Technical Report

Review of TDEM Analysis of WIPP Brine Pockets

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Contents

Tables

Figures

Executive Summary

Pressurized brine has been encountered when drilling into the Castile Formation, an anhydrite/halite formation in the Delaware Basin which underlies the WIPP repository. It was originally postulated by the U.S. Department of Energy (DOE) and its contractors that pressurized brine reservoirs were concentrated adjacent to the Capitan Reef at the margin of the Delaware Basin. However, large amounts of brine were encountered when the WIPP-12 borehole, lying about 1 mile north of the WIPP repository, was deepened into the Castile in 1981. Because of concern that the underground reservoir associated with WIPP-12 might underlie the repository, DOE commissioned a geophysical study using the time domain electromagnetic induction method (TDEM) to further characterize the possible existence of pressurized brine pockets under the WIPP repository. The TDEM study provided the basis in the 1992 WIPP performance assessment conducted by Sandia National Laboratories (SNL) for estimating the probability of intersecting a brine pocket with an intruding borehole. In the CCA, DOE took a different approach to estimating the probability that the WIPP site was underlain by brine pockets. DOE conducted a geostatistical analysis of the fraction of oil and gas boreholes around the WIPP site that had encountered Castile brines and estimated that the probability of a borehole through WIPP waste intersecting a brine pocket was 8% (CCA, Chapter 6, p. 6-197, Docket:A-93-02, II-G-1).

EPA was not satisfied with the CCA treatment of assigning a fixed value to this uncertain parameter and consequently conducted its own review of the TDEM study. EPA used the results of its analysis to establish a probability distribution for the parameter PBRINE (the probability of an intrusion borehole intersecting a brine pocket in the Castile Formation) as the basis setting the parameter values to be used in the EPA- mandated Performance Assessment Verification Test (PAVT). As documented in the Table 3.5-1 of the PAVT Sensitivity Analysis Report (Docket:A-93-02, II-I-13), the CCDFs were not sensitive to changes in this parameter. The present report summarizes EPA's review of the TDEM study and provides the basis for developing the distribution for the parameter PBRINE (ID No. 3493) used in the PAVT.

A drawback of the TDEM study was that only a limited number of measurements were made – 36 measurements were taken on a grid covering 1 x 1.5 km with only one measurement taken near WIPP-12. However, the study was conducted and analyzed in a competent manner and the conclusions in the TDEM survey report (EAR88) appear defensible given the limited data base. Some concern exists as to the implications of using a one-dimensional analysis to describe a three-dimensional problem. Rule-of-thumb estimates suggest that the TDEM technique might miss detecting brine reservoirs less than 5 meters in thickness.

In the 1992 WIPP performance assessment (PA), SNL used a random model and a block model to generate probability distribution functions for the occurrence of brine reservoirs under the WIPP. These models appear to reasonably bound the expected range of probabilities. Results developed in this study closely reproduce the results presented in the 1992 PA. However, our analyses of approach taken in the 1992 PA indicate that consideration of the entire repository as an aggregate rather than considering the repository on a panel-by-panel basis can result in different proabilities when using the block model. The fraction of panels 1 and 8 (i.e., those nearest WIPP-12) underlain by brine ranges from 50 to 88%, while for panels 5, 6, 7, and 9, the fraction ranges from 10 to 50%. Probability distributions for the remote handled (RH) TRU waste disposal areas were very similar to those for the main disposal areas.

1. Introduction

Understanding whether subsurface regions containing brine exist below the waste storage panels at the WIPP site is important in developing disturbed case scenarios for the WIPP repository. The particular brine pocket pathway of concern involves an accidental encounter of a brine pocket and repository waste during drilling for resources. In such a scenario, transport of brine-mobilized waste to the accessible environment could be facilitated. In order to assess the effects of this scenario, a description of the subsurface distribution of brines is required. One of the main difficulties associated with creating a quantitative description of subsurface brines at the WIPP is that the brines are generally located at depths in excess of 1000 m below the surface. This depth precludes the use of high resolution surface geophysical techniques utilizing seismic, acoustic, and ground penetrating radar technologies.

Two methods have been used to describe the brines at depths in excess of 1000 m—down-hole logging of existing boreholes and time domain electromagnetic induction (TDEM) methods. These two methods represent the extreme ends of the spectrum of tools available for subsurface characterization. Borehole techniques are intrusive and direct and, generally, provide isolated point-samples of the subsurface. In contrast, TDEM is a surface geophysical technique which is non-intrusive, has low spatial frequency resolution, and provides averaged, or integrated, information about the subsurface.

DOE has used these two tools to estimate the number, type, and distribution of brine reservoirs beneath WIPP, and, subsequently, to develop probability distribution functions describing the likelihood that boreholes would intercept brine. This report critiques the process used by SNL for detecting, parameterizing, and quantifying the brines with TDEM methods and the methods used to develop probability distribution functions used in the 1992 performance assessment (SAN92) for modeling brine-related scenarios. On the basis of this review, EPA developed a distribution function for the probability of intersecting a brine pocket in the Castile be used in the EPA-mandated PAVT (see, for example, “Technical Support Document: Overview of Major Perforamnce Assessment Issues,” Docket:A-93-02, V-B-5). Background information is presented in Sections 2 and 3; Section 4 reviews the TDEM geophysical survey; and

Section 5 reviews the basis for developing a probability distribution function for the presence of pressurized brine under the repository waste panels.

2. Local Geology

The WIPP repository is located in the Salado Formation at a depth of 658.5 m below the surface (380.5 m amsl)[1]. The Salado, which is about 540 m thick near the repository, is composed of halites with thin interbeds of clay, and anhydrites deposited during the Permian period (about 255 million years ago) (SAN92).

The Salado is underlain by the Castile Formation which is composed of thick evaporite beds of either high purity halite or interlaminated carbonate and anhydrite. The Castile is 301 m thick near the WIPP (at borehole DOE-2). Units in the Castile have been informally named (beginning from the bottom of the Salado) as Anhydrite III, Halite II, Anhydrite II, Halite I, and Anhydrite I. All of these units are not found in all boreholes.

Brine in the Castile Formation is usually found in fracture zones in the anticlinal structures in the uppermost anhydrite layer (SAN92, Vol. 3, page 5-4, taken from LAP89). This unit is generally Anhydrite III (or in its absence, Anhydrite II). In the vicinity of the ERDA-9 borehole, just north of the repository footprint (244 m north of repository panel 1), the bottom of Anhydrite III is about 330 m above the top of the Bell Canyon Formation (although this borehole did not penatrate to the Bell Canyon).

The Bell Canyon Formation (the uppermost unit in the Delaware Mountain Group) lies below the Castile. This is "the first laterally transmissive unit below the WIPP repository" (DOE96). The Bell Canyon has been divided into the following units beginning with the uppermost Lamar (DOE96):

- Lamar limestone (or shale)
- Ramsey sand
- Ford shale
- Olds sand
- Hays sand

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[1]amsl: above mean sea level

Of the Bell Canyon units, the Hays sand has the highest transmissivity (ca. 10^{-7} m^2/s) while the Lamar limestone has the lowest (ca. 10^{-11} m^2/s).

