PROBABILITY OF ENCOUNTERING CASTILE BRINE BENEATH THE WIPP WASTE PANELS USING THE TDEM BLOCK METHOD

Contract Number EP-D-10-042
Work Assignment No. 5-12

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June 2017

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Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)		Initial issue

EXECUTIVE SUMMARY

This Technical Support Document (TSD) is a record of the review by the U.S. Environmental Protection Agency (the Agency or EPA) of changes to the Waste Isolation Pilot Plant (WIPP) Performance Assessment (PA) parameter used to determine the probability of a future borehole intersecting a waste panel and a pressurized brine reservoir in the Castile Formation, denoted as GLOBAL:PBRINE or more simply, PBRINE. The Castile Formation underlies the repository. This was one of many parameters used as inputs to the Department of Energy's (DOE) 2014 Compliance Recertification Application Calculations Performance Assessment (CRA PA-2014) calculations for the WIPP.

In the 1998 Compliance Certification Application (CCA), the DOE values for the PBRINE parameter were reviewed by EPA and determined to be unsupported, so EPA and mandated a probability distribution for use in DOE's follow-on calculations, called the Performance Assessment Verification Test (PAVT). The 1998 mandated PBRINE distribution has been used in both DOE's CRA-2004 and CRA-2009 PAs for WIPP. The probability distribution was based on reported drilling data in the WIPP vicinity and on site-specific Time Domain Electronic Magnetic (TDEM) data. The Agency's position is that the development of the PBRINE parameter must be consistent with the following:

- Available geologic and hydrologic information;
- Current understanding of reservoir development and behavior;
- The use and importance of the data in WIPP PA;
- Available-site specific data; and
- With drilling information on brine encounters.

In DOE's CRA-2014 PA submitted to EPA the DOE modified the PAVT PBRINE parameter. The Agency has rejected DOE's modification because, similar to rationale for the original Certification, it solely relied on reported brine encounters provided in driller logs and did not consider the other four criteria listed above.. The EPA has re-evaluated the 1998 distribution and has determined it should be revised revision.

The Agency has developed an alternative PBRINE probability distribution that meets all five criteria presented above. The revision is two pronged; first it considers the likelihood of encountering a brine reservoir beneath a specific waste panel using results from the TDEM and seismic data, and secondly, if a reservoir is encountered, the brine volume within that reservoir is sampled. The resulting modification is a conditioned probability for PBRINE. The Agency's updated approach incorporates both high-yield releases that would be noticed and logged by a driller and also low-yield releases that are not likely to be noticed but could completely saturate a waste panel over time.

ACRONYMS

AE	Accessible Environment
CCA	Compliance Certification Application
CRA	Compliance Recertification Application
DOE	Department of Energy
DQA	Data Quality Assessments
DQI	Data Quality Indicators
DQO	Data Quality Objectives
EPA	Environmental Protection Agency
ERDA	U.S Energy Research and Development Administration
OAR	Office of Air and Radiation
OMB	Office of Management and Budget
ORIA	Office of Radiation and Indoor Air
PA	Performance Assessment
PBRINE	Probability Distribution of Encountering Brine
QA	Quality Assurance
QAC	Quality Assurance Coordinator
QAPP	Quality Assurance Project Plan
RPD	Radiation Protection Division
SC&A	Sandy Cohen and Associates
TBD	To Be Determined
WAM	Work Assignment Manager
WIPP	Waste Isolation Pilot Plant

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1.0 Introduction

1.1 Overview

The Waste Isolation Pilot Plant (WIPP) is a transuranic waste repository located in southeast New Mexico. The WIPP waste panels are in excavated salt beds approximately 650 meters below the surface in the Salado Formation. The WIPP is operated by the Department of Energy (DOE) and regulated by the Environmental Protection Agency (EPA). The DOE is to demonstrate, via a Performance Assessment (PA), that potential radionuclide releases from the repository will meet the EPA's radioactive waste disposal standards. The first WIPP certification application was submitted by the DOE to the EPA in 1996. The EPA certified DOE to receive transuranic waste at WIPP in 1998. The DOE conducts a PA for the WIPP as part of the recurring five-year Compliance Recertification Application (CRA) process identified by the WIPP Land Withdrawal Act. The most recent CRA is 2014.

During early site investigations, and prior to WIPP being certified, boreholes drilled within the boundary identified by the Land Withdrawal Act intercepted a pressurized brine located in the Castile Formation. The Castile Formation is located several hundred meters below the Salado Formation. The brine in the Castile is not uniformly distributed, and varies in volume and pressure, and is assumed to exist in localized highly fractured areas forming pressurized brine reservoirs. Multiple boreholes drilled in the region in the vicinity of the WIPP site over the past 50 years' have encountered pressurized brine in the Castile (Appendix Data, CRA 2014) . However, because of these encounters, future drilling into a waste panel and a pressurized brine reservoir could result in radionuclide releases to the accessible environment (AE).

In the 1996 Compliance Certification Application (CCA) for the WIPP, the DOE proposed a method for determining the probability of encountering Castile brine beneath the WIPP waste panels that using brine encounters reported by drillers during deep exploratory drilling in the northern Delaware Basin (Powers et al. 1996). The probability of encountering Castile brine in an exploratory borehole in sufficient quantities to affect repository performance (in a brine reservoir or brine pocket) is denoted in WIPP PA by the parameter GLOBAL:PBRINE or more simply as PBRINE. Refer to Appendix PA , Section PA-1.1.3 (CRA,2014) for additional discussion of PBRINE.

During the CCA review, the Agency expressed concerns over the appropriateness of that approach because it did not incorporate uncertainty and it ignored site-specific geophysical data suggestive of elevated brine content in the Castile Formation beneath the WIPP waste panels. The Agency therefore mandated a revised approach that included uncertainty and was based on both the geophysical data and the drilling data to help bound this uncertainty (EPA 1998; Docket Number A-93-02 V-B-14)]).

The Agency's mandated approach was used by the DOE in the CRAs in 2004 and 2009 but not in CRA-2014. In DOE's CRA-2014, the updated drilling frequency was accompanied by a modification to the assessment of where Castile brine reservoirs could be located that differed from what was calculated in previous PAs (Kirchner et al. 2012). In the review of DOE's CRA-2014approach to developing the PBRINE probability distribution, EPA has identified that DOE's revised approach does not meet 4 of the 5 criteria that EPA believes are important for defining PBRINE and are discussed in greater detail below. As a result, the Agency has updated the approach to predict the probability of encountering a Castile brine reservoir.

This Technical Support Document describes how the EPA developed a probability distribution for PBRINE, which is the likelihood of a future drilling event to intrude both a WIPP waste panel and a pressured Castile brine reservoir underneath the waste panel over a 10,000-year period. The updated probability distribution differs from that adopted in the 1998 CCA and 2004 and 2009 CRAs. The updated approach predicts the probability of a future borehole intersecting a pressurized brine reservoir that takes into account site-specific geology underlying the repository footprint.

The WIPP is located in the northern part of the Delaware Basin in Eddy County, New Mexico (Appendix DEL, Figure DEL-3, CCA, 1996). The Delaware Basin is a structurally downwarped crustal area of about 31,000 km^2 and contains up to 5,500 m of sediments dominated by Permian age strata (Popielak et al. 1983, p. 4). The Capitan reef bounds the Delaware Basin on the north, east and southwest. The Castile and Salado Formations form the salt section beneath the WIPP site. The halite and anhydrite beds of the Castile Formation were deposited in a deep inland sea within the Delaware Basin delimited by the reef, while the bedded salt of the overlying Salado Formation was deposited over the reef and ultimately covered a larger area than within the reef. The bedded salt of the Salado Formation provides containment for the disposal of radioactive waste at the WIPP.

The occurrence of pressurized brine reservoirs in the Castile Formation has been documented over the past 70 years (Appendix PA, Section PA-4.2.10, CRA 2014). These reservoirs were encountered during exploratory drilling for hydrocarbons and in some cases were sufficiently pressurized *via* lithostatic pressure for brine to flow to the ground surface when encountered. When an exploratory borehole encountered a pressurized, high permeability fracture in the Castile, brine can flow to the surface in volumes that would be noticed and logged by the drillers. The brine generally emanates from fractured anhydrite layers in the Castile Formation, contains hydrogen sulfide gas, and has been associated with deformed strata in the Castile (Popielak et al. 1983, p. 5). Drilling encounters with brine have not been predictable, however, because reservoirs have not necessarily been noticed and logged by drillers in association with all deformed strata. Most boreholes in the northern Delaware Basin were drilled for the purpose of locating minerals or oil and gas reserves, rather than for hydrological characterization. Reporting encounters with brine reservoirs is voluntary and incidental to the primary purpose of most drilling activities and, as a result, the Agency does not expect drilling reports of Castile brine encounters to be statistically representative because the purpose and variability of reporting these encounters will vary based on the ‘reporting entities’’.

Information on the location and characteristics of brine reservoirs is sparse. As discussed in Section 5, only two reservoirs out of dozens of reported brine encounters have been studied for their geological, hydrological, and geochemical properties. Brine reservoirs have been encountered primarily in anhydrite interbeds subjected to structural deformation and fracturing. Initial releases of brine encountered during drilling have been rapid and high volume. These releases are thought to be associated with drilling penetrations of relatively large subvertical fractures that are interconnected with networks of smaller fractures. The large initial flow is followed by lower, secondary releases that are indicative of brine flowing from an areally extensive network of smaller, interconnected fractures and microfractures that provide most of the brine storage capacity of the reservoir (Popielak et al. 1983, p. H-59). A more detailed description of brine reservoir characteristics is given in Section 5.

Encountering a Castile brine reservoir can impact waste isolation at the WIPP repository. A future exploratory borehole inadvertently drilled through a closed WIPP waste panel could penetrate pressurized brine in the underlying Castile Formation and release that brine into the waste panel. The release could occur during drilling; through open, unplugged portions of the borehole after abandonment; and through slower but longer term seepage through degraded borehole casing and plug materials after plugging. The presence of brine in a waste panel is important to WIPP performance because it enhances microbial growth and waste corrosion, which in turn create elevated gas pressures that drive several pathways for radioactive releases to the accessible environment.

Because the drilling frequency in the region can change annually and the frequency is an important parameter for PA, EPA requires DOE to update the estimated probability of future drilling into a waste panel in every five-year recertification. The DOE updated drilling frequencies in developing their PBRINE parameter for each CRA that reflect increased drilling activity in the vicinity of the Delaware Basin and, specifically, the vicinity of WIPP. The Delaware Basin is located in the southwestern portion of the United States and has extensive mineral, oil and gas reserves. Drilling and exploration for these resources in the basin have taken place over the past 100 years. For additional discussion see Appendix Data Attachment A (CRA 2014).

This report provides an updated method for developing the probability distribution for parameter PBRINE. The updated method is based in part on the results of time domain electromagnetics (TDEM) geophysical soundings that identified zones of high electrical conductivity in the Castile beneath the WIPP waste panels. These zones were interpreted as very likely indicating the presence of elevated brine content. This updated method also includes new information on drilling encounters that have occurred since 1998. The updated method was designed to be consistent with the following criteria:

- Available geologic and hydrologic information;
- Current understanding of reservoir development and behavior;
- The use and importance of the data in WIPP PA;
- Available-site specific data; and
- With drilling information on brine encounters.

As described in Section 2, DOE’s CRA- 2014 method for estimating the probability of hitting a brine pocketonly meets the last criteria listed above. An overview of EPA’s updated method is presented in Section 3. Detailed discussions of the conceptualizations and justifications for the parameters used in the updated method are presented in Sections 4 and 5. These discussions are followed by conclusions in Section 6. Additional details are provided in the appendices. Appendix A provides a summary of the steps in the statistical estimation of PBRINE and Appendix B provides the probability distribution of PBRINE that is to be used in WIPP Performance Assessment. Appendix C provides comprehensive documentation of the model described in this report for calculating PBRINE. Appendix D presents information on the frequency of encountering a specific zone of high electrical conductivity beneath each WIPP waste panel. Appendix E reviews the implementation and results of the quality assurance measures described in the project’s Quality Assurance Project Plan (QAPP) (SC&A 2016) and Data Quality Objectives (Economy 2016).

1.2 Problem Statement

In preparing the CRA-2014, the DOE developed and used an alternative approach from that mandated by the EPA and applied in previous applications for determining the value of PBRINE. This alternative approach relied on a different statistical analysis of brine encounters during deep exploratory drilling in the northern Delaware Basin, an updated database of such encounters, and included an evaluation of uncertainty (Kirchner et al. 2012). EPA expressed concern over the appropriateness of this alternative approach, primarily because it ignored the site-specific TDEM geophysical data and relied solely on a statistical analysis of brine encounters as reported by drillers. DOE's sole reliance on drilling data remained problematic because drillers are not required to report brine encounters.. Essentially, drilling reports may only document the subset of brine encounters where brine releases are of sufficient pressure and volume to be judged as significant enough by a driller to be reported in the driller's log. Since smaller brine pockets under lower pressures may not be noticed or recorded by the driller the Agency believes that brine encounters of potential significance to repository performance are more frequent than DOE's estimates. . However, the Agency believes that the drilling data reported by drillers are useful, along with site-specific data, to help define the lower bound in the probability distribution of brine encounters. EPA has refined its mandated 1998 approach to include this reported ancillary drilling data as well as a more rigorous statistical analysis of the TDEM data than was used in the previously mandated approach. The intended use of these results is, therefore, to provide an updated approach for determining the probability of encountering Castile brine beneath the WIPP waste panels for use in WIPP performance assessment.

2.0 Previous Methods for Estimating PBRINE

The PBRINE parameter was originally introduced in the 1996 Compliance Certification Application (CCA) by the DOE as a constant probability equal to 0.08. This value was based on the results of a geostatistical analysis of reports by drillers of pressurized brine encounters in the Castile in the vicinity of the WIPP site (Powers et al. 1996, p. 36). A TDEM geophysical survey that had previously been conducted at the WIPP site indicated horizons of high and low electrical conductivity beneath the WIPP waste panels. The contrasts between the high and low conductivity horizons (rather than the absolute magnitudes of those conductivities) were interpreted as very likely due to elevated brine content in the high conductivity horizons (The Earth Technology Corporation 1987). The TDEM survey also provided estimates of the depths of the uppermost high conductivity horizons that were used to identify the geologic formation containing those horizons.

The Agency noted that the additional quantitative TDEM information on the possible presence of brine beneath the site supported a higher probability of brine pocket interception (i.e., PBRINE) than proposed by DOE and did not appear to have been used in developing DOE's proposed value (EPA, 1998b). To more comprehensively address the uncertainty in the value of PBRINE, in 1998 the Agency mandated that PBRINE be sampled from a uniform distribution with a wide probability distribution range of 0.01 to 0.60 (EPA 1998a, p. 18). The areal extent, volume, and pressure of possible brine reservoirs beneath the waste panels are unknown. Consequently, a uniform probability distribution was selected for PBRINE because it is the maximum entropy distribution when little is known about a parameter except for its range. This method has been used in support of the original WIPP certification as well as the 2004 and 2009 recertifications.

