660e	613687	3570701	W03	225
9221	SOTOL FEDERAL COM #2	24	31	1	1980s	1980w	619347	3568037	W03	226
9310	LILLY "ALY" FEDERAL #2	24	31	3	660n	1980e	616525	3568813	W03	226
9312	LILLY "ALY" FEDERAL #4	24	31	3	1980n	660e	616932	3568421	W03	226
9317	LILY ALY FEDERAL #5	24	31	3	2310s	990e	616834	3568113	W03	226
9203	SOTOL "A" FEDERAL WD#1	24	31	12	1980n	1980w	619358	3566830	W03	227
9224	PURE GOLD "D" FEDERAL #1	23	31	28	1980n	660w	614082	3571609	W03	230
9433	SUNDANCE "1" FEDERAL #3	24	31	1	2310n	330e	620251	3568362	W03	231
9798	Y-13	23	31	28	2700s	100w	613910	3571440	W03	231
9238	STERLING SILVER "33" FEDERAL #2	23	31	33	1980n	1980e	614902	3570009	W03	232

9378	STERLING SILVER "33" FEDERAL #7	23	31	33	1980s	660w	614102	3569595	W03	232
9471	LOTOS "11" FEDERAL #2	24	31	11	1780n	660e	618552	3566881	W03	233
9647	STERLING SILVER FED #10	23	31	33	660s	1980w	614509	3569199	W03	234
9367	STERLING SILVER "33" FEDERAL #4	23	31	33	1830n	660w	614097	3570047	W03	236
9236	TRIPLE S "33" FED #1	23	31	33	1980n	2310e	614802	3570008	W03	238
1259	Patoil Corporation, Wright-Federal #2	23	31	33	1980n	660w	614097	3570001	S02	243
9268	PURE GOLD "D" FEDERAL #17	23	31	28	1980n	330w	613981	3571608	W03	243
9792	S-14	23	31	33	2029n	709w	614100	3569980	W03	247
9629	STERLING SILVER "33" #1	23	31	33	1980n	810w	614143	3570002	W03	249
9411	STERLING SILVER "33" FEDERAL #6	23	31	33	1980n	1980w	614500	3570005	W03	266
1342	Fenix & Scisson, Inc., WIPP No. H-9C	24	31	4	2482n	193w	613974	3568234	S02	

Listing G.2: File *H-9_dissolution_margin.txt*. UTM X and Y coordinates (m) in NAD27, Zone 13.

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