A summary of the geological information is presented in Figure 2.2-1 of SAN92, Vol. 3. The figure shows that the nearest borehole to the disposal area, ERDA-9, was only deep enough to reach the top of the Anhydrite III member in the Castile Formation. Cabin Baby-1, located approximately 2 miles south of the disposal region extended entirely through the Castile Formation into the Bell Canyon. It encountered all three anhydrite members within the Castile. WIPP-12, located north of the disposal area, identified three anhydrite layers with different depths and thicknesses than Cabin Baby-1 and a large brine pocket. DOE-2, located further north, identified only one thick anhydrite member.

An oil/gas borehole in Section 15 (i.e., the northeast corner of the WIPP site) intercepted 293 m of Bell Canyon rock.

At DOE-2, located at the north edge of the WIPP land withdrawal area, the depth to the top of the Bell Canyon is 1240 m; while at Cabin Baby-1, just beyond the southern edge of the land withdrawal boundary, the depth to the top of the Bell Canyon is about 1230 m (SAN92, Vol. 3, p. 2-5). A generalized large-scale contour map (Docket:A-93-02, II-G-1, Appendix HYDRO, Figure 7) shows that the top of the Lamar shale (i.e., the top of the Bell Canyon) slopes downward from west to east across the WIPP site. A smaller scale contour map presented in Chapter 2 of the CCA as Figure 2-6 (Docket:A-93-02, II-G-1) provides additional detail but similar conclusions.

3. Brine Encounters Near the WIPP

During the early phases of site characterization, it was postulated that brine reservoirs in the Castile Formation were associated with a disturbed zone which extended into the Delaware Basin for about six miles from the basin-ward margin of the Capitan Limestone. Although the anhydrite and halite in the Castile generally have low permeability, DOE surmised that fracturing of the upper anhydrite due to structural deformation created zones of higher permeability which contain brine at pressures exceeding hydrostatic (DOE96). WIPP-12, which lies within the Basin but outside the disturbed zone, was initially drilled in 1978 to a depth of 850 m (about 20 meters into the Castile) and no brine was encountered. Because WIPP-12 was underlain by an anticlinal structure (as determined from seismic reflection profiles), the hole was deepened in 1981 and large amounts of brine were encountered (17 million barrels) (POP83).

As shown in Figure 3-1, brine has been encountered in several other holes near the WIPP site. This figure also shows estimated areas of the WIPP-12 brine reservoir based on three assumed reservoir thicknesses (18, 37, and 91 m) (NEI83). Based on this simple geometric model, brines associated with WIPP-12 could underlie the repository. However, data from ERDA-9, DOE-2, and WIPP-13, which did not encounter brine, suggest that the WIPP-12 reservoir must either have a thickness of about 90 m (300 ft)[2] and/or be elongated in the NE/SW direction. It should be noted that, although brine was not encountered in ERDA-9, this borehole only penetrated about 6 m into the Anhydrite III unit of the Castile.

[2] Based on information in Appendix BH (DOE96), the thickness of the Anhydrite III unit in WIPP-12 is 85 m. Since the upper 20 m apparently did not contain brine based on the initial drilling observations, this suggests that the maximum (uniform) reservoir thickness could not exceed 65 m.

Figure 3-1. Occurrence of Brine in WIPP Site Boreholes

4. Review of TDEM Study

A number of studies have been carried out to examine various aspects of the brine issue at WIPP (see LAR89, for example). This section is not written to provide a review of this body of literature, but to revisit the specific question of the 1992 WIPP brine parameterization through the application of TDEM techniques. In this regard, the documents reviewed specifically for this report are limited and described briefly herein.

The following broad progression of events has led to the current state of understanding of the nature of the WIPP brines:

- Brines were observed in oil and gas industry exploration wells in the region for several years.
- A large amount of brine was encountered when WIPP-12 was deepened in 1981. Interpretations were made of well log data relating observed brines to possible brines at WIPP (POP83, NEI83). This led to the conclusion that the WIPP-12 brine reservoir could underlie the waste panels.
- TDEM data were collected to investigate brines at WIPP (EAR88).
- Data were interpreted and a "Depth to Conductive Layer" map created.
- Based on TDEM data, probability distribution functions (PDFs) describing brine pocket occurrence were created for the 1992 WIPP PA (SAN92).
- "Three or four" reservoirs were identified (e.g., AXN94).

The Earth Technology TDEM Final Report (EAR88) played a central role in the evaluation of WIPP brines and provided much of the data used for quantification of brine distribution by DOE in repository performance assessment (SAN92). The Earth Technology report describes the results of a TDEM survey conducted in 1987 by Blackhawk Geosciences, a sub-contractor to Earth Technology. The results of this survey were used by SNL to provide a basis for quantifying subsurface brines at WIPP.

The Earth Technology report was comprehensive, accurate, and complete with respect to the subject matter. A companion report which describes the field operation, equipment deployment and calibrations procedures, data reduction methods, etc., was informally published as "A Field Operations Plan and Field Operations Report" was unavailable for this study. The available Earth Technology report provides sufficient information to review the basis for brine distribution conclusions made by DOE in the 1992 PA.

As part of the review, Pieter Hoekstra and Mark Bloom, both current employees of Blackhawk, were contacted and interviewed. Dr. Hoekstra and Mr. Bloom were both involved in the field work, data analysis, and reporting of the TDEM study. Additionally, Dr. Mary Poulton of University of Arizona, Laboratory of Advance Subsurface Imaging, and Dr. Cathy Pfeifer of DOE's Idaho National Engineering Laboratory (INEL) were contacted in reference to the use of TDEM type data.

4.1 SUMMARY OF THE EARTH TECHNOLOGY TDEM REPORT

The fundamental geophysical phenomenon being exploited to detect and characterize the brines at WIPP is related to the fact that brine saturated rocks are electrically more conductive than the salt deposits of the overlying Salado Formation (e.g., KAU83). In this setting not only are the brines naturally conductive, but the contrast of this condition with the highly resistive rocks of the Salado makes the electrical properties of the brine-saturated regions geophysically distinct.

In order to detect brine saturated rocks the time domain electromgnetic induction method is employed. With the TDEM method, electrical impulses are imparted into the earth via large electrical coils on the surface. The recording of subsequent transient decay functions from receiver coils provides the data used in the analysis and interpretation stages of the study. During the study at the WIPP, 38 such "soundings" were made. Due to the depth involved (over 1000 m), large transmitter loops (500 m by 500 m) were required. This large loop size was needed to impart sufficient energy into the ground to illuminate the subsurface at these depths. The tradeoff of the increased energy associated with a coil of such large size is a reduced spatial resolution of the resulting data.

Of the 38 readings, 36 were used to create a map of the WIPP site, and 2 were used as control data (at boreholes WIPP-12 and DOE-1). The 36 readings were laid out on a grid over the waste storage panel area of the WIPP site covering 1 x 1.5 km. This layout is shown in Figure 4-1 (from SAN92). The observation locations were laid out in a north-south grid, with a northerly and easterly station spacing of 250 m. Blackhawk used the Geonics EM-42 TDEM center loop device for all data collection. One recording station in the grid was located near borehole ERDA-9, and was used as a "calibration" site.

Figure 4-1. TDEM Grid Used to Measure Distance Below Surface to First Major Conductor. Hand Drawn Shaded Areas Represent Extent of First Major Conductor (SAN92, Figure 5.1-2).