The low end of the Agency's 1998 range (0.01) for PBRINE was selected consistent with the conceptualization of a fractured reservoir where Castile brine is only available in sufficient quantities to affect repository performance from rare subvertical fractures with sufficient yield to be noticed and logged by a driller. The low end of the range reflected the reduced probability of intersecting subvertical fractures with vertical boreholes. Selecting a low end based on drilling data recognized that relying on reports of pressurized brine encounters by drillers would tend to underestimate their occurrence because drillers were not required to report such encounters. The tendency for drilling data to underestimate brine encounters made such data appropriate for establishing a lower bound because the actual frequency of encounters would likely be higher. The intent of selecting bounding values for a distribution of a parameter is to capture the full range of uncertainty in the value of that parameter. Because the low end value was intended to be bounding, it was specifically selected to be lower than the value of 0.08 determined by DOE from geostatistical analysis of drilling data. The lower bounding value of a distribution should be slightly lower than or equal to the lowest potential value of the distributed parameter. Because the parameter PBRINE is itself a probability, the lower bounding value of PBRINE should be lower than or equal to the lowest potential value of the frequency of encountering pressurized brine in the Castile beneath the WIPP waste panels.

The high end of the 1998 range of PBRINE (0.60) was selected consistent with the conceptualization of a fractured reservoir where Castile brine is available from a fracture network with a sufficiently wide range of fracture densities, sizes, and orientations that a penetrating borehole would be likely to encounter brine in sufficient quantities to affect repository performance. The high end of the range was again intended to be bounding and represents a value that is higher than the highest value (0.55) that had been interpreted by DOE from the TDEM depth data. That interpretation was documented by Borns (1996, Table 1) and represents the estimated maximum proportion of the waste panel area that is underlain by a high electrical conductivity zone in the Castile Formation. This maximum value was based on assuming that all TDEM depth data were overestimated and should have been 75 m shallower, based on the reported potential error of ±75 m in the TDEM depth data (The Earth Technology Corporation 1987, p. 19). Borns' calculation placed more of the TDEM high electrical conductivity horizons within the Castile Formation where they could affect repository performance rather than in the underlying Bell Canyon Formation where they would not affect performance. Additional discussions of the Bell Canyon and the basis for concluding that Bell Canyon brine would not affect repository performance are presented in Section 5.2.

The conceptualization associated with the high end of the mandated range of probability envisioned a more densely fractured reservoir with a wide range of fracture sizes and orientations as well as a wide range of brine yields, some of which could be too small to be noticed and logged by a driller but could still be important to repository performance. For such a reservoir the Agency assumed that a borehole intersecting a TDEM high electrical conductivity horizon would penetrate sufficient numbers of large subvertical fractures, intermediate size connecting fractures, or pervasive microfractures to yield sufficient long-term brine migration through an open borehole or a degraded borehole plug to be of concern to repository performance.

3.0 Overview of Updated Method for Estimating PBRINE

The Agency's updated method provides refined statistical analyses of the TDEM depth data and implementation of the conditional probability that a high electrical conductivity horizon would yield sufficient brine to be important to repository performance. This section presents an overview of the updated method and the resulting distribution of PBRINE. Details of the statistical approach are presented in the Appendices to this report. The supporting conceptualizations, justifications for the parameter values used in the analysis, and considerations for implementing the sampled values of PBRINE in WIPP PA are provided in Sections 4 and 5.

TDEM is one of several widely used, surface-based electromagnetic geophysical methods. It can be used effectively to detect differences in the resistivity (or its reciprocal, the conductivity) of stratigraphic horizons beneath the ground surface. It is commonly used for mapping subsurface strata where contrasts in resistivity are present. Such contrasts can result, for example, from changes in mineralogy from one rock type to another, from changes in moisture content such as in detecting the presence or absence of groundwater, and from changes in salinity. TDEM soundings can be made on land, from the air, and over water. Comprehensive overviews of TDEM methods as well as other environmental geophysical methods have been prepared by the Agency (EPA 2011). The Agency's TDEM overview describes basic concepts, data acquisition, and data processing and interpretation. It also describes the increasing versatility of the method due to the capability of field-portable computers to process a series of one-dimensional soundings into two dimensional images of subsurface strata. As recent examples, TDEM methods were used to delineate the spatial distribution of shallow brines in the sediments beneath the freshwater Sea of Galilee in Israel (Hurwitz et al. 1999) and the U.S. Geological Survey successfully applied TDEM methods to characterize the subsurface hydrogeology and stratigraphy at 14 locations in Dawson County, Nebraska (Payne and Teeple 2011).

The fundamental strength of the TDEM method is shared by other geophysical methods: it provides information on subsurface conditions that might otherwise be unobtainable. For example, at the WIPP site the information provided by TDEM could potentially be obtained from boreholes but drilling through or beneath the waste panels could compromise repository integrity and is therefore not an option. The principal weaknesses of TDEM are also shared by other geophysical methods: it is only effective in mapping strata with contrasting electrical resistivities; it provides only indirect information on what is typically the actual property of interest, such as the presence of water or brine; and the quantitative data it provides are accompanied by uncertainties. As described in this report, the TDEM method is particularly appropriate at WIPP: the presence of brine provides a strong resistivity contrast; given the mineralogy of the strata, the elevated presence of brine is the only likely cause of such a contrast; data from nearby boreholes have confirmed the relationship between resistivity and the presence of brine; the uncertainty in the TDEM data was quantified and addressed in the data analysis; and the information the method provided relative to the presence of Castile brine beneath the waste panels could only have been obtained using geophysical methods. The Agency therefore considers the TDEM data to be validated for its intended use in providing information on the possible presence of Castile brine reservoirs beneath the WIPP waste panels.

The results of the TDEM survey of the WIPP site are described in a report by The Earth Technology Corporation (1987). The TDEM sounding locations are shown in Figure 1 and consist of a regular 5 x 7 grid of 35 points, one additional sounding at the northeast corner of the grid, and corroborative soundings near boreholes WIPP-12 and DOE #1. The depth to the first electrically conductive horizon beneath the WIPP site was determined at each sounding location by The Earth Technology Corporation from the TDEM results. The points in the array of sounding locations are spaced 250 m apart. To establish spatial correlations within the array, it was assumed that, at any point within the array, the best estimate depth was the depth measured at the nearest sounding. This assumption established a 'block model' consisting of an array of square surfaces 250 m on a side representing different depths to the first conductive horizon beneath the waste panels. An illustration of this model is shown in Figure 2. The depth of these horizons is important because electrically conductive horizons were found in both the Castile and the underlying Bell Canyon Formations but no such horizons were found in the overlying Salado Formation. As previously noted, only horizons above the Castile – Bell Canyon contact are potentially important to repository performance and only those horizons are considered in this report. Refinements made by the Agency to the block model in the statistical approach include accounting for uncertainty in the depth determined from each TDEM sounding and for uncertainty in the depth of the Castile – Bell Canyon contact.

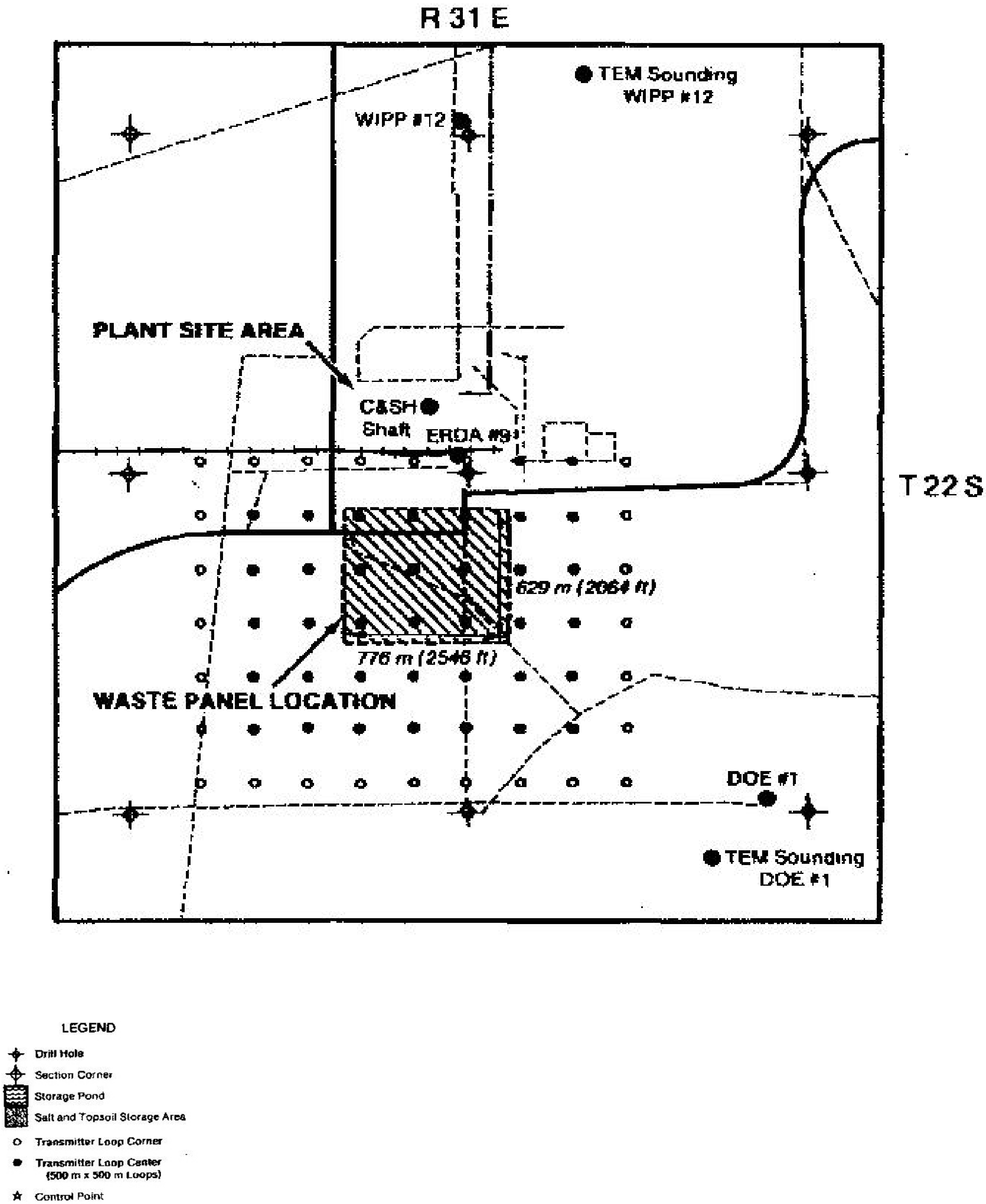

Figure 1. TDEM sounding locations at the WIPP site (from The Earth Technology Corporation 1987, Figure 1-1).

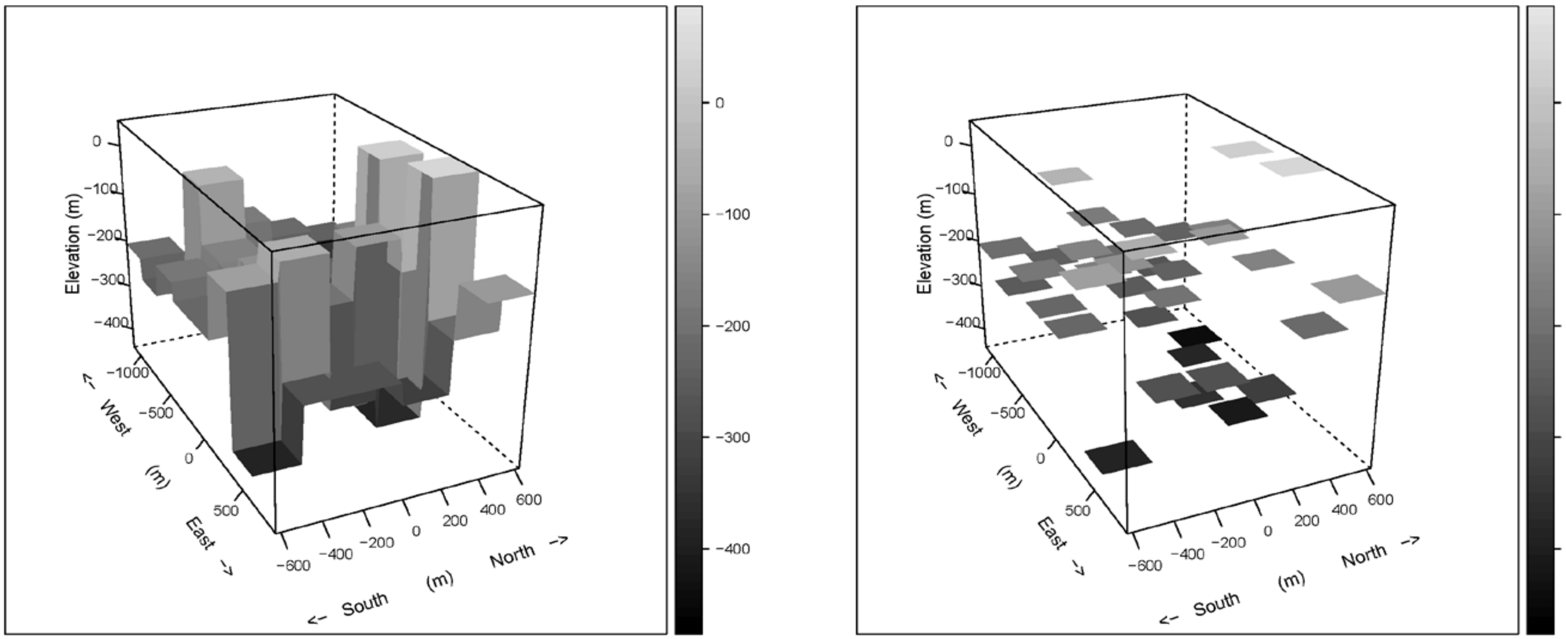

Figure 2. Schematic illustrations of the block model for TDEM depth data, 3-dimensional (left) and laminar (right) views. All dimensions are in meters and the elevation datum is sea level. Shading increases with greater depths (adapted from EPA 1998b, Figure 5-1A).

Two statistical distributions are needed to determine the uncertainty in PBRINE. The first is a distribution of the probability that a borehole penetrating a waste panel would also penetrate an underlying high electrical conductivity zone in the Castile Formation (*pHCZ*). This probability is based on the TDEM data which indicates that the likelihood of hitting a high conductivity zone varies between waste panels. Details are given in Section 4. The second is a distribution of the conditional probability that a borehole that intersects a high electrical conductivity zone would also yield brine in sufficient quantity to be important to WIPP performance (*p[brine|HCZ]*). Details are given in Section 5. These two distributions are described below. The minimum requisite repository brine volume for a Direct Brine Release is 17,400 m^3 (CRA-2014, Appendix PA, Section PA 1.1.9). Smaller brine volumes, however, could be important to gas generation rates resulting in higher repository pressures potentially leading to greater releases.