In practice, the collected TDEM data are processed to produce curves referred to as apparent resistivity profiles, which are subsequently analyzed numerically to generate geoelectric profiles. (A geoelectric profile is a prediction of the electrical properties of the media with increasing depth.) In this case, the electrical conductivity (inverse of resistivity) of the media is estimated at various depths. This data analysis process is regularly performed in the geophysical industry, and no specialized routines or algorithms were developed as part of the Blackhawk activity.

In order to analyze (invert) the data to create the geoelectric section, assumptions are required about the gross electrical properties of the region. The "starting model" in this case was derived from data taken from drill holes in the general area. For example, the resistivity of the Salado Formation was set at a fixed resistivity value of 120 ohm-m, based on direct data from borehole logs. Wherever possible, Blackhawk used borehole log data to establish constraints on the data analysis and to verify results.

Because it is "difficult in induction resistivity to determine the absolute value of highly resistive layers sandwiched between two conductive layers," Blackhawk set the Salado resistivity at
120 ohm-m via data from the dual-induction log of ERDA-9.

The results of the TDEM study include geoelectric sections of all 38 readings. In the cases where TDEM data were collected near existing boreholes (i.e., DOE-1 and WIPP-12), the results compare well with borehole log data. The WIPP-12 brine was seen in TDEM data at 802 m, with a clear observable feature in the data associated with this known brine occurrence[3]. Since the 802 m deep brine was clearly detected in the TDEM data, and no other similar observations were made in the 36 data sets collected over the waste panels, a high degree of confidence was placed on the interpretation that no brine pockets exist above 1000 m in the area of the WIPP waste storage panels. This conclusion is important in itself, but also implies that the first occurrence of a high

[3]During the deepening of WIPP-12, the brine was actually encountered at a depth of 919 m (DOE/CAO-1996-2184, Appendix BH)

conductivity layer below the Salado Formation lies in either the Castile or Bell Canyon rocks. Since each TDEM datum recorded over the waste storage panel area showed evidence of a deep (> 1000 m) and highly conductive layer, each inversion procedure was structured to estimate the depth to the conductive body, its thickness, and its resistivity.

The Earth Technology report concluded that the "(TDEM data) show a continuous brine layer within the Bell Canyon Formation," 1200 m in depth or greater. As such, 36 subsequent estimates of the depth to the top of the basal conductive member were made. These data were contoured to create a "map" of the brines, and interpretations of this "map" led to the assumption that three or four brine pockets lie in the Castile Formation above 1200 m depth.

Several questions and concerns surround the basis of these inferences. For example, how accurate are the depth estimates; what size brine pocket can be detected; and, are other equally valid interpretations of the data possible?

Blackhawk attempted to answer these questions in the TDEM report. However, limitations of the TDEM method itself disallow definitive responses. To address the question of the accuracy of depth estimates, a sensitivity analysis was performed which yielded a qualitative depth accuracy level of 75 m. This "error bar" represents the variability in conductor depths which can be estimated from the data.

The question of what size brine pocket can be detected is even more difficult to answer, because the factors which drive this issue are poorly evaluated with the TDEM method. Four issues control the detectability of a brine saturated region—depth, orientation, size, and resistivity of the body. Due to the depth of the targets (> 1000 m), the resulting TDEM survey produced sparse surface data on a coarse 250 m grid. The resulting low data density forced Blackhawk to employ a one-dimensional approach to inversion of the data (producing 1D geoelectric profiles). Blackhawk used the Automatic Ridge Regression Inversion (ARRTI) program created by Interpex Ltd for data manipulation. Thus, the TDEM results do not account for the possibility of obliquely orientated or oblong-shaped brine pockets (two- and three-dimensional features).

Blackhawk recognized this limitation of the technique, and compared the 1D results from ARRTI with available geoelectric sections from borehole log data. Further, they specifically recommended that additional data be collected around WIPP-12 in order to map the two-dimensional (and/or three-dimensional) extent of the detected brine. However, since only one TDEM measurement was made at WIPP-12, rather than a series of measurements, the areal extent of the brine, seen both in the borehole log data and in the TDEM data, is impossible to determine. The question of the brine being a small pocket or extensive layer near WIPP-12 is unanswered.

From results of hydrostatic tests in EDRA-6 and WIPP-12, one can infer that the volume of high permeability brine is limited, with the vast majority in low permeability microfractures. This suggests a brine reservoir morphology which may be overly complex for accurate representation with a one-dimensional model.

As executed, the TDEM study is a series of one-dimensional interpretations used to represent the three-dimensional distribution of brines beneath the WIPP site. The question of using several 1D results to represent 3D problems is addressed specifically in Stolz et al. (STO96), who concluded that, in general, one must be guarded in the use of such 1D methods and that for "final quantitative definition of subsurface resistivities," 3D analysis is necessary.

In terms of detectability, a general rule of thumb used by geophysicists who regularly employ TDEM methods for subsurface investigations is that TDEM methods can generally detect layers with conductance values of about 1/3 or greater than the sum of conductance values from all above-lying strata with conductance defined as the ratio of thickness to resistivity. For this review, Table 4-1 was generated from the generalized geoelectric section presented in Earth Technology Report.

The sum of each constituent conductance to the depth of 1250 m is 20 ohm^{-1}. Thus, underlying layers with a conductance greater than about 7 ohm^{-1} should generally be observable. With a resistivity level of between 1 and 10 ohm-m in a brine layer, the minimum observable thickness should range between about 7 and 70 m, respectively. This crude estimate suggests that a thin brine pocket (say, 5 m thick) with a resistivity of 1 ohm-m, could go undetected.

Table 4-1. Generalized WIPP Geoelectric Section

Formation	Thickness (m)	Resistivity (ohm-m)	Conductance (ohm^{-1})
Supra-Rustler	200	30	6.7
Rustler	50	10	5.0
Salado	1000	120	8.3

As stated above, under the assumption that the estimated depth of the first conductive layer between 1050 and 1400 m is associated with a brine layer, some of the TDEM measurements show evidence of Castile brines and the remainder Bell Canyon brines. Of 36 brine depth estimates, 11 estimates indicate depths above 1200 m and 25 estimates below 1200 m. In its simplest form, the existence of Castile brines is suggested in 36% of the area surveyed.

Blackhawk compared their results with related studies and found good agreement with the magneto-telluric technique (CSAMT) results of Bartel et al. (BAR89), and the EM31/EM34 magnetic induction results of Skokan et al. (SKO89).

During this review, technical discussions were carried out with several geophysicists familiar with the brine issue at WIPP and the TDEM study (see contacts in Appendix A). All concurred that the study was carried out in a comprehensive and professional manner, that no erroneous assumptions were made or scientific principles violated, and that given the type and density of TDEM data collected, the conclusions were valid and defensible. However, it was concluded by all contacted, including the authors of the Blackhawk report, that new methods could now be employed to collect more appropriate data and perform more accurate analyses.

4.2 CONCLUSIONS REGARDING THE TDEM GEOPHYSICAL STUDY

The TDEM study, conducted by Blackhawk Geosciences, is a comprehensive and professional report, containing no erroneous or misleading assumptions, which adheres to sound scientific principles. The conclusions drawn from the report appear defensible and accurate, and are derived from appropriate methodologies and techniques.

Given the type of TDEM data collected, the general spatial location of the targets (>

1000 m deep), and the level of technology available at the time of the study, the conclusions drawn are valid, accurate, and defensible.

The data support the argument that multiple brine saturated areas may exist in the Castile Formation beneath the waste storage panel area. The error associated with the depth estimates to the top of the brines, estimated to be 75 m, is not well defined, and may influence the estimates of brine occurence.

5. Review of Brine Pocket Probability Distribution Function

5.1 INTRODUCTION

This section presents a review of the approach followed in the WIPP 1992 PA to determine a subjective probability distribution for the percentage of the excavated WIPP disposal area underlain by pressurized brine reservoirs in the Castile Formation. This parameter, which is used in the 1992 WIPP PA for analysis of the consequences of drilling intrusion scenarios, controls the relative proportion of drilling intrusions that hit brine. Due to limited information on the prevalence of brine reservoirs in the Castile Formation underlying the disposal site, the parameter is assigned a constructed probability distribution that was derived using Monte Carlo methods. The constructed distribution resulting from the Monte Carlo analysis performed for the 1992 PA ranges from 25% to 55% with a median of 40% of the waste panel area underlain by pressurized brine.

The 1992 PA adopts the Monte Carlo approach to simulate the effects of large uncertainties in two critical pieces of information required to determine the percentage of the excavated disposal area that is underlain by brine. Uncertainty in the geology of the Castile is reflected in the choice of which specific members of the Castile formation beneath the disposal region may contain brine pockets. Additional uncertainty arises in defining specific procedures for incorporating limited data available from the 1987 TDEM study; the study attempted to measure the elevation of the first subsurface conducting level (presumed to be brine) on a grid surrounding the WIPP site.

Although an alternative approach to determining the distribution of the percent of the disposal area underlain by brine was used in the CCA (see Chapter 6, Section 6.4.12.6, Docket:A-93-02, II-G-1), this review concentrates on the logic and results of the simulation methodology as reported in the 1992 PA, Volume 3, Section 5.1 (SAN92). The CCA approach of using a fixed value does not appropriately capture the uncertainity in this parameter. However, the TDEM geophysical study provides an experimentally-based foundation for characterizing the subjective uncertainity in the probability that brine pockets underlie the WIPP.

5.2 UNCERTAINTY IN AVAILABLE INFORMATION

Determination of the presence of pressurized brine in the Castile beneath the disposal area requires both geologic and geophysical information. Geophysical studies involving transient electromagnetic methods can be used to estimate the depth to the first conducting layer in the vicinity of the disposal site. This layer is presumed to be liquid-bearing. If the layer falls within a portion of the Castile that may accommodate pressurized brine pockets, then penetration of this layer may contribute to E1 or E1E2 type events in the drilling intrusion scenarios. However, if the first conducting layer lies below the portion of the Castile that accommodates pressurized brine pockets, the liquid may be unpressurized. Current understanding suggests that penetration of unpressurized brine-filled regions below the base of the Castile formation will not contribute to E1 or E1E2 type events, due to hydrostatic pressure at these depths.

The 1992 WIPP PA Monte Carlo model used to address the two major sources of uncertainty—the sparsity of the geophysical data and the geology of the Castile—is described in the following sections.

5.2.1 Uncertainty in Elevation of First Conductor Data

In the 1992 and previous PAs, the primary source of information on the frequency of brine reservoirs underlying the disposal region was a limited set of transient electromagnetic geophysical measurements that were made on a 250 m surface grid in the immediate vicinity of the disposal region. The TDEM survey method infers the existence of brine reservoirs in the Castile by measuring the impact of the fluids on subsurface electrical conductivity. The raw data requires a substantial amount of processing, referred to as inversion, to determine an estimate of the depth to the first conductor. It is reported in the 1992 PA that the uncertainty of the reported depth-to-first-conductor measurements is $\pm$75 m. In this review, we will assume that this reported value represents the standard deviation of the measurement error, denoted by σ_{MEAS} even though the statistical basis for this datum was not provided in EAR88 or SAN92.

The TDEM study produced a total of 36 measurements of the depth to the first conducting region, as reported in Figure 5.1-2 of SAN92, Vol. 3. Nine measurements were located directly above the disposal area, which is defined to include the eight main panels and the northern and southern central panels. The TDEM measurement grid extended approximately 500 m beyond the eastern, southern and western boundaries of the disposal region, providing an additional 27 measurement locations in regions adjacent to the disposal area. No additional measurements are available beyond the upsloping northern boundary. Ancillary information suggests that the prevalence of brine reservoirs increases in the northern direction, including a very large (over 17 million barrels, by some estimates) reservoir encountered in the WIPP-12 borehole.

Volume 3 of SAN92 includes two contour maps which were derived from the TDEM data set. Figure 5.1-2 of SAN92 shows a hand-drawn contour map prepared by the original investigators (See Figure 4-1 of this report). Figure 5.1-3 of SAN92 shows a "conservative" computer generated contour map drawn from the same data set that was used in the 1991 PA analysis. The TDEM data set has only 36 data points on a grid covering 1.75 million square meters surrounding the disposal region, hence it is noted in the 1992 analysis that there is a large degree of uncertainty in the depth-to-first-conductor contours reported in the two figures.

The 1992 PA includes a discussion of the spatial correlation of the TDEM data set. Surprisingly, the data exhibit no discernable spatial correlation in any direction at distances larger than the scale of the measurement grid (250 m). The analysis concludes that no meaningful statement can be made concerning the correlation at smaller distances. Spatial correlation measures the degree of association between the numerical values measured at two different locations. In most cases we would expect two points which are near neighbors to have more correlation than two points which are separated by a larger distance. Hence, spatial correlation is usually measured as a function of distance.

For the TDEM data, the pairs of observations are relatively far apart, on a 250-meter grid. Thus, there is no opportunity to measure the spatial correlation of the TDEM data at distances less than 250 meters. Attempts to measure the correlation at distances of 250 meters and greater showed no statistically significant correlation pattern.

The lack of statistical significance may be attributable to one or more of several factors:

1. The true depth-to-first-conductor "surface" (if such a surface exists in actuality) may have structural features that are smaller than the dimensions of the grid chosen for collecting the data;

2. The measurements may be precise, but the depth of the actual "surface" that is being measured is highly variable, with no defined structure at any distance of separation; or

3. The measurement procedure may have a large degree of measurement error, both horizontally and vertically, which masks the true correlation pattern of the data.

Factor 1 suggests that the measurements were made on too large a grid, missing the features that exist. Factor 2 suggests that there are no features to measure. Factor 3 suggests we would not be able to distinguish between situations 1 and 3, even if a data collection design with more closely spaced data points were used.

Given the limitations of the data, two differing assumptions were proposed in the 1992 PA:

a. It is possible that the TDEM data have high correlation (values near 1.0) at distances less than 250 meters. This would be expected if the features which underlie the depth-to-first-conductor data are approximately of this size or smaller. This assumption leads to the probability model for the TDEM data referred to as the Block Model, with a very high degree of spatial correlation assumed at smaller distances.

b. It is also possible that the TDEM data have limited spatial correlation (values near 0) at distances less than 250 meters. This assumption leads to the Random Model, which is a simple Gaussian probability model for the TDEM data, with no spatial correlation assumed at any distances.