To develop the distribution of *pHCZ*, the probability that a borehole penetrating a waste panel would also penetrate an underlying high electrical conductivity zone was separately determined for each waste panel by randomly selecting 100 borehole locations in each panel and determining whether each borehole would intersect a high electrical conductivity zone in the Castile. The frequency of intersection determined from these 100 boreholes provided one estimate of the value of *pHCZ*. This step was then repeated 100 times to give 100 estimates of *pHCZ* for each panel. The 100 estimates were used to construct the cumulative probability distribution of *pHCZ* for each panel shown in Figure 3. In all, 100 estimates of *pHCZ* were developed for each panel for a total of 1,000 estimates.

The conditional probability that a borehole intersecting a high electrical conductivity zone would also yield brine in sufficient quantity to be important to WIPP performance, *p[brine|HCZ]*, was separately developed as a uniform distribution with a wide range of *plower*=0.05 to *pupper*=1.0. The low end of the range (0.05) was selected based on the updated frequency of drilling encounters with pressurized brine in the region surrounding the WIPP site presented in Kirchner et al. (2012, p. 2) and on EPA's conceptualization of the brine reservoir that supports the low end of the currently mandated range. The high end of the range (1.0) is equal to the bounding value of the brine reservoir conceptual model that supports the high end of the currently mandated range. These models are consistent with the current understanding of reservoir development and behavior. Detailed geological and hydrological information supporting the development of *p[BRINE|HCZ]* is provided in Section 5.0.

A uniform distribution was chosen because it is the maximum entropy distribution when little is known about a parameter except for its range. The limits of this range were selected as bounding values and the range is intentionally broad. It encompasses what is known and not known about the presence of Castile brine beneath the WIPP waste panels, alternative models of the brine reservoirs and their fracture networks, and the types of brine encounters that could be potentially important to WIPP performance.

The conditional probability *p[BRINE|HCZ]* was separately applied to each of the boreholes identified as penetrating a high electrical conductivity zone above the base of the Castile to determine whether that borehole yielded sufficient brine to be important to WIPP performance. This step is more fully described in Appendix C. This step provided 100 estimates of PBRINE for each waste panel and a total of 1,000 estimates for all 10 panels. The estimates for each panel were used to develop the Cumulative Distribution Function (CDFs) shown in Figure 4 and the 1,000 individual estimates for all panels were combined to develop the CDF shown in Figure 5. Because the panels are not all the same size, when combining results for individual panels the larger panels 1 through 8 were assigned higher weights and the smaller panels 9 and 10 were assigned lower weights to compensate for the different probabilities of random borehole intersections. A detailed description of the weighting methodology is provided in Appendix C.

Figure 4 shows that the probability of encountering brine is lowest for Panels 5, 6, 7, and 9 and highest for Panels 1 and 8. A step-by-step description of the application of this conditional probability to pHCZ and the calculation of PBRINE is presented in Appendix A. The alternative of combining the CDFs for the individual panels by horizontal averaging was considered but rejected because that approach would not adequately represent the upper and lower tails of the distributions. In addition to better representing

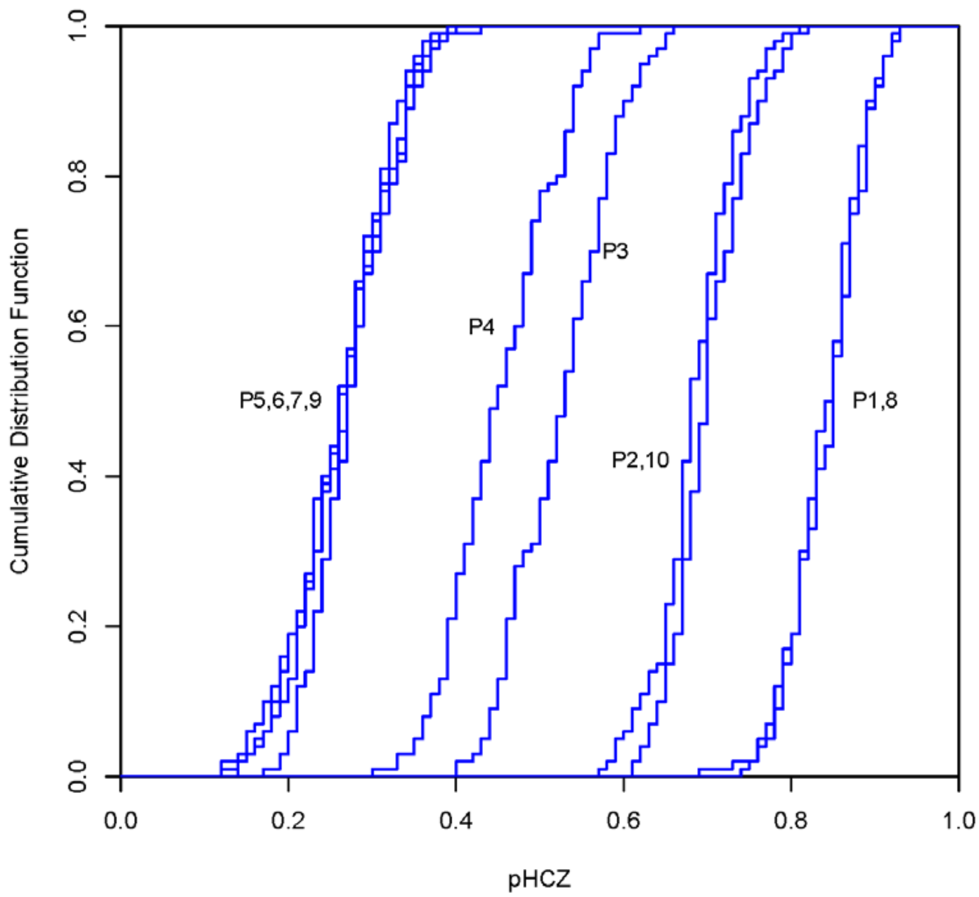

Figure 3. Cumulative distribution functions (CDFs) of pHCZ by waste panel.

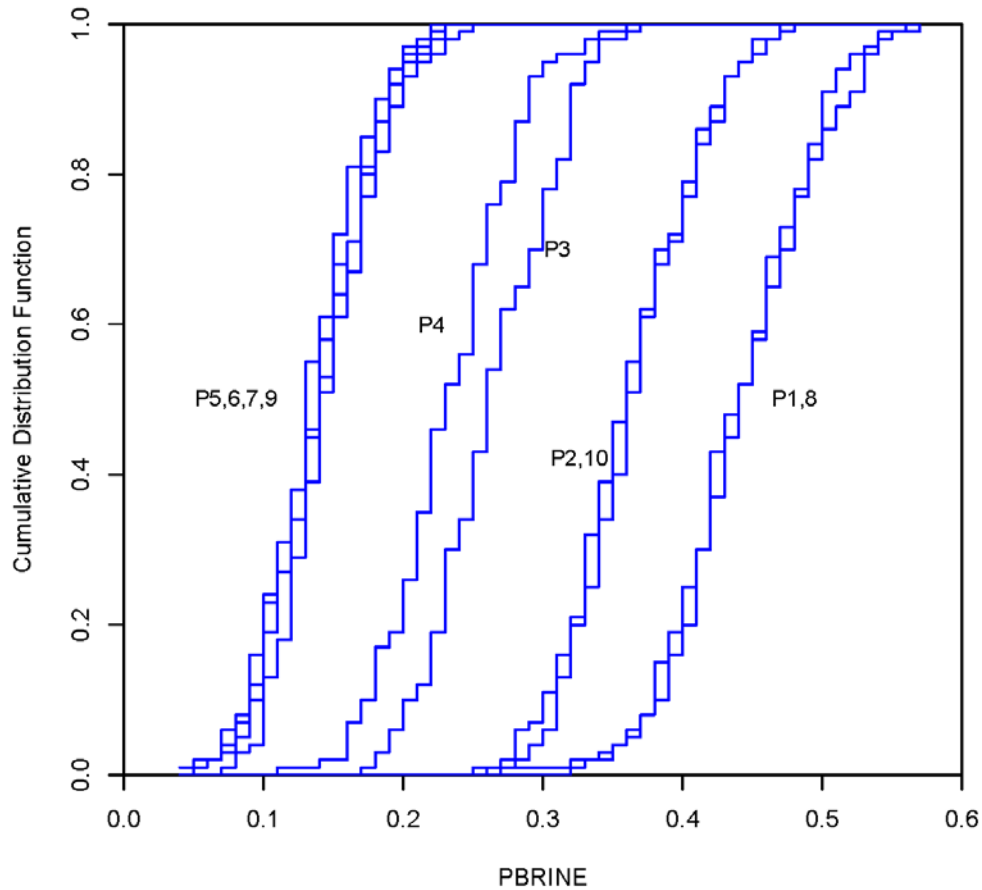

Figure 4. Cumulative distribution functions (CDFs) of PBRINE by waste panel.

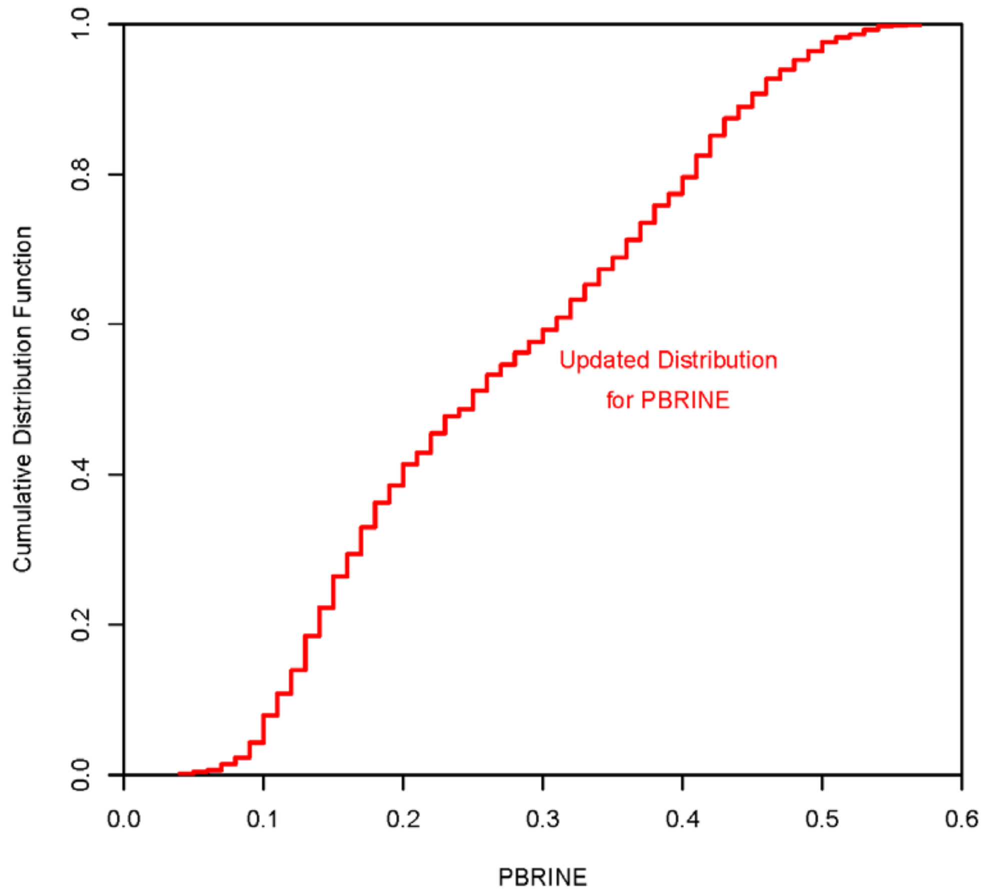

Figure 5. Combined cumulative distribution function (CDF) of PBRINE for all waste panels.

the extreme values, the adopted approach is also consistent with the way in which borehole penetrations of individual waste panels are treated in WIPP PA. This is further explained in Section 5.2.

Figure 5 shows a joint CDF representing the probability that a randomly placed borehole that penetrated a WIPP waste panel would encounter brine in sufficient quantity to be important to WIPP performance. The data in Figure 5 are presented in the form of a histogram in Figure 6 to more clearly show the form of the updated PBRINE distribution. The histogram ranges from 0.04 to 0.57 and is almost identical with the 0.01 to 0.60 range of PBRINE in the currently mandated distribution, which is also shown in Figure 6. The density is irregular, as would be expected from the irregular spacing of the CDFs for the individual waste panels shown in Figure 4. The distribution is bimodal with peaks at PBRINE values of 0.13 and 0.41. The highest peak at a PBRINE value of 0.13 reflects the aforementioned cluster of four waste panels with low values of *pHCZ* and PBRINE. The median of the distribution is 0.25. The long tail to the right toward higher values of PBRINE reflects the more even spacing of the CDFs in the remaining panels. In DOE's CRA-2014 approach the normal approximation of the distribution of PBRINE (mean=0.127, SD=0.0272) will result in simulated frequencies of brine intrusions that cover the same range as that produced using the uniform distribution ([0.01, 0.60]) but showing a greater degree of positive skewness, i.e. showing a mode that is shifted to the left (Figure 7, Kirchner et al. 2012).

The derived distribution was compared with several standard distribution functions, including gamma, beta, and lognormal distributions, but none adequately represented the bimodal characteristics and abrupt truncation of the right tail. This tail is a reflection of the TDEM data and should be retained. The Agency therefore concludes that the most reliable values of GLOBAL:PBRINE are those sampled directly from the actual, derived CDF shown in Figure 5.

Although the CDF in Figure 5 is based on 1,000 ranked values of PBRINE, many duplicate results were obtained because the analysis is based on 100 boreholes per panel and all estimated values of PBRINE are therefore whole numbers between 4% and 57%. The vertical jumps in the CDFs in Figures 3, 4, and 5 are artifacts of this duplication. The individual values of PBRINE in the combined distribution are tabulated in Appendix B. The tabulation shows that the analysis produced 54 unique values of PBRINE that ranged from 0.04 to 0.57. The tabulation also shows the probability of sampling each of these values. The highest probability was the probability of 0.046 of sampling the mode of 0.13 and the lowest was the probability of 0.001 of sampling values of 0.55 and higher at the upper end of the distribution. Similar tables are included in Appendix B for the values of pHCZ and PBRINE for each of the 10 waste panels.