These assumptions represent the two logical extremes, ranging from perfect correlation to no correlation. Details of the bounding analyses for the two different Monte Carlo simulation models to reflect uncertainty in the depth-to-first-conducting surface are described as follows:

1) Random Model

The TDEM data are assumed to have no significant correlation at any separation distance. The 1992 PA concludes that the best estimate of the elevation of the first conducting layer at any given point (x, y) within the disposal region is simply the mean elevation of the entire TDEM data set, which is M_{POP} = -211 m from mean sea level. (This elevation

is near the base of the Castile Formation beneath the disposal area. The uncertainties surrounding its value provide a separate issue which will be discussed in greater detail in the next section.)

Under the random model assumptions, all points in the disposal region have the same likelihood of being underlain by brine, regardless of proximity to any specific TDEM measurement locations with higher or lower than average elevation measurements.

The mean square difference between all pairs of observations is given by $\sigma^2_{SILL} \simeq (160\ m)^2$, described in the 1992 PA analysis as the sill value of the variogram. This is proposed as the variance for the simulated random variable which represents the elevation of the first conducting level in the Monte Carlo analysis.

2) Block Model

The TDEM data are assumed to be almost completely correlated at distances less than 250 m. Under this assumption, at any given point (x, y) within the disposal region, the best estimate of the elevation of the first conducting layer is the elevation of the nearest TDEM data point. A "block" is defined by the set of all points (x, y) in the plane of the disposal region with a given TDEM data point as nearest neighbor. The mean value surface described by the nearest-neighbor assumption for the elevation of the first conducting level variable in the Monte Carlo simulation under the Block Model is shown in Figure 5-1A. The corresponding mean value surface for the random model is shown in Figure 5-1B—a plane at elevation -211 m.

Figure 5-1A. Nearest Neighbor Mean Elevation Surface Using Block Model for TDEM Data

Figure 5-1B. Mean Elevation Surface Using Random Model for TDEM Data

> A value of twice the measurement error variance $2\sigma^2_{MEAS}$ is used in the 1992 PA as the variance for the simulated random variable which represents the elevation of the first conducting level in the Monte Carlo analysis of this model.

Alternative mean value surfaces which were not considered in the 1992 PA are shown in Figures 5-1C and 5-1D. Both these alternative surfaces are bounded within the random and block models described above.

In Figure 5-1C, the block model mean value surface shown in Figure 5-1A is truncated near the base of the Castile at -200 m elevation. This truncated block surface provides a more realistic picture of the surface only where it is within the brine-containing region of the Castile. The lower portions of the block surface which were removed from this figure are difficult to interpret, because they are deeply imbedded in the Bell Canyon Formation.

Figure 5-1D shows an alternative approach to estimating the mean value surface from the TDEM data. In this case, the elevation of each point was determined as the inverse distance weighted average of the elevations of the four nearest TDEM data points. This surface is also truncated near the base of the Castile. The distance weighted surface has peaks that correspond to the highest blocks in Figure 5-1C, but the estimated elevation falls off rapidly. Because higher elevations in the mean value surface result in a higher percentage of the site being underlain with brine, the block model surface shown in Figure 5-1A is the most conservative model of the four described here.

Figure 5-1C. Block Model Mean Elevation Surface Truncated at -200 m Elevation

Figure 5-1D. Inverse-distance Weighted Mean Elevation Surface Truncated at -200 m

In summary, the block and random models described above span the range of possible correlation values for distances smaller than the 250 m grid spacing of the TDEM measurements. The random model proposes zero correlation at any separation distance, while the block model proposes almost complete correlation at small separation distances.

5.2.2 Uncertainty in Geology of the Castile

Due to the limited number of boreholes in the immediate vicinity of the disposal area, several important features of the Castile Formation are difficult to quantify. The extent of this uncertainty is characterized by the several different values that can be found in the 1992 PA document. The parameter sheet on page 2.10, SAN92, Vol. 3, indicates that the probability distribution for the elevation top of the Bell Canyon (i.e., the base of the Castile) ranges from -228 m to -198 m, with a median at -213 m. The Monte Carlo analysis in Section 5.1 of the same volume uses a range from -230 m to -170 m with a median at -200 m. Similar discrepancies appear for the base of the Anhydrite III: the PDF given in the parameter sheet on page 2.9 ranges from 53 to 127 m, with a median of 127 m; the Monte Carlo analysis uses a range from 70 m to 140 m, with a median at 105 m.

Although the existence of brine regions in the local vicinity has been well established, exact locations of brine-filled regions immediately below the disposal area have not been established to date. In the general vicinity of the WIPP site, brine regions are commonly associated with the anhydrite members of the Castile. However, it is difficult to characterize the anhydrite members or their extent. Cores from several boreholes near the disposal region present varying profiles in terms of the number and extent of the anhydrite members directly below the disposal area.

The 1992 Monte Carlo procedure attempts to span this range of uncertainty by proposing two extreme cases. At one extreme, the base of the Castile is used as the lower cutoff for the region where brine pockets may exist. At the other extreme, the base of the uppermost anhydrite member (Anhydrite III) is used as the cutoff for the region where brine pockets may exist. Under either assumption, a range of values is assigned due to the uncertain geology.

5.3 PREDICTING MONTE CARLO RESULTS USING EXACT CALCULATIONS

The selection of a cutoff depth for the existence of pressurized brine is clearly an important determinant of the probability of hitting the brine. If one assumes that the pressurized brine only exists in the uppermost Anhydrite III member of the Castile, the probability of hitting brine is greatly reduced. Alternatively, if it is assumed that pressurized brine may exist anywhere in the Castile, not only in the uppermost regions, then the probability of hitting brine is greatly increased. Thus, the selection of the Block or Random model to reflect the geostatistical uncertainties surrounding the TDEM data is of much less importance than the selection of the appropriate region of the Castile which might contain pressurized brine.

The choice of the random or block model alternatives for the elevation of the first conducting layer below the disposal area, and the choice of using the base of the Castile Formation or the base of its Anhydrite III member for the cutoff in defining a pressurized brine reservoir yield four possible models for the percent of the disposal area underlain by brine. These four alternatives lead to four different distributions for the percentage of the disposal area underlain by brine.

In the 1992 PA, separate analyses were conducted and reported for the block and random models. In these analyses, the two possible cutoff assumptions (Castile or Anhydrite III) were not reported separately, but, instead, were combined into a single CDF by assigning a 50% probability to each cutoff possibility. Although all four models were simulated, the 1992 PA selected to use the combination of a block model for the elevation variable and the base of the Castile for the cutoff variable for constructing the final subjective distribution used in the 1992 PA Latin Hypercube Sampling procedure.

In the following sections, the four possible modeling approaches are unified in the present study into a single modeling framework, amenable to exact calculations to determine the probability of encountering brine.

5.3.1 Specification of Monte Carlo Model Random Cutoff Variable

The selection of a random cutoff elevation C for defining pressurized brine reservoirs is accomplished by assigning a uniform distribution to the appropriate range of elevations noted in Section 5.2.2. There are two possible sets of elevation limits (i = 1, 2) considered in the 1992 PA.

> i=1: If the base of the Castile is used for the cutoff, a lower elevation limit L_1 = -230 m and an upper elevation limit U_1 = -170 m are assigned for the uniform distribution; or

> i=2: If the base of the Anhydrite III is used for the cutoff, a lower elevation limit L_2 = 70 m and an upper elevation limit U_2 = 140 m are assigned for the uniform distribution.

The two possible sets of limits for the cutoff variable C_i are shown in Equation 5-1.

$$
\begin{gathered}
i = \underline{1 \text{ Bottom of Castile}}: \\
L_1 = -230 \text{ m},\ U_1 = -170 \text{ m} \\
i = \underline{2 \text{ Bottom of Anhydrite III}}: \\
L_2 = 70 \text{ m},\ U_2 = 140 \text{ m}
\end{gathered}
$$

The uniform distribution assigns equal probability to all values of the cutoff variable from its lower limit to the upper limit. The expected value of the uniform distribution is the elevation at the center of the interval, -200 m for the base of the Castile and +105 m for the base of the Anhydrite III. For comparison, the mean elevation for the TDEM data set is M_{POP}= -211 m. The mathematical form of the distribution f_i for the cutoff variable C_i is determined solely by the selection of the lower and upper limits and is shown in Equation 5-2.

$$
\begin{gathered}
C_i \_ \text{Uniform}[L_i, U_i], \\
f_i(c_i) = \frac{1}{U_i - L_i},\ L_i \le c_i \le U_i,\ i = 1, 2
\end{gathered}
$$

5.3.2 Specification of Monte Carlo Model Random Elevation Variable

The selection of a random elevation variable to represent the level at which the first conducting layer is located is accomplished by assigning a normal distribution. There are two possible normal distributions (j = 1, 2) considered in the 1992 PA.

j=1: If the random model is assumed for the elevation of the first conducting layer, the normal distribution selected for the elevation variable is assigned a mean equal to the mean of the TDEM data set (M_{POP}) at all points (x, y) within the disposal region. This mean elevation surface is shown in Figure 5-1B. The square root of the sill variance, σ^2_{SILL}, is used for the standard deviation of the normal distribution.

j=2: If the block model is assumed for the elevation of the first conducting layer, the normal distribution is assigned a mean equal to the elevation of the nearest TDEM data point. This mean elevation surface is displayed in Figure 5-1A. The square root of twice the measurement variance $2\sigma^2_{MEAS}$ is used for the standard deviation of the normal distribution.

The two possible sets of parameters for the random elevation variable $ELEV_j$ are shown in Equation 5-3.

$$\begin{array}{ll} j = \underline{1\ \ Random\ Model}: & j = \underline{2\ \ Block\ Model}: \\ M_1(x,y) = M_{POP} \approx -211\,m & M_2(x,y) = ELEV\ (nearest\ TDEM\ ) \\ S_1^2 = \sigma_{SILL}^2 \approx (\ 160\ m\ )^2 & S_2^2 = 2\ \sigma_{MEAS}^2 = 2\ (\ 75\ m\ )^2 \end{array}$$

The normal distribution assigns a bell-shaped probability distribution to all values of the cutoff variable. These distributions for j = 1 or 2 are represented by the notation shown in Equation
5-4.

$$ELEV_j(x,y)\ \_\ Normal\ [\ M_j(x,y\ ),S_j^2\ ],\ \ j = 1, 2$$

5.3.3 <u>Exact Procedures for Calculating Monte Carlo Model Expected Values</u>

If a random cutoff value is selected from either of the uniform distributions in Equation 5-2, then the probability of randomly selecting an elevation exceeding the selected cutoff can be computed from the normal distribution in Equation 5-4, conditional on the chosen cutoff value C_i. This conditional probability, written here as $P_{i,j}(x,y \mid c_i)$, is equal to the probability that a normal distribution with the given mean and variance will exceed the cutoff value selected, as shown in Equations 5-5 and 5-6.

$$P_{i,j}(x,y \mid c_i) = Pr\{ ELEV_j(x,y) > C_i \mid C_i = c_i \}$$

$$P_{i,j}(x,y \mid c_i) = 1 - \Phi[(c_i - M_j(x,y))/S_j]$$

The unconditional probability of obtaining a random elevation which exceeds the random cutoff value is calculated by averaging the conditional probability of Equation 5-6 over all possible values that could be obtained for the cutoff C_i. This requires evaluation of an integral of the cumulative normal distribution function Φ over the interval selected for the uniform distribution assigned to C_i. The required calculations are shown in Equation 5-7.

$$P_{i,j}(x,y \mid L_i, U_i, M_j, S_j) = \int P_{i,j}(x,y \mid c_i)\, f_i(c_i)\, dc_i$$
$$= 1 - \frac{1}{U_i - L_i} \int_{c_i = L_i}^{U_i} \Phi[(c_i - M_j(x,y))/S_j]\, dc_i$$

In Equation 5-8, the integral is reduced to a calculation of the average height of the Φ function over the range of the uniform random variable C_i, as shown in Figure 5-2.

$$1 - P_{i,j}(x,y) = \frac{\int_{c_i/S_j = L_i/S_j}^{U_i/S_j} \Phi[(c_i - M_j(x,y))/S_j]\, d(c_i/S_j)}{\frac{U_i - L_i}{S_j}}$$

Using a linear approximation, the average height may be estimated by averaging the height of the Φ function at the end points of the interval. Using the range assigned in Equation 5-1 for the base of the Castile cutoff, the average height is approximated by (0.45+0.60)/2 =
0.525. Thus, the expected value for the Monte Carlo model under the assumptions of

the random elevation model is easily computed from a table of the standardized normal distribution. If sufficiently large sample sizes are used in the Monte Carlo simulation, the simulated mean value for the proportion of disposal area underlain with pressurized brine should be near a value equal to one minus the average height, 1 - 0.525 = 0.475 (47.5%) using the random model with the base of the Castile as a cutoff variable.

Figure 5-2. Cumulative Distribution Function for Elevation Variable Using Random Model

When the base of the Anhydrite III is used as the cutoff variable, the average height is near one, and the percentage of disposal area underlain by pressurized brine under these assumptions falls dramatically. The corresponding mean for the Anhydrite III case is approximately 1 - (0.94+0.98)/2 = 0.04 (4%). This significantly lower value is a result of the cutoff being moved to an elevation which is approximately two standard deviations above the mean of the elevation distribution assumed under the random model.

Equivalent exact calculations for the block model are complicated by the need to identify the closest TDEM data point to each portion of the disposal area to calculate $M_2(x, y)$ in Equation
5-3. The assignment of the disposal region into as many as 36 different subregions is necessary, since $M_2(x, y)$ may equal any of the 36 TDEM elevations. Given that this segmentation of the disposal area is a function of the geometry of the disposal area with respect to the TDEM measurement grid, the above linear approximation procedures could then be applied separately within each subsection of the disposal area.

The main difficulty in determining the sectioning required to create the subregions for the block model is the requirement to specify the disposal region geometry, with coordinates that can be transformed to the coordinate system established for the TDEM data. Once this task was completed, Monte Carlo simulation of both the block and random models was possible. The results of these simulations are discussed in the following section.