4.0 Consideration of High Electrical Conductivity Zones

4.1 The Block Model

The block model provides a method of approximating the lateral extent of horizons of high electrical conductivity and therefore elevated brine content. The model uses the results of the TDEM survey described in The Earth Technology Corporation (1987). The Earth Technology

Corporation made a total of 38 TDEM soundings at the WIPP site, of which 35 were in a square 1 x 1.5 km grid with soundings 250 m apart, one additional sounding was made off the northeast corner of that grid, and two were made at control sites near existing boreholes WIPP-12 and DOE #1. The data points of primary interest in developing the block model are within the grid of 35 soundings. This grid represents an array of point values at different depths within a 3-dimensional space, with each point indicating the presence of high electrical conductivity. Based on the stratigraphic layering of the Castile Formation and the conceptualization of brine reservoirs occurring within those layers, each TDEM sounding result was therefore interpreted to represent a point on a laterally extensive horizon of high electrical conductivity. Such horizons were in turn interpreted to represent horizons of elevated brine content because there were no other likely causes of electrical resistivities as low as about 1 ohm-m beneath the WIPP site (The Earth Technology Corporation 1987, p. 5).

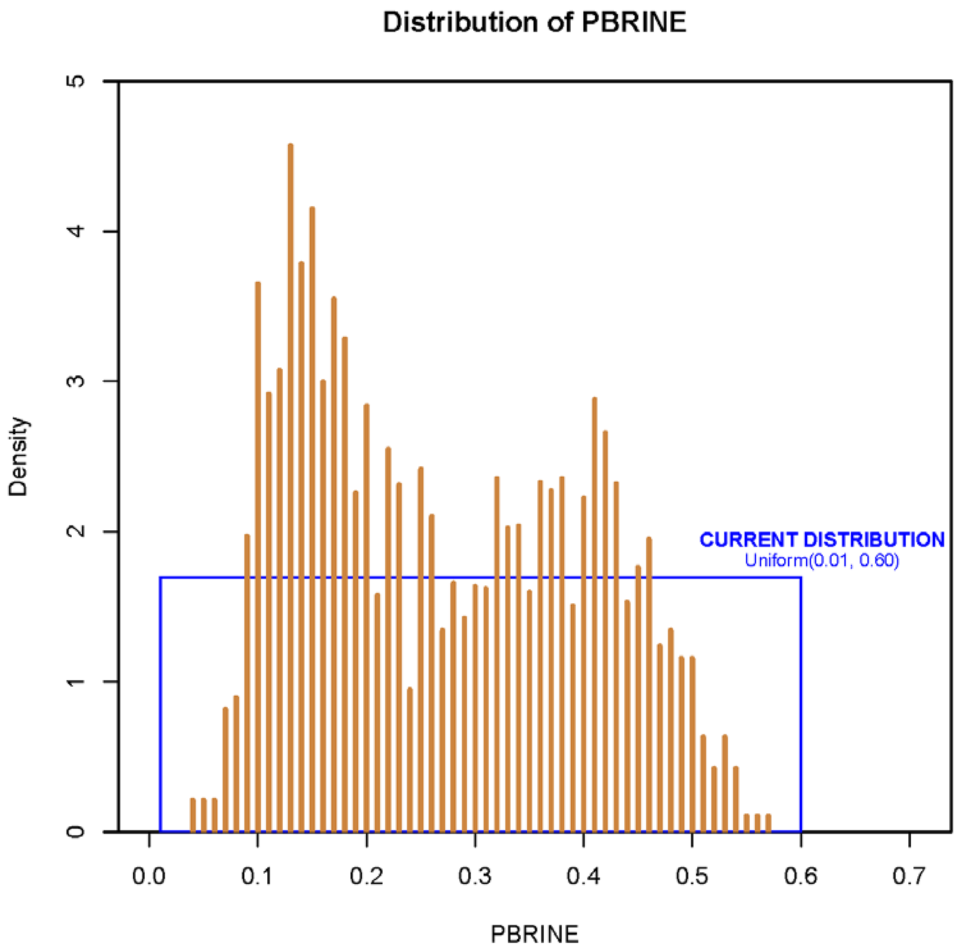

Figure 6. Frequency distribution of PBRINE of the updated approach compared with EPA's 1998 currently mandated uniform distribution used in the CCA, CRA-2004 and CRA-2009.

A block model and a random model were used by DOE to interpret the TDEM data in the 1992 WIPP Preliminary Performance Assessment (SNL 1992, Volume 3, Section 5.1). These models were reviewed by EPA in a 1998 Technical Support Document (EPA 1998b, p. 19). The alternative random model assumed a very limited lateral extent of such horizons and was rejected by the Agency because it is inconsistent with the aforementioned conceptualization that brine reservoirs occur within laterally extensive stratigraphic horizons in the Castile. The models of brine reservoir occurrence are further discussed in Section 5. The block model assumes that the horizon of electrical conductivity indicated by each TDEM sounding extends laterally to a distance halfway to the next neighboring sounding and that the TDEM depth measurement is representative of the depth of that horizon. In other words, the block model assumes that at any given point (x,y) within the TDEM sounding array, the best estimate of the depth of the first conducting horizon is the depth of the nearest TDEM data point. An illustration of this model is shown in Figure 2. The depth of these horizons is important because electrically conductive horizons were found in both the Castile and the underlying Bell Canyon Formations, but only horizons in the Castile are important to repository performance.

The block model also recognizes that the TDEM depth data represent the first, or shallowest reservoir encountered. A contour plot of those data has been made by The Earth Technology Corporation (1987, Figure 3-3), which is reproduced in this report as Figure 7. Contouring these data implies that the data could represent a continuous surface. However, because of the expected layering of brine reservoirs in stratigraphic horizons and the possible vertical isolation of those reservoirs from one another, the array of TDEM sounding depths may in fact not represent a continuous surface because reservoirs at shallower depths may overlap and be physically independent of deeper reservoirs. The block model therefore represents an approximation of the lateral correlation that exists within a brine reservoir at a given depth but could also be uncorrelated with a portion of a laterally adjacent reservoir at a greater depth.

4.2 Uncertainty in TDEM Depth Data

The nominal depths (in meters) to the first major conductor used in this updated analysis are shown for each sounding location on Figure 7. The Earth Technology Corporation (1987, p. 19) reported an uncertainty of ±75 m in the depths associated with the TDEM soundings but did not associate that uncertainty with a more rigorous statistical definition. In preparing this updated method for estimating uncertainty in PBRINE, the reported uncertainty of ±75 m was treated as a measurement error of one standard deviation of a normal distribution about each TDEM depth value. The Agency acknowledges that interpreting the reported TDEM depth uncertainty of ±75 m in terms of a more rigorous statistical definition requires judgement. The Earth Technology Corporation (1987, p. 19) states that the ±75 m range was developed based on an evaluation of ‘three typical soundings’ from the survey area. The TDEM results were evaluated using a 4-layer model. The thicknesses of the two horizons above the salt section (the Dewey Lake and Rustler) were known and held constant while the thickness of the high resistivity salt section (Salado and Castile) above the first conductive horizon was varied. The combination of these three thicknesses gave the depth to the fourth layer, which was the top of the first conductive layer. The Earth Technology Corporation (1987, p. 18) acknowledged that inversions of geophysical data are not unique, but stated that there generally is a range of values for each parameter that matches the observed data with the same error of mismatch. That range of values is called the equivalence of the solution.

The Earth Technology Corporation (1987, Figures 4-4, 4-5, and 4-6) calculated the root mean squared (RMS) error in the thickness of the salt section for the three typical soundings for 15 combinations of parameter values using a forward model. They then plotted those results against the thickness of the salt

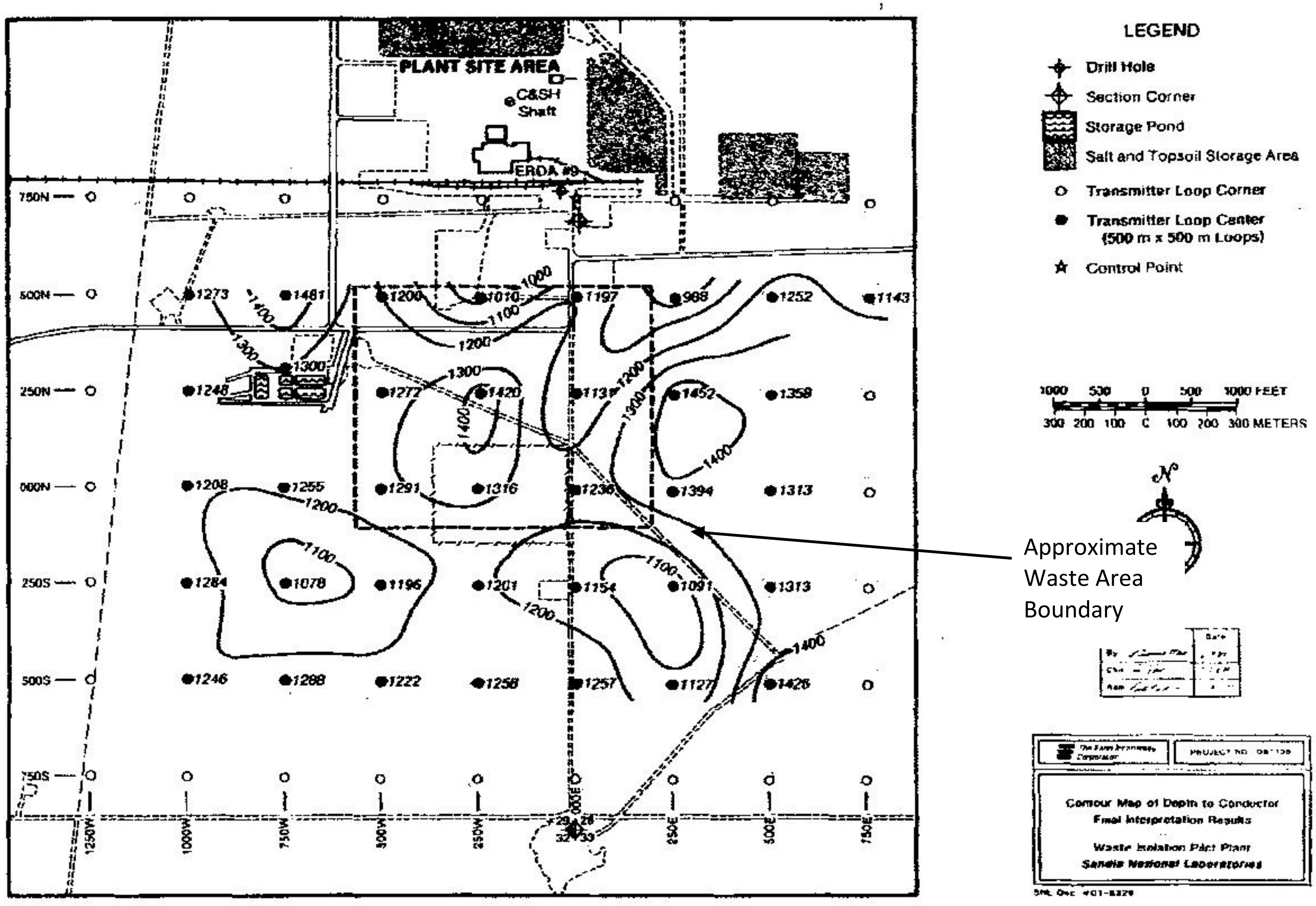

Figure 7. TDEM array showing depths (in meters) at the sounding locations (modified from The Earth Technology Corporation 1987, Figure 3-3).

section, identified the RMS error associated with the equivalence of the solution, and from that they determined the range of uncertainty (or range of equivalence) in the thickness of the salt section. This range of uncertainty is also the range of uncertainty in the depth of the top of the first conductive horizon below the salt section. Figure 8 presents an example plot. In the three soundings studied by The Earth Technology Corporation, the validity of the range of uncertainty was corroborated by the results of ridge regression inversions of the apparent resistivity curves determined from the field soundings, each of which lay within the uncertainty range. Figure 8 shows hand-written scaling performed by the Agency to determine the width of the range of equivalence. In the case of Figure 8, the range was about 140 m, representing an uncertainty of ±70 m. The results of the other two soundings showed ranges of 106 m, or ±53 m, and 94 m, or ±47 m. Based on these results, The Earth Technology Corporation (1987, p. 19) apparently conservatively selected a potential error of ±75 m and stated that "It can be concluded from Figures 4-4, 4-5, and 4-6 that the accuracy of determining depth to brine is better than 75 m."

The Agency understands how the foregoing conclusion could be reached when based only on results from the three figures. However, the soundings associated with these figures were selected by The Earth Technology Corporation because they were "typical" and not because they were bounding. If all 36 soundings from the survey grid had been similarly evaluated, perhaps a bounding error would have been identified. But only three out of 36 soundings were evaluated and it is unlikely that one of those three represented a bounding error value. The question then remains, how should the ±75 m error range be interpreted in terms of the standard deviation of a normal distribution of measurement error, and more specifically, should this error represent one standard deviation or two standard deviations? The Agency considered the following factors affecting its judgement as to which approach is most consistent with the data.

- If the ±75 m measurement error is assumed to represent two standard deviations, it would have to be considered a bounding value encompassing about 95% of the results. If the ±75 m error range is assumed to represent one standard deviation, it would encompass a smaller fraction (about 68%) of the results and would include the majority of results but would not be considered a bounding value.
- The ±75 m error range was developed based on only three out of 36 TDEM soundings and those three were selected because they were typical and not because they were bounding.
- The ±75 m error range was based on RMS error values which are very similar to the standard deviation. The RMS error is a measure of the deviation from the expected value of a parameter while the standard deviation is a measure of the deviation from the mean value. If the expected value and the mean value are the same, as in a normal distribution, the RMS error and the standard deviation are the same.

Based on the foregoing considerations, the Agency concludes that considering the ±75 m error range to represent one standard deviation is the more defensible approach.

4.3 Uncertainty in Depth of the Castile – Bell Canyon Contact

The Castile – Bell Canyon contact represents the bottom of the Castile Formation and the top of the Bell Canyon Formation. The depth of this contact beneath the waste panels is uncertain because of the understandable lack of borehole information beneath the waste panels. Two different estimates of the uncertainty in the depth of this contact were made for DOE's 1992 WIPP Preliminary Performance Assessment (SNL 1992). The first estimate is documented on a parameter data sheet and indicates that the elevation of this contact is represented by a uniform distribution ranging from -228 m to -198 m above mean sea level (amsl), with a median of -213 m (SNL 1992, Volume 3, p. 2.10). The second estimate was used in a Monte Carlo analysis described in Section 5.1 of the same document with a range from -230 m to -170 m amsl and a median of -200 m.

In preparing the first estimate, SNL states that, due to the lack of boreholes, the elevation of the top of the Bell Canyon and the elevation of the base of Anhydrite III in the Castile Formation directly below the repository "…can only be inferred from a geologic cross section (Figure 2.2-1)." (SNL 1992, p. 2-4). SNL's Figure 2.2-1 is reproduced in this report as Figure 9. SNL further states (SNL 1992, p. 2-4):

> "The geologic structure is uncomplicated, thus the uncertainty is likely to be small on the regional geologic scale. Because the information is important to evaluating the potential for and size of brine reservoirs under the repository, uncertainty bounds have been placed on these two elevations inferred from the geologic cross section."