5.4 SIMULATION RESULTS: BLOCK MODEL WITH BASE OF CASTILE CUTOFF

Although the block and random models may be combined with the choice of the base of the Castile or the Anhydrite III cutoff to yield a total of four possible combinations, the 1992 PA conservatively chose to use the block model, combined with the base of the Castile cutoff, for the subjective PDF assigned for the proportion of disposal area underlain by brine variable. Although the 1992 PA notes that detailed results by panel were also generated, the discussion does not indicate the range of results of this detailed analysis. The 1992 analysis also omits discussion of RH TRU waste areas, and the proportion of these areas that is underlain by brine.

To further the understanding of the block model results summarized in the 1992 PA PDF, an attempt was made in this study to duplicate this distribution using a detailed panel-by-panel analysis.

5.4.1 Simulation Methodology

A scale drawing of the WIPP disposal region, shown in Figure 3.1-2 of SAN92, Vol. 3, was used to create a database of 633 non-overlapping rectangular regions which cover the entire disposal region area. Separately identified sets of rectangles were constructed for:

1. the waste disposal rooms and drifts within each panel 1 to 8 and the southern and northern central panels (identified as panels 9 and 10, respectively);

2. the RH areas lining the side walls of rooms and drifts in panels 1 to 8;

3. the pillars and seals within each panel; and

4. the large interpanel regions located between panels 1 to 4 and 5 to 8.

All edges of the rectangles were referenced to a horizontally oriented (x-y) coordinate system which has an origin at the southwestern corner of the disposal area. TDEM measurement locations shown in Figure 5.1-2 of SAN92, Vol. 3, were also tabulated, with locations referenced to the disposal region coordinate system. The resulting database permits the determination of the nearest TDEM data point to any given point within the disposal region, providing information required to construct the nearest-neighbor mean elevation surface $M_2(x, y)$ defined in Equation 5-4 of Section 5.3 for the mean of the random elevation variable in the Monte Carlo simulation of the block model.

The simulation was constructed somewhat differently than the one described in the 1992 PA, which conducted the simulation on a grid of 2,000 points constructed to span the rooms and drift disposal areas in all ten panels. To provide similar results for R-H areas, pillars, and seals in the disposal region, our simulation selected random (x,y) coordinates within the entire disposal region, which were then identified as belonging to either the room/drift areas, RH areas, pillars, seals, or interpanel-panel regions. Because the entire disposal area is approximately 5 times larger than the panel/drift area, our simulation increased the sample size for a single iteration from 2,000 to 10,000 to obtain comparable coverage over the entire disposal region.

Separate simulations were run for the random model and the block model. For each simulation, a total of 100 iterations were performed using the base of the Castile as the cutoff variable, and 100 using the base of the Anhydrite III as the cutoff variable. Each iteration proceeds in the following fashion.

1. A random value for the cutoff variable is selected using the distribution in Equation 5-1. The value of this variable is fixed for the remainder of the iteration.

2. A random (x, y) point in the disposal region is selected and identified by type of area.

3. A random elevation is selected from the appropriate random elevation distribution shown in Equation 5-3. This value represents the elevation at which the first conducting layer occurs below the point (x, y).

4. The random elevation is compared to the cutoff variable to determine if the elevation is above the cutoff level. If so, the point (x, y) is determined to be underlain with pressurized brine.

5. After 10,000 random points have been selected and the presence or absence of brine determined for each, the percentage of area underlain by brine is estimated by calculating the ratio of the number of points identified with brine to the total number of points within each type of disposal area.

6. After 100 iterations have been performed, a set of 100 estimates for the proportion of area underlain by brine is generated. The cumulative distribution function (CDF) is calculated for these 100 values and is reported as the PDF for each separately identified area within each panel.

Although the simulation model generated results separately for RH areas, we found that the percentage underlain by brine for these areas closely approximates the room/drift area results within each panel. Hence, only results for the room/drift areas are reported in this discussion. Similar results were obtained for RH areas separately, and for room/drift/RH areas combined within each panel.

5.4.2 Simulation Results

The CDFs resulting from a simulation of the block model with the base of Castile cutoff are shown in Figure 5-3 for the rooms and drifts within each panel. As is evident in the

graph of the block model mean elevation surface in Figure 5-1A, the northernmost panels have the highest simulated percentage of area underlain with brine. The CDFs for panels 1 and 8
range from 50 to 88 percent of the area underlain with brine. Panel 2 and the northern central panel have the next highest CDFs for the percentage underlain with brine. The remaining six more southerly panels have correspondingly lower CDFs.

An equivalent set of CDFs for panels 1 to 10 using the random model for the depth to the first conducting layer is shown in Figure 5-4. As indicated in the graph of the random model mean elevation surface in Figure 5-1B, all ten panels are estimated to have approximately the same CDF for the percentage of area underlain with brine.

Figure 5-3. Simulated Cumulative Distribution Function for Percentage of Panel Area Underlain by Brine - Block Model with Base of Castile Cutoff

The results presented in the 1992 PA were aggregated to the all-panel level. Corresponding aggregate results were calculated during the four simulations for:

1. Block model with base of Castile cutoff;
2. Block model with base of Anhydrite III cutoff;
3. Random model with base of Castile cutoff; and
4. Random model with base of Anhydrite III cutoff.

Figure 5-4. Simulated Cumulative Distribution Function for Percentage of Panel Area Underlain by Brine - Random Model with Base of Castile Cutoff

These four aggregate CDFs are shown in Figure 5-5. The block and random model yield very similar results, whether using the base of the Castile or the base of the Anhydrite III. In this respect, the difference between the two models is smaller in our simulation than the difference reported in Figure 5.1-8 of SAN92, Vol. 3. As was indicated in the graph of Figure 5-2, the results using the base of the Anhydrite III as a cutoff variable show a very small percentage of area underlain with brine.

Figure 5-5. Simulated Cumulative Distribution Functions for Percentage of Entire Waste Disposal Area Underlain by Brine - Block and Random Models

Results for (1) Base of Castile and (2) Base of Anhydrite III Cutoffs, and (3) 50-50 Weighted Combination of (1) and (2)

The logic presented in the 1992 PA suggests that, because there is a great deal of uncertainty as to using the base of the Castile or the base of the Anhydrite III as the cutoff for defining pressurized brine, it may be reasonable to assign equal weights to each set of results. Combining the CDF for the Castile cutoff using a 50/50 weighting with the CDF for the Anhydrite III cutoff results in the two summary curves which appear in the central portion of Figure 5-5.

As noted at the beginning of this section, the conclusion of the 1992 PA was to use the block model with a base of Castile cutoff for the final PDF assigned to the percentage underlain with brine variable. The selection of the block model with the base of Castile cutoff appears to be somewhat conservative, since this selection results in the most extensive definition of area underlain with brine. Results for the random model using either cutoff variable, for the block model with the base of Anhydrite III as the cutoff, and for the 50/50 weighting of the two choices of cutoff variable are shown here (and in the 1992 PA) for comparative purposes only.

Although selection of the block model with the base of Castile cutoff appears to be a conservative selection, the panel-by-panel results for this selection shown in Figure 5-3 have a range of CDFs for the percentage of area underlain with brine which is not reflected in the aggregate all-panel CDF curves.