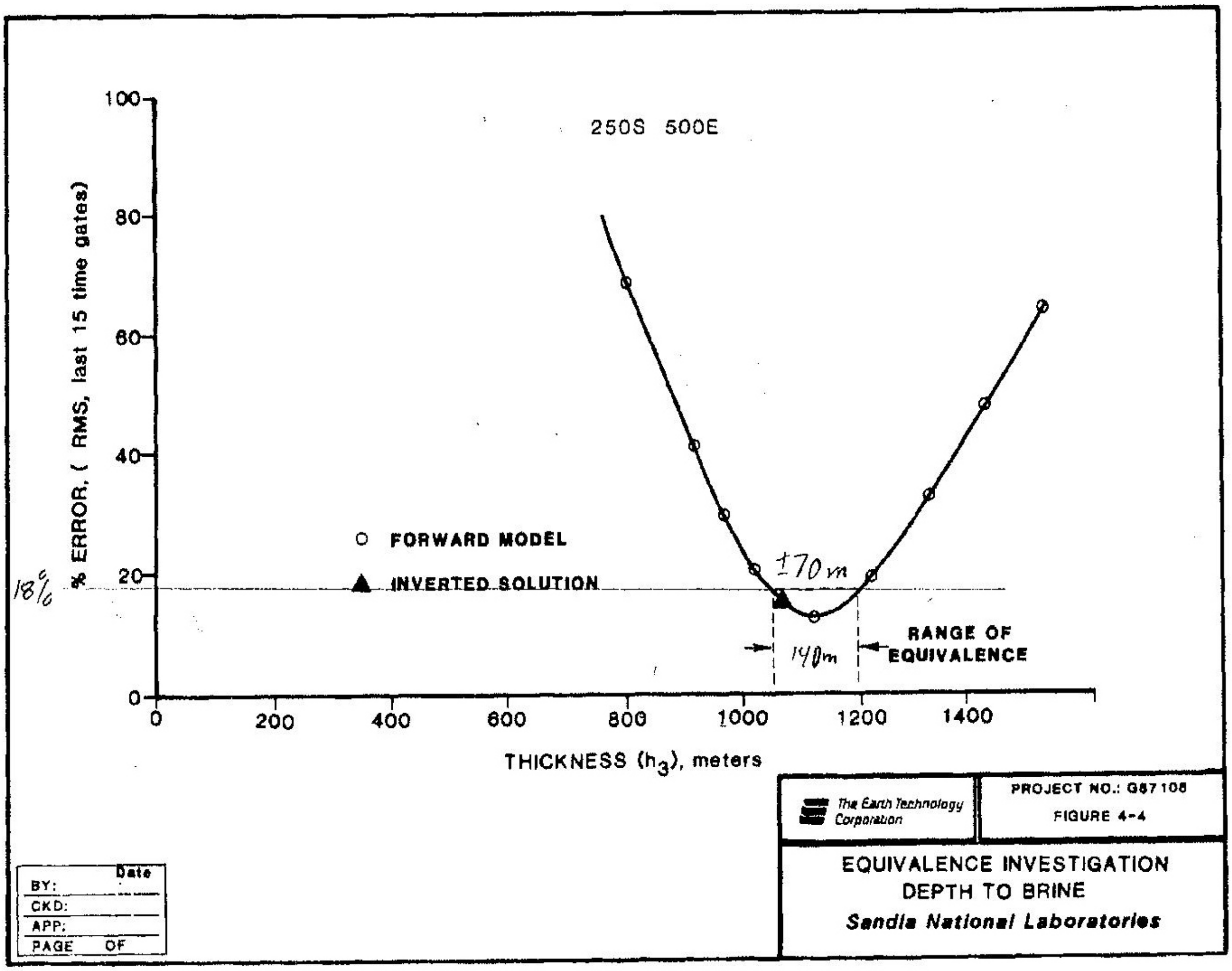

Figure 8. Illustration of uncertainty in depth to brine (modified from The Earth Technology Corporation 1987, Figure 4-4).

Projecting from the two closest wells (Cabin Baby-1 and DOE-2) that provide data for the top of the Bell Canyon, SNL estimated the elevation of the top of the Bell Canyon at the location of borehole U.S Energy Research and Development Administration (ERDA-9) to be -213 m amsl with the foregoing uncertainty range of -228 m to -198 m amsl. Although the vertical line on Figure 9 that represents ERDA-9 extends to Anhydrite 1 in the lower Castile, ERDA-9 was only drilled to the top of the Castile. However, this well is located immediately north of the repository waste area and was used by SNL as a reference location for the waste panels on the cross section (see Figure 1).

In preparing the second estimate of the top of the Bell Canyon, SNL describes the TDEM survey and then states (SNL 1992, p. 5-2):

> "The entire Bell Canyon Formation directly beneath the Castile Formation is a good conductor. However, in several places underneath the WIPP disposal area, the elevation to the first major conducting media detected lay above the top of the Bell Canyon Formation (~ -200 ±30 m
> [-654 ±100 ft]) in the ERDA-9 well but below the bottom of the Salado Formation (178 m [582 ft] in ERDA-9) (see Figure 2.2-1 and Section 2.2)."

Although the foregoing text is not entirely clear because the ERDA-9 well does not penetrate to the top of the Bell Canyon, this second estimate is likely a more generalized version of the first estimate. Both estimates refer to the same figure and section of SNL (1992) for further information, however that section describes the rationale for the first estimate but not the second. The Agency chose to use the first estimate in determining the uncertainty in PBRINE because of the lack of clarity in the basis for the second estimate and because the first estimate places more of the TDEM high electrical conductivity zones within the Castile Formation and may therefore be slightly more conservative.

The TDEM data are given as depths with reference to the ground surface while the data for the top of the Bell Canyon are given as elevations with reference to mean sea level. To be compatible, these two data sets must be expressed relative to the same reference point. To accomplish this, the Agency converted the elevation data to depth beneath the ground surface. The ground surface elevation above the waste panels is required to make this conversion and this elevation must be considered a nominal reference value because the ground surface at the WIPP site is nearly but not completely level. The reference elevation was determined based on the following information. Popielak et al. (1983, p. H-49) state that the floor of the disposal facility at the Experimental Shaft Station is at an elevation of about 1265 feet amsl, which is equivalent to about 385 m amsl, and Hanson (2003, p. 7) states that the WIPP repository is situated at a depth of 655 m below the ground surface. Adding these two gives a nominal ground surface elevation of 1,040 m amsl. The best estimate depth of the Castile – Bell Canyon Contact was therefore determined to be 1,253 m below the ground surface with an uncertainty range of 1,238 m to 1,268 m (30 m). Because little is known about the shape of this distribution, it was assumed to be uniform

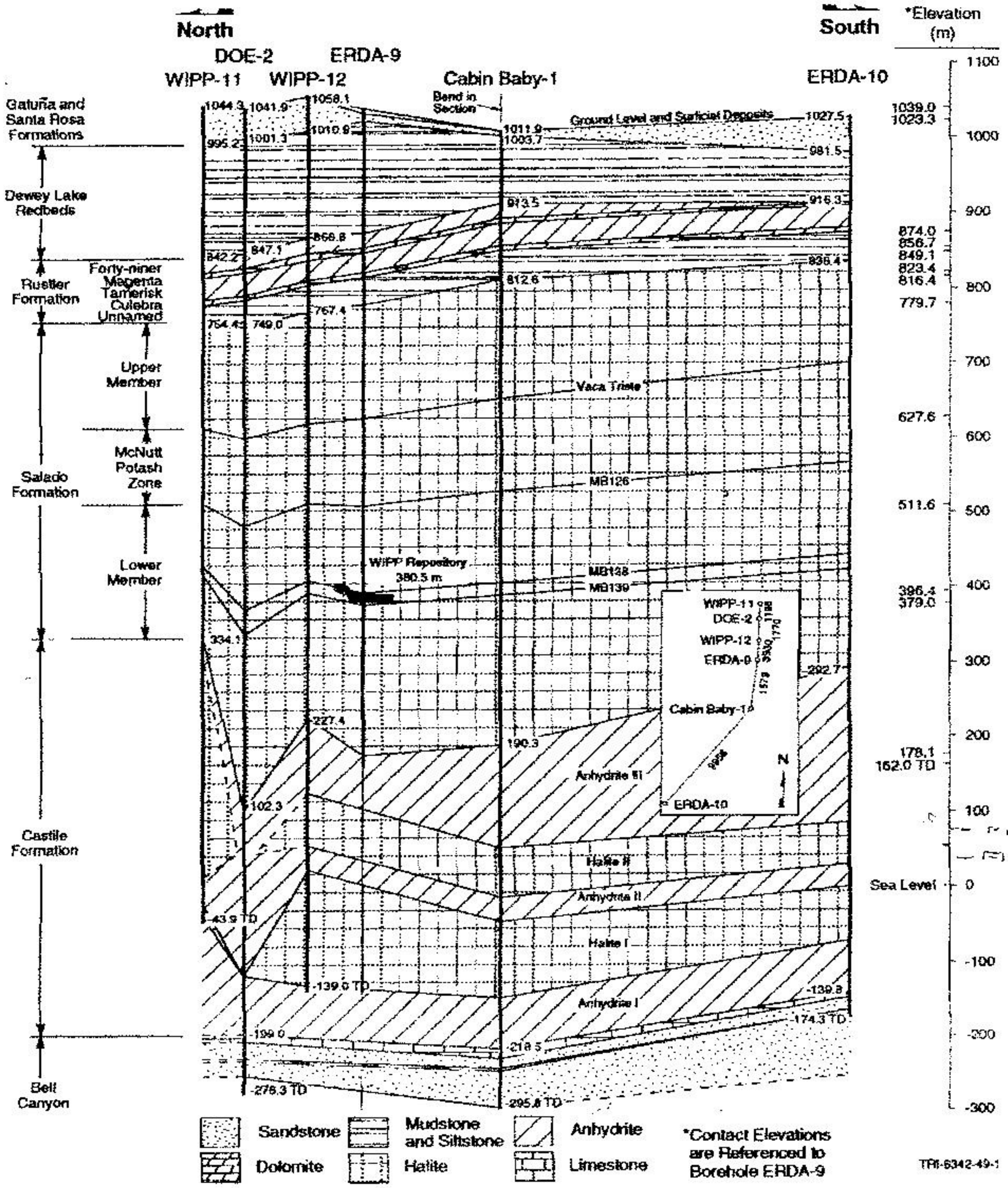

Figure 9. Stratigraphy to the top of the Bell Canyon in the vicinity of the WIPP site (from SNL 1992, Figure 2.2-1).

consistent with the assigned distribution in SNL's Preliminary Performance Assessment (SNL 1992, Volume 3, p. 2-10).

4.4 Waste Panel Area and Location

Accurate estimates of the waste panel floor areas and locations relative to the TDEM sounding grid are needed for the updated PBRINE calculation. The waste panel floor areas of panels 9 and 10 are smaller than the areas of panels 1 through 8, making it less likely for a randomly placed borehole to intersect the two smaller panels. Also, the TDEM grid must be accurately superimposed over the underlying waste panels to correlate between the waste panel floor area and the block model cells.

The BRAGFLO-DBR grid used in WIPP PA was used to determine the waste panel floor areas. This grid provides the plan view of the waste area of the WIPP repository used to calculate direct brine releases (DBRs). A copy of this grid is presented in Figure 10 and shows the widths of the columns and rows of the waste rooms to an accuracy of 1/100 of a meter.

The Agency's initial analysis of the BRAGFLO-DBR grid determined that the total waste area shown was slightly smaller than the total area of 1.115×10^5 m^2 reported in DOE's CRA-2009 (DOE 2009, Appendix PA-2009, p. PA-44). To get a consistent data set, it was assumed that the areas of Panels 1 through 8 are accurately depicted on the BRAGFLO-DBR grid, that the above total waste disposal area was consistent with the engineered repository design, and that the waste disposal rooms in Panels 9 and 10 are depicted as slightly narrower than final size. Panels 9 and 10 will occupy drifts that are currently used as access corridors to Panels 1 through 8. Panels 9 and 10 are to be completed to final size by widening those corridors prior to emplacing waste (DOE 2011, p. 1). For purposes of the updated PBRINE analysis, the areas of Panel 9 and 10 corridors were increased by about 3% to achieve the final total waste disposal area of 1.115×10^5 m^2. The original and modified widths of these corridors are shown in Table 1. The final waste disposal areas used in the updated analysis are shown in Table 2 along with the areas of other features that make up the repository waste region.

Table 1. Original and Modified Widths of Panel 9 and 10 Corridors

Feature	Corridor	Halite	Corridor	Halite	Corridor	Halite	Corridor
Column No. on Figure 10	17	18	19	20	21	22	23
WIPP Corridor Designation	W 170		W 30		E 140		E 300
Original Width (m)	4.30	42.20	4.30	46.50	7.60	38.00	4.30
Modified Width (m)	4.57	41.93	4.58	46.22	7.60	37.72	4.58

The Agency prepared a true-to-scale representation of the waste panels and the TDEM sounding locations using information from Figures 7, 10, and 11. The dimensions of the underground waste area were primarily obtained from Figure 10 as described above. The locations of TDEM soundings relative to the waste panels were determined by combining the locations of borehole ERDA-9 and the TDEM grid from Figure 7 with the locations of ERDA-9 and the waste panels from Figure 11. The two drawings were superimposed at the same scale using the north-south orientations of the waste panels and TDEM grid with ERDA-9 as a common point. From this superposition a scale drawing was prepared showing the locations of TDEM soundings in the vicinity of the projected locations of the underlying waste panels. This drawing shows coded cells representing the waste and non-waste pillar, DRZ, and other unexcavated areas for use in the statistical sampling to determine *pHCZ,* and is presented in Figure 12.

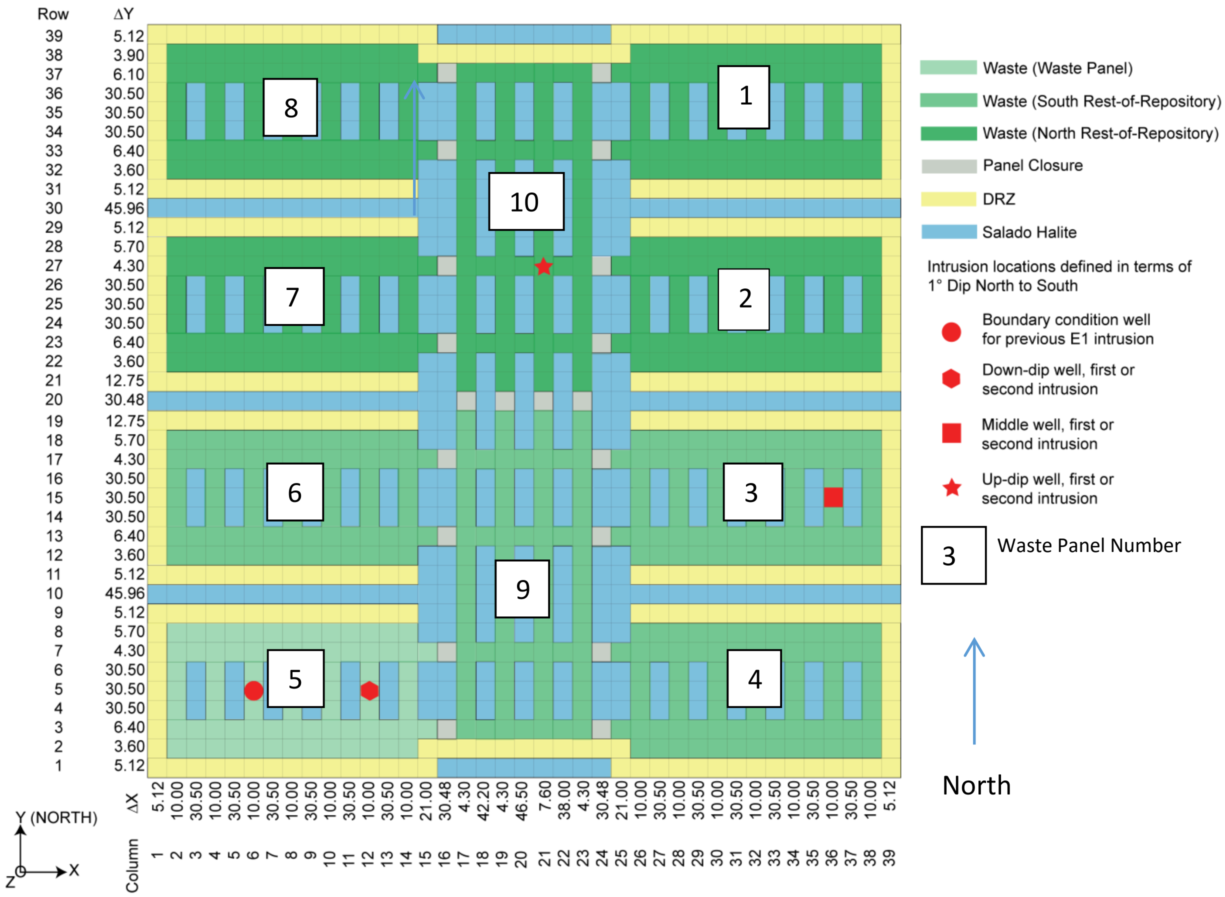

Figure 10. Waste panel dimensions in meters from BRAGFLO-DBR grid used in WIPP PA (modified from DOE 2014, Appendix PA, Figure PA-24).

Table 2. Waste Disposal Areas Used in the Updated PBRINE Calculation

Waste Panel	Waste Disposal Area (m^2)	Panel Closure Area (m^2)	DRZ Area (m^2)	Unexcavated Pillars (m^2)	Total Waste Region Area (m^2)
1	11,728	381	3,522	21,640	37,271
2	11,690	326	5,183	21,934	39,133
3	11,690	326	5,183	21,934	39,133
4	11,690	326	3,507	21,748	37,271
5	11,690	326	3,507	21,748	37,271
6	11,690	326	5,183	21,934	39,133
7	11,690	326	5,183	21,934	39,133
8	11,728	381	3,522	21,640	37,271
9	8,844	650	530	37,438	47,462
10	9,064	0	574	33,337	42,975
Inter-Panel Unexcavated Area					82,656
Totals	111,502	3,369	35,896	245,286	478,709

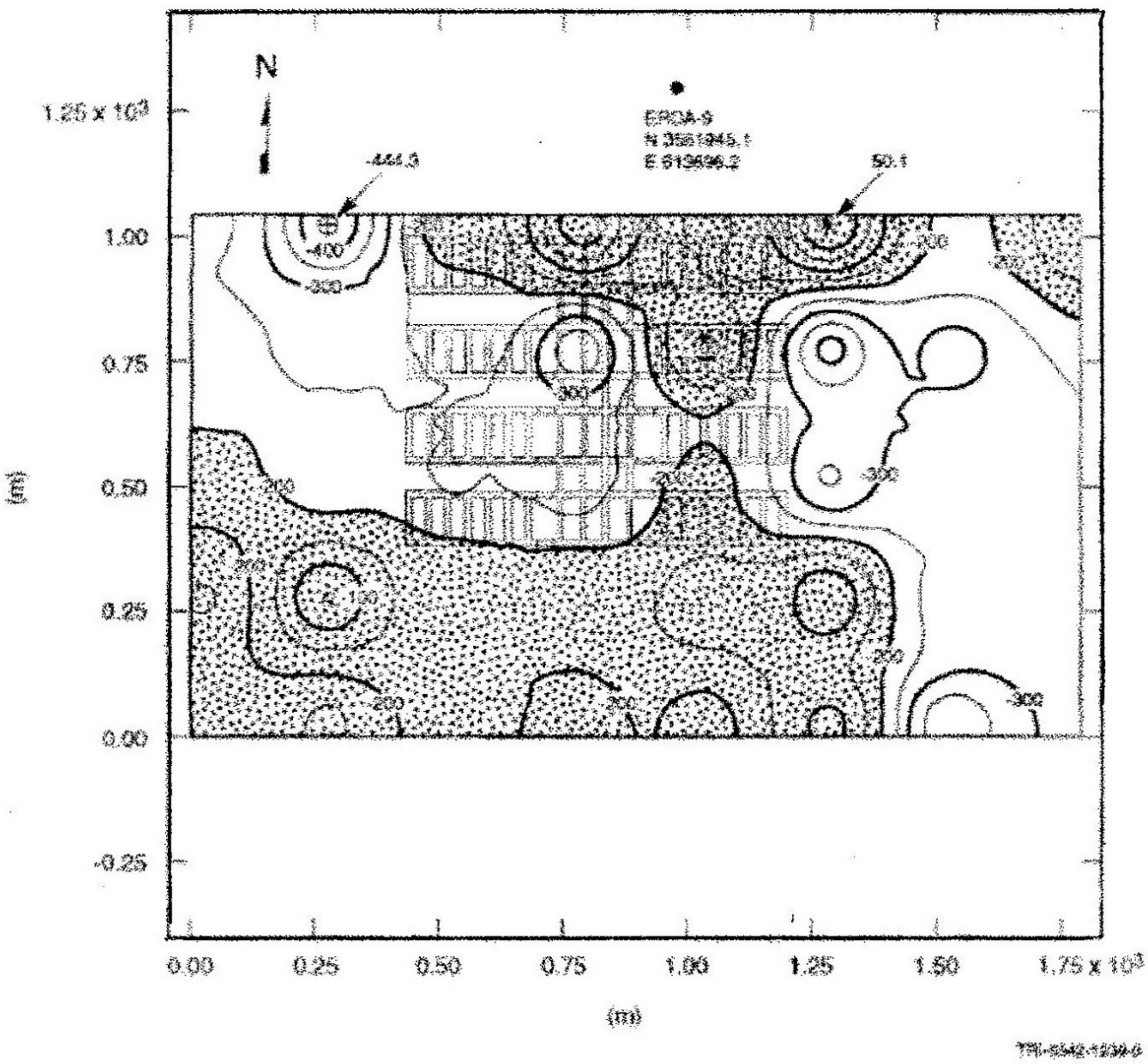

Figure 11. Elevation map (in meters) relative to sea level of first major conductor below waste panels and ERDA-9 (from Kirchner et al. 2012, Figure 8).

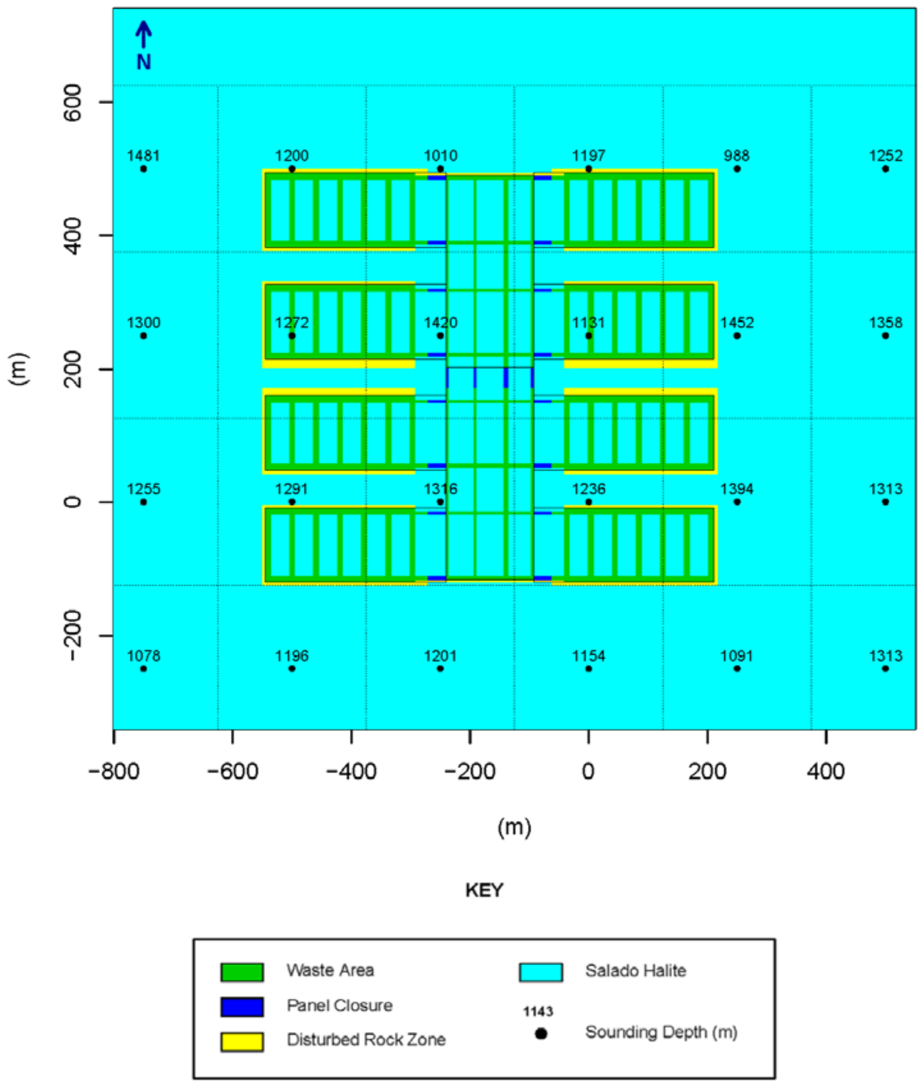

Figure 12. Locations of TDEM soundings near the waste panels relative to the projected locations of the underlying waste panels. The estimated depth in meters to the first high electrical conductivity zone is shown for each sounding.

The contour lines of depth below ground surface (Figure 7) and elevation above sea level (Figure 11) of the first major electrical conductor were added by the original authors of those figures. As mentioned above, the Agency questions the physical meaning of the contour lines on these two figures because they imply that the first conductive horizon can be represented as a continuous surface. In fact, the data in Figure 7 may represent depths to portions of laterally continuous horizons, such as anhydrite beds, that are vertically isolated and therefore vertically discontinuous. Although the contour lines on these two drawings were not used in the Agency's updated analysis, Figure 7 was taken from the original TDEM analysis report (The Earth Technology Corporation 1987) and the depth data (in meters) accompanying each sounding location shown on the figure were used as described in Section 4.2.

5.0 Consideration of Brine Yields Important to WIPP Performance

The way in which encounters of Castile brine are used in WIPP performance assessment is instructive in identifying the types of releases that could be important to WIPP performance. This section addresses the importance of Castile brine encounters in WIPP performance, the treatment of Castile brine in WIPP PA, and alternative models for brine reservoir formation and fracture system geometry that affect the probability of encounter in a borehole. This section ends with a discussion of available information regarding the possible presence of Castile brine beneath the WIPP waste panels.

5.1 Importance of Castile Brine Encounters in WIPP Performance

The importance of Castile brine encounters in WIPP performance is illustrated by the sensitivity to the presence of Castile brine of every release pathway that depends on repository pressure or brine saturation. Sensitivity analyses of WIPP performance assessment results only rarely identify GLOBAL:PBRINE (or simply PBRINE) as a key parameter because PBRINE only determines whether a brine reservoir is intersected. The consequences of that intersection to waste isolation, such as the magnitudes of direct brine releases (DBRs), are determined by other parameters such as brine reservoir compressibility, permeability and pressure, independent of the value of PBRINE. However, a brine reservoir must be randomly determined to be encountered before the properties of that reservoir are of any consequence.

In describing the consequence of intersecting a Castile brine reservoir in the PABC-2009 PA, DOE states (2009, Appendix PA-2009, p. PA-15):

> "The primary consequence of penetrating a pressurized reservoir is to provide an additional source of brine beyond that which might flow into the repository from the Salado. Direct releases at the ground surface resulting from the first repository intrusion would be unaffected by additional Castile brine, even if it flowed to the surface, because brine moving straight up a borehole will not significantly mix with waste. However, the presence of Castile brine could significantly increase radionuclide releases in two ways. First, the volume of contaminated brine that could flow to the surface may be greater for a second or subsequent intrusion into a repository that has already been connected by a previous borehole to a Castile reservoir. Second, the volume of contaminated brine that

may flow up an abandoned borehole after plug degradation may be greater for combinations of two or more boreholes that intrude the same panel if one of the boreholes penetrates a pressurized reservoir. Both processes are modeled in PA.

All WIPP release pathways that are functions of repository pressure and/or brine saturation are sensitive to the presence of Castile brine in the repository. The presence of Castile brine in a waste panel increases brine saturation, which is necessary for DBRs and releases through the Culebra or Salado. The presence of brine also increases gas generation from waste degradation which increases repository pressure and drives brine as well as spallings releases. The effects of encountering a Castile brine reservoir are illustrated in the results of the PABC-2009 PA (DOE 2009, Appendix PA-2009, Section PA-8.5). The largest maximum spalling volumes occurred in scenarios where an exploratory borehole intruded a Castile brine reservoir. With regard to DBRs, the solubility uncertainty for actinides in the +III oxidation state, the initial brine pore pressure in the Castile, the inundated corrosion rate for steel, and the frequency with which Castile brine intrudes the repository accounted for more than 50% of the total uncertainty. Three out of four of these DBR drivers are related to the presence of brine. Although releases by subsurface transport in the Salado or Culebra made essentially no contribution to total releases, they are also clearly driven by gas and brine pressure within the repository and the availability of a mobile brine phase.

Based on the foregoing observations, the Agency concludes that the presence of a brine reservoir beneath the WIPP site and the release of Castile brine into a waste panel are important to the results of WIPP PA , and that the frequency and magnitude of potential brine releases are sensitive to the range and probability distribution for PBRINE.