5.4.3 Comparison with 1991 PA and Helton and Shiver 1994

A newer approach which applies Monte Carlo simulation to model stochastic uncertainty in the WIPP PA has been proposed by Helton and Shiver[4] (HEL94). In this approach, a single uniformly distributed random variable is used to select a specific panel, and to select whether or not brine is encountered, in a single step. The new approach uses panel-specific scalar fractions to represent the percentage of area underlain with brine, but does not allow for a CDF for this percentage within each panel. The percentage of area underlain with brine for each panel reported in Helton's Table 5 are derived from the 1991 PA analysis of brine, which is summarized in Table 5.1-1 of SAN92, Vol. 3. Apart from the apparently erroneous reversal of labels for the Northern and Southern panels, the percentages agree with interpolated values from the 1991 PA table at a non-stochastic, fixed cutoff depth of 1250 m for pressurized brine. Hence, Helton's 1994 approach did not use the 1992 PA results which incorporate uncertainty in the selection of a random cutoff level for the base of the Castile.

In Table 5-1 of this report, percentages of area underlain by brine taken from Helton's Table 5 are compared to the range and median of the simulated CDFs for each panel

[4] Subsequently referred to as Helton or Helton (1994).

shown in Figure 5-3. At the all-panel level of aggregation shown at the bottom of Table 5-1 of the present report, the scalar value used in Helton's Table 5 is very close to the median of the simulated distributions of values from Figure 5-3. However, on a panel-by-panel basis, it is evident from the magnitude of the differences that the interpolated 1991 PA percentages used in Helton's Table 5 are more extremely varied than the simulated panel-by-panel results in Figure 5-3. The northern panels with the highest percentage of area underlain with brine have positive differences, while the southern panels with the lowest percentage underlain by brine have negative differences. Panel 1 is assigned a value of 100 percent in Helton's Table 5, for example, while the maximum in the present simulation was 88 percent underlain by brine. In panels 6 and 7, Helton assigns 0 percent, while the block model simulation has a minimum of about 10 percent of the area of these panels underlain by brine.

Table 5-1. Comparison of Simulation Results to Helton (1994)

Panel	Simulated (Figure 5-3) BLOCK Model			Helton, Table 5 (1991 PA)	Difference (points)
	Min	Max	Median		
1	60	88	75	100.0	25
2	50	72	60	71.5	12
3	35	68	48	30.7	-17
4	24	51	37	76.9	40
5	12	50	29	41.9	13
6	10	46	28	0.0	-28
7	11	48	27	0.0	-27
8	52	86	71	64.4	-7
Southern (9)	11	39	25	12.0 *	-13
Northern (10)	43	72	59	45.0 *	-14
All panels:					
BLOCK	36	58	46	45.1	-1
RANDOM	39	56	47	45.1	-2

* Values transposed from values in Table 5.

5.4.4 DOE Approach for the CCA

The calculations performed for CCA (Chapter 6, Section 6.4.12.6, Docket:A-93-02, II-G-1) are based on a single scalar value of 8 percent for the area underlain by brine. Technical information for defending this assumption has been developed, based on a geostatistical study of boreholes in the area which encountered brine.

The use of a random variable for the percentage of area underlain by brine has been a component of each of the previous PAs. The uncertainty surrounding the existence and extent of brine

reservoirs suggest that this variable should be retained as a LHS random input parameter, rather than converted to a scalar parameter. The variations from panel to panel which are apparent in the TDEM data also suggest that no single scalar value will suffice for the entire disposal area.

Although the Monte Carlo procedures presented in HEL94 are discussed in terms of a single table of scalar values for the percentage of each panel underlain by brine, it is possible to use a different subjective random variable for the percentage of each panel underlain by brine when simulating stochastic uncertainty using the new procedures. Thus there appears to be no computational constraints to using a random parameter for this percentage.

6.0 Summary and Conclusions

The Earth Technology TDEM report which provided the basis for developing probability distributions for the fraction of the waste panels which might be underlain by brine was reviewed and found to be comprehensive, accurate, and complete. However, the TDEM survey was based on a limited data set which did not permit analysis of two- and three-dimensional characteristics of brine pockets. Additionally the measurement technique could fail to detect thinner reservoirs (i.e., <5 m).

The procedures used in the WIPP 1992 PA to estimate the proportion of the waste disposal area underlain by pressurized brine from the TDEM measurements were reviewed here. The 1992 PA introduced the block and random models for elevation of the first conducting layer, and suggested the use of either the base of the Castile or the base of the Anhydrite III member of the Castile as the "cutoff" level for encountering pressurized brine. These two bifurcations provide four alternative ways to model the TDEM data.

A simulation analysis was conducted to

1. verify TDEM simulation results reported at the "All Panel" level of aggregation in the 1992 PA, Vol. 3, Section 5.1;

2. determine the sensitivity of the model results to the four alternative ways to model the TDEM data;

3. generate panel-by-panel results, which were not reported in the 1992 PA; and

4. compare the RH disposal areas within each panel to the main waste disposal area in terms of the percentage underlain by brine. The RH areas were not addressed in the 1992 PA.

Our simulation was designed to be similar to that reported in the 1992 PA, Volume 3, Section 5.1. The block and random models for the TDEM data were simulated separately, following the definition of the models in the 1992 PA. The SC&A simulation was conducted by creating a set of 633 rectangles to represent all types of regions within the disposal area. The coordinates of the rectangles were then referenced to the coordinate system used for the TDEM measurements, thus permitting the determination of the nearest-neighbor TDEM measurement for each point within the disposal region when the block model is used.

The selection of the block or random models have little impact on the estimated percentage underlain by brine at the "All Panel" level of aggregation. However, panel-by-panel results are distinctly different for these two models. Under the block model, each panel has a unique distribution for the percent underlain by brine. However, all panels have nearly the same distribution for the percentage underlain by brine when using the random model.

The selection of the Base of the Castile or the Base of the Anhydrite III member for the cutoff level for pressurized brine is a very important determinant of the simulation. The statistical reasons for this large sensitivity are explained in Section 5.3.1. With the random model, the mean value of the fraction of the excavated area underlain by brine was 47.5% usung the base of the Castile as the cutoff and 4% using the base of the Anhydrite III layer as the cutoff.

Combining the results of both the block and random models, the fraction of the excavated area underlainby brine vaied from about 1% at zero cumulative probability using the base of the Anhydrite III layer as the cutoff to about 58% at 100% probability using the base of the Castile as the geologic cutoff.

The results of the simulation analysis verify the "All Panel" results as reported in the 1992 PA. The simulation also provides detailed panel-by-panel estimates of the percentage underlain by brine, not reported in the 1992 PA. The panel specific results indicate a wide range of variability in the percentage underlain by brine, with panels 1 and 8 ranging from 50 to 88 percent underlain by brine, while panels 5, 6, 7, and 9 range from 10 to 50 percent underlain by brine.

In the simulations reported here, RH areas within each panel were found to have probability distributions for the percentage of area underlain with pressurized brine that are very similar to the distribution for the main disposal area within each panel.

Alternative TDEM surfaces to the block and random models were also generated.

These simulations were found to lie between the block and random model results, indicating that these two models provide suitable bounding conditions for the analysis.

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Appendix A

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