5.2 Treatment of Castile Brine in WIPP Performance Assessment

Brine reservoirs can be encountered beneath the WIPP site in the Castile Formation as well as in the underlying Bell Canyon Formation. Brine pressures in the Castile are high, likely due to the creep properties of Castile halite, and are sufficient to lift brine to the repository elevation as well as to the ground surface. The Bell Canyon sandstones are part of the sedimentary Delaware Mountain Group (Popielak et al 1983, p. G-10) and do not have the creep properties of Castile halites. Brine pressures in the Bell Canyon are lower than in the Castile and are sufficient to lift brine to the repository elevation but not to the ground surface at the WIPP site (see Popielak et al 1983, Figure 4). As discussed below, Bell Canyon brine can only enter the repository during drilling before the borehole is cased through the salt section and before it is plugged and abandoned.

5.2.1 Modeling of Brine Releases into the Repository

In WIPP PA, Castile brine encountered in an exploratory borehole is released into the repository under different conditions at different times. Upon completion of drilling, the borehole is assumed to be plugged using one of three randomly selected plugging patterns. Release of Castile brine into the waste panel is only modeled if plugging pattern #2 is selected, which occurs approximately 60% of the time (DOE 2014, Appendix PA, p. PA-45). This is because it is the only pattern with no plugs between the Salado and Castile Formations. This pattern consists of a surface plug, one plug above the waste panels at the Salado-Rustler contact, and one plug below the waste panels at the Castile-Bell Canyon contact. Release of Castile or Bell Canyon brine into a penetrated waste panel when the borehole is open during drilling is not considered in WIPP PA because the quantities involved are expected to be small compared with the quantities of brine available from sources within the Salado. These other sources include anhydrite interbeds in the Salado and drainage of the disturbed rock zone (DRZ) surrounding the waste panel (Wilson et al. 1996, Section 3.12).

For the first 200 years after drilling, the borehole is assumed to be open and Castile brine is modeled to flow up the borehole and into the penetrated waste panel, potentially flooding the panel with Castile brine. Beginning 200 years after drilling, the steel casing and plug above the waste panel at the Rustler/Salado interface are assumed to have completely failed, allowing the entire borehole down to the Castile-Bell Canyon plug to fill with the hydrologic equivalent of a silty sand. After 1200 years and until the end of the 10,000-year regulatory period, the permeability of the silty sand is reduced by one order of magnitude in the Salado and Castile beneath the repository due to creep closure of the borehole (DOE 2014, Appendix PA, Table PA-7). WIPP PA therefore models a relatively short, 200-year period when Castile brine flows up an open borehole followed by a period of potentially thousands of years when the brine flow is considerably slowed by filling material. The borehole plug below the Castile brine reservoir at the Castile-Bell Canyon contact is in a less aggressive chemical environment and is not modeled to fail in WIPP PA. This plug therefore permanently isolates the waste panels from the long-term flow of Bell Canyon brine.

To be consistent with use of the data in WIPP PA, the estimate of PBRINE should be based not only on the high pressure, high yield brine reservoirs that are large enough to be noticed and logged by a driller, but also on the pressurized but lower yield releases that could continue over thousands of years but would not be noticed or logged by a driller. The larger, high permeability fractures that produce substantial brine volumes are relatively rare and are therefore rarely encountered. Smaller, lower aperture fractures would be more commonly encountered during drilling and would support a smaller flow rate but could provide a long-term source of brine to a waste panel. Depletion of the accumulated brine in a waste panel is modeled in WIPP PA to occur by several mechanisms, including direct brine releases (DBRs), waste degradation, flow up a degraded borehole into the Culebra, and flow out anhydrite interbeds. The continuing availability of brine in a waste panel is important to waste degradation and the consequent increases in gas pressure that drive the important DBR and spallings releases.

The Agency investigated the possibility that brine reservoir pressure might be reduced over time and that flow into the repository might eventually become inconsequential. Pressure reduction could be caused by a major release during drilling, by a prior borehole penetration of the same reservoir, or by long-term flow up a degraded borehole. These possibilities were evaluated by Popielak et al. (1983), who concluded that pressure drops due to short-term brine releases would soon recover and that over the long term, brine flow would not drop to zero but would stabilize at a low rate. They found that recovery of reservoir pressure after a major but short-term brine release during drilling would be fairly rapid due to the continuing effects of halite creep. As an example, the reservoir at WIPP-12 produced about 80,000 barrels (12,700

m^3) of brine during drilling and testing (Popielak et al. 1983, p. H-54) but “After more than nine months of recovery, the WIPP-12 reservoir should be near equilibration.” (Popielak et al. 1983, p. H-53). With regard to long-term flow, the flow rate would drop over time as the brine in the larger fractures is depleted but, with regard to WIPP-12 for example, Popielak et al (1983, p. H-56) state: “The flow rate would not drop to zero however, but would instead stabilize at the rate at which the microfractures recharge the large fractures. Considering the slow, long-term pressure buildup rate and the low permeability of microfractures, that rate would likely be less than one bbl/day.” One bbl/day is equivalent to about 0.0001 m^3/min. The potential significance of such a flow rate to WIPP performance is discussed in Section 5.3.

5.2.2 Modeling of Borehole Penetrations into Waste Panels

The sampled value of PBRINE only provides the probability that brine is encountered, it does not indicate that brine is actually encountered in a borehole. When the first borehole intrusion of a waste panel is determined to occur and a value of PBRINE is sampled, an additional determination of whether or not that borehole actually encounters Castile brine is made. If a borehole is determined to encounter Castile brine, the reservoir containing that brine is assumed in WIPP PA to be large enough to underlie all ten waste panels. Thus, if the first borehole is determined to intersect a brine reservoir, then any subsequent boreholes that penetrate the waste area are assumed to intersect that same reservoir.

The Agency also observes that its updated approach to estimating PBRINE has quantified the spatial variability of PBRINE beneath the WIPP waste panels. This quantification has shown that the probability of intersecting Castile brine is greater beneath some panels than others. In considering how this spatial variability can be most successfully addressed in WIPP PA, the Agency reviewed the two-dimensional structure of the BRAGFLO PA model and its ramifications.

BRAGFLO provides detailed modeling of one waste panel and the remaining nine panels are combined in the South and North Rest of the Repository (SRoR and NRoR). These repository features are shown on the BRAGFLO grid in Figure 13. The single modeled panel does not represent a specific panel but rather represents a hypothetical panel with attributes selected for different purposes. For example, the single panel represents the unique, extreme down-dip southern panel (Panel 5 on Figure 10) for the purpose of maximizing brine accumulation by gravity flow. However, this same single modeled panel is assumed to contain the average waste inventory of all panels for the purpose of simulating gas generation and geochemical evolution. In addition, the long-term effects of all boreholes that intersect the waste area are calculated using this same single panel. Thus all boreholes that yield Castile brine are assumed to intersect the same waste panel as well as the same brine reservoir. The evolution of geochemical conditions in the repository, the impact on those conditions from the accumulation and disposition of brine, and the effects of borehole penetrations on the repository environment are all determined in this panel.

The Agency concludes that this single panel is not intended to be representative of all panels, nor is it intended to be a worst-case or extreme example, but rather it represents a combination of bounding conditions (with regard to brine accumulation by gravity flow); of average conditions (with regard to waste inventory); and of extreme conditions (with regard to borehole intrusions), each reflective of the different modeling objectives. In keeping with the recognition of spatial variability in DBRs and spallings releases, which include solid material carried into the borehole during rapid depressurization of the waste disposal region, the Agency concludes that it is consistent with WIPP PA methodology to recognize the spatial variability now quantified in PBRINE. This can be conceptually accomplished by considering the single modeled panel as representing a randomly selected waste panel for the purpose of sampling PBRINE.

The distributions of PBRINE for individual waste panels shown in Figure 4 can be used to support a conceptual explanation of how a sampled value of PBRINE can be used in WIPP PA. A waste panel is randomly selected and then a value of PBRINE is selected from the PBRINE distribution for that panel. The value of PBRINE for the first intersecting borehole in the randomly selected panel is logically the value randomly selected from the distribution of PBRINE for that panel and can be any value from that distribution. Following the approach adopted in BRAGFLO, for purposes of addressing Castile brine encounters, the next intersecting borehole is assumed to penetrate that same waste panel and that same brine reservoir so the evolution of conditions in that waste panel (such as changes in brine saturation and gas pressure over time) can be modeled including the potential influence of Castile brine.

More than 50% of the floor area of all but three of the waste panels overlies a single TDEM block representing a single brine reservoir and in most realizations that reservoir is the one that will be randomly hit by the first as well as by subsequent randomly located boreholes hitting that same panel (see Appendix D). For consistency with the current implementation of PBRINE in WIPP PA, the Agency therefore concludes that the presence or absence of brine in the second borehole intersection can

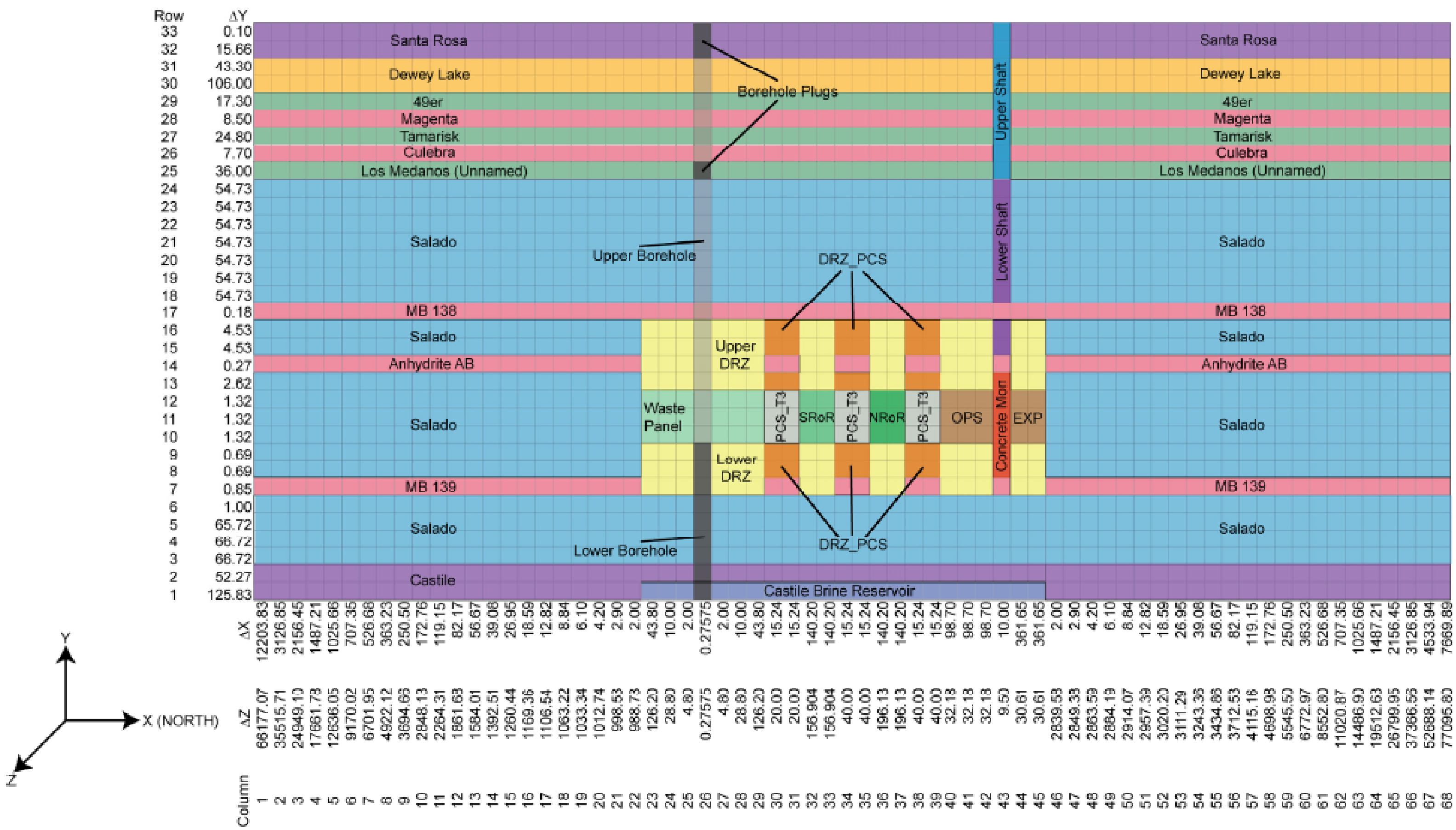

Figure 13. BRAGFLO grid and material map for an E1 Intrusion showing locations of the Castile brine reservoir, the single waste panel, and the South and North Rest-of-the-Repository (SRoR and NRoR) (from Camphouse 2012, Figure 3-7).

be appropriately treated as identically correlated with the sampled results for the first borehole. Thus, if the first borehole is determined to encounter a Castile brine reservoir, the next borehole in the same realization can be considered to encounter that same reservoir.

The conceptualization described above for addressing the variability in PBRINE across the ten waste panels in the two dimensional BRAGFLO Salado flow model representation of the repository is illustrated using the following steps.

1) For the first realization, randomly determine which of the ten waste panels the single modeled panel is to represent for purposes of sampling PBRINE.
2) For the first borehole intersection of the waste area in that realization, sample a value of PBRINE from the uncertainty distribution for the selected waste panel.
3) Based on the sampled value of PBRINE, determine whether a brine reservoir is encountered by the first borehole.
4) Assume that any subsequent boreholes in that realization intrude the same panel and encounter the same reservoir.
5) Repeat Steps 1 through 5 for each subsequent realization, randomly selecting a waste panel and a value of PBRINE from the distribution for that panel.

In practice, the first two steps in this process can be reduced to a single step by directly sampling from the single CDF in Figure 5 that has been developed by the Agency and includes the probability-weighted distribution of all individual panel results for PBRINE. This simplification holds as long as it is assumed that for a given vector the individual waste panel is randomly selected, that all subsequent borehole penetrations occur in the same waste panel as the first penetration, and that each subsequent borehole hits the same Castile brine reservoir as the first borehole. When this process is repeated 100 times to create 100 vectors, as will be done in WIPP PA, the median value of PBRINE is expected to be similar to the median value determined if an averaging approach for combining individual panel results had been used. However, the upper and lower bound values of PBRINE are also important to EPA and are expected to be more accurately represented by sampling from the distribution in Figure 5 than if using an averaging approach.

The foregoing discussion explains how the sampling of PBRINE from the CDF in Figure 5 best honors the differences in the probability of encountering brine among individual panels while accepting the constraints of the two-dimensional, single waste panel repository representation in the BRAGFLO Salado flow model. Although the information available from this updated method can support other conceptual approaches to implementing PBRINE in performance assessment, it is the Agency's intention that the updated method described in this document only changes the process for determining the value of PBRINE and does not change the implementation of that value in WIPP PA.

In conclusion, the approach used by the Agency for combining the individual panel CDFs into a joint CDF representing all panels provides an adequate representation of the variability in PBRINE and is to be used when sampling PBRINE in WIPP PA.

5.3 Flow Rates Important to WIPP Performance

Past investigators have focused only on large brine releases that were noticed and logged by drillers with the generally unstated assumption that only those types of releases would be important to repository performance. However, the Agency is not aware of any analysis supporting this assumption or the evaluation of whether smaller brine releases that would not be noticed and logged by drillers could also be important to WIPP performance. To provide a quantitative approximation of lower brine flow rates that would be of potential importance to WIPP performance but would likely not be noticed and logged by a driller, the brine flow rate required to fill a waste panel in the 200-year period of open borehole was compared with typical minimum drilling mud flow rates for deep well mud pumps. This analysis involved the following considerations: 1) the initial pore volume of a waste panel is the maximum volume of Castile brine that the panel could accommodate; 2) a waste panel saturated with Castile brine has the potential to impact repository performance; and 3) 200 years is relatively short compared with the 10,000-year regulatory time frame for the WIPP repository.

Initial brine discharges at the ground surface from driller reports of encountering Castile brine reservoirs have ranged from 700 to 20,000 barrels per day (0.08 to 2.21 m^3/min; Popielak et al. (1983, p. H-37).

Popielak et al. (1983, p. H-55) estimate that the maximum volume of brine derived from the WIPP-12 brine reservoir that could flow into the WIPP repository is 2.4 million barrels (380,000 m^3). The initial pore volume of an intruded waste panel, not including the DRZ or pillars between rooms and considering a filled waste panel initial porosity of 0.848 (DOE 2014, Appendix PA, Table PA-3), is about 40,000 cubic meters. The flow rate up an open borehole needed to fill the panel in 200 years is about 0.0004 m^3/min. Typical flow rates for 11 models of Gardner-Denver deep well mud pumps range from a minimum of 200 gpm to a maximum of 600 gpm (0.8 to 2.3 m^3/min; Gardner-Denver 2015). The brine flow rate of 0.0004 m^3/min that would fill a waste panel in 200 years is an example of a low flow rate that would be important to WIPP performance but is only 0.05% of the minimum mud pump flow rate of 0.8 m^3/min. Such a small increase in mud flow rate is unlikely to be noticed and logged by a driller, yet it would fill a waste panel with Castile brine in a relatively short time compared with the 10,000-year regulatory time frame. Such a flow rate is potentially important to WIPP performance but would not have been considered if estimates of PBRINE are only based on reported encounters during drilling. Furthermore, although the pressure may initially decrease due to the penetration the brine pocket, the pressure is transient and pressures will gradually increase until they eventually reach lithostatic pressures which are sufficient to bring the brine to the repository as well as land surface.

As previously stated, long-term flow rates from Castile brine reservoirs are not expected to drop to zero. Long-term flow from the interconnected microfractures in a Castile brine reservoir have been estimated by Popielak et al (1983, p. H-56) to be less than one bbl/day or about 0.0001 m^3/min. The context of this estimate indicates that it was with reference to flow at the ground surface and flow at the repository elevation would be greater. Considering that a brine flow rate of 0.0004 m^3/min would fill a waste panel to 100% saturation in 200 years, a long-term flow as low as 0.0001 m^3/min at the repository elevation would increase the waste panel brine saturation to about 25% even if no other source of brine was available. Mobile brine must be present in the repository for a brine release to the accessible environment to occur and the brine saturation in the repository must therefore exceed the residual brine saturation of the waste material. The residual saturation in a waste panel is currently sampled from a uniform distribution ranging from 0.0 to 0.552 (DOE 2014, Appendix PA, p. PA-131). At the minimum flow rate of 0.0001 m^3/min, the volume of Castile brine entering a waste panel would assure a brine saturation of at least 0.25 after 200 years and even without any additional brine inflow, such as from anhydrite interbeds in the Salado, flow from the Castile would be treated as a mobile brine phase in nearly half of all PA realizations. The Agency concludes that the volume of brine that could enter the repository at even this minimum flow rate would be potentially important to WIPP performance. The Agency considers all brine in the Castile to be under pressure because of its depth and the stress effects of halite creep, and that low yield releases will be controlled primarily by lower permeabilities rather than lower pressures. These observations are consistent with the models and hydrologic testing of two brine reservoirs in the Castile anhydrite beds described by Popielak et al. (1983, p. H-59) which, upon drilling encounter, show an initial, rapid release followed by a long-term, progressively slowing release as the primary system of large fractures is depleted.

5.4 Castile Brine Reservoir Models

Studies of brine reservoirs in the Castile Formation commissioned by the DOE have included the work of Borns et al. (1983), who provided an early evaluation of alternative reservoir models; the work of Popielak et al. (1983), who provided geological, hydrological, and geochemical analyses of the ERDA-6 and WIPP-12 brine reservoirs, and the work of Powers et al. (1996), who provided additional insights into the correlation between brine encounters and structural deformation in the Castile.

The evaporate stratigraphy in the vicinity of the WIPP site is shown in Figure 9. The Castile Formation beneath the WIPP site is comprised of five principal members. In ascending order, these are: Anhydrite I, Halite I, Anhydrite II, Halite II, and Anhydrite III. As reported by Popielak et al. (1983, p. G-1), the anhydrite rock is microcrystalline and dense, with thin bedding laminae made up of carbonates, organic material, and clays. Fractures that dip between 70° and vertical in Anhydrite III [the uppermost anhydrite], in Anhydrite II, and in an anhydrite stringer within Halite II were encountered in WIPP-12. Although the data are sparse, the figure indicates that the Castile becomes increasingly deformed north of the WIPP site and appears to be less deformed to the south.

Drilling data indicate that Castile brine encounters large enough to be noticed during drilling often occur in anhydrite interbeds that have been subjected to structural deformation and fracturing associated with thickening of an underlying halite bed. An example is provided in Figure 9 where thickening of Halite I at WIPP-12 has uplifted and deformed the overlying Anhydrite II and Anhydrite III beds and is likely associated with the large brine reservoir encountered in WIPP-12 (Popielak et al. (1983, p. G-2). A 1996 structure contour map of the top of the Castile Formation is shown in Figure 14. Although the map is dated and data are sparse in some areas, it clearly depicts major areas of structural deformation north and east of the WIPP site. More recent information on brine encounters during drilling, presented later in this report, do not change the structural trends presented in this figure. Most brine encounters have been associated with a belt of deformation in the Castile that parallels the Capitan reef subcrop. According to Popielak et al. (1983, p. G-2), this belt of deformation also underlies the WIPP site. The brine releases reported by drillers most often occur from fractures in the uppermost Castile anhydrite unit present at each drilling location although some brine releases have been reported from the intercalated halite units and from halite-anhydrite contacts (Powers et al. 1996, Table 4.2-2).

5.4.1 Models for Brine Reservoir Development

The models for reservoir development consider two aspects: the source of the brine and the source of the fracturing. As will be seen, alternative models have been proposed for each and in neither case has a single, definitive model been accepted. This suggests that brine reservoirs might have developed under different conditions at different locations. Models for the brine reservoirs are important because they suggest the types of conditions that might lead to reservoir development and the types of structural features that might indicate their potential presence. Knowing what structural features to look for could help in evaluating the possible presence or absence of brine reservoirs beneath the WIPP site.

Models for the Source of Brine

Popielak et al. (1983, p. 5) considered several potential sources of the large volumes of brine that have been encountered during drilling, including (1) original connate water trapped interstitially or within grains of the evaporites at the time of deposition; (2) local fluid entrapment by, for example, the dissolution of evaporite minerals by meteoric water, closely followed by recrystallization and entrapment, and (3) water formed by the dehydration of gypsum to anhydrite. While the potential exists for small quantities of connate water described in the first source to be trapped interstitially or within grains, this source is unlikely to have provided the large brine volumes that have been observed.

The two remaining potential sources are closely tied to the models for the source of the fracturing discussed below. Local fluid entrapment would result in locations with higher porosity and is closely tied to the gravity foundering model for fracturing, discussed below. Alternatively, about 50% of the original system volume of gypsum converts to water during the conversion of gypsum to anhydrite

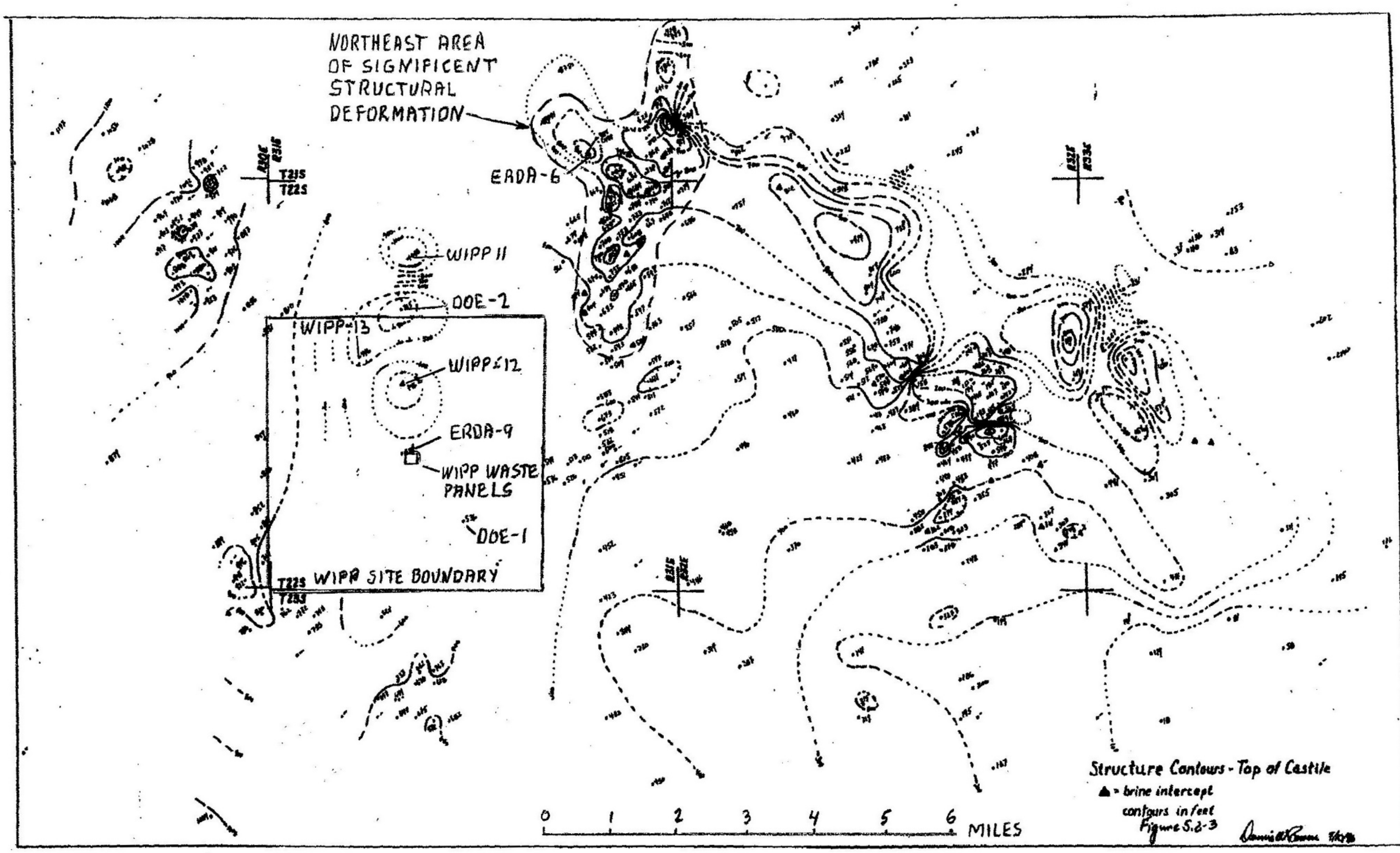

Figure 14. Elevation of the top of the Castile Formation (modified from Powers et al. 1996, Figure 5.2-3)

(Popielak et al. 1983, p. G-50). Considering the 100 m or more thickness of the anhydrite beds shown in Figure 9, dehydration of gypsum would have provided significant quantities of brine. Such dehydration could also provide high pore pressures over large areas that would reduce friction and facilitate gravity sliding of the overlying halite down low angle inclines on the halite-anhydrite contacts.

Models for the Source of Fracturing

Fracturing of the anhydrites is thought to be the result of salt movement in the intercalated halite beds that has resulted in variations in the thickness of those beds. These variations in thickness are locally expressed in domal or antiformal structures and in depressions or synformal structures that have deformed the overlying anhydrite beds causing them to fracture. Such structures are evident in the regional map of the top of the Castile presented in Figure 14 and also in the seismic data at the WIPP site presented in Figure 15. A simple model of tensile fracturing of the anhydrite beds was developed by early investigators related to the extension of relatively horizontal beds as they were flexed by movement of the underlying halite (Popielak et al. (1983, p. G-44). An illustration of this model is presented in Figure 16. Fractures formed by this mechanism would ideally tend to be perpendicular to the surface of the anhydrite bed. Although this model is supported by the aforementioned observation that fractures observed in the anhydrites at WIPP-12 dip between 70° and vertical (Popielak et al. 1983, p. G-1), vertical fractures created by any mechanism are more likely than horizontal fractures to remain open when the primary principal stress is vertical.

In more highly disturbed areas where anhydrite deformation is significant, fracturing can occur by extension as well as by compression and shearing. The Castile in the vicinity of WIPP-11 and WIPP-13 north of WIPP-12 is identified in Figure 15 as a disturbed zone of intense deformation and complex structure. This deformation is also evident in Figure 9. This area is described by Barrows et al. (1983, p.19):

> “The largest feature of interest is the disturbed zone (DZ) in the northern part of the site. In the DZ, the seismic sections indicate a blocky, discontinuous structure in the Castile Formation with abrupt offsets or changes in dip between units (faults?). … The seismic data in this unmapped area are valid, but the geologic structures are too complex to map with these data.”

ERDA-6 is in an area northeast of the WIPP site that has undergone severe deformation and the fractured reservoir encountered there is quite different from the reservoir at WIPP-12. These differences are more fully described below.

Borns et al. (1983, Section 4) considered five hypotheses on the origin of the observed anhydrite deformation, and concluded that gravity foundering and gravity sliding were the most likely explanations.

Gravity foundering or incipient doming would be the result of vertical stresses imposed by overlying strata on locally weaker areas of the underlying halites, causing the halites to flow laterally to locations where the halite accumulates and the bed thickens. Borns et al. (1983, Section 4.1) suggest that areal variations in intergranular brine may have locally changed halite strength and led to deformation in those areas. Areas with higher intergranular brine content and therefore higher porosity would have been weaker and would also have exhibited salt creep at lower stresses. Lateral creep would continue until halite dewatering resulting from the imposed strain coupled with a strong hydraulic gradient toward newly-created, lower pressure fractures in overlying, disturbed anhydrite beds increased resistance to halite creep and the movement stopped. Gravity foundering is supported by Borns' (1983, Section 3.1) observation that petrofabrics in the deformed Castile halites are consistent with pressure solution and intergranular fluids but is weakened by the lack of a clear mechanism for significant local variations in water content and the lack of a supporting mechanical analysis demonstrating the feasibility of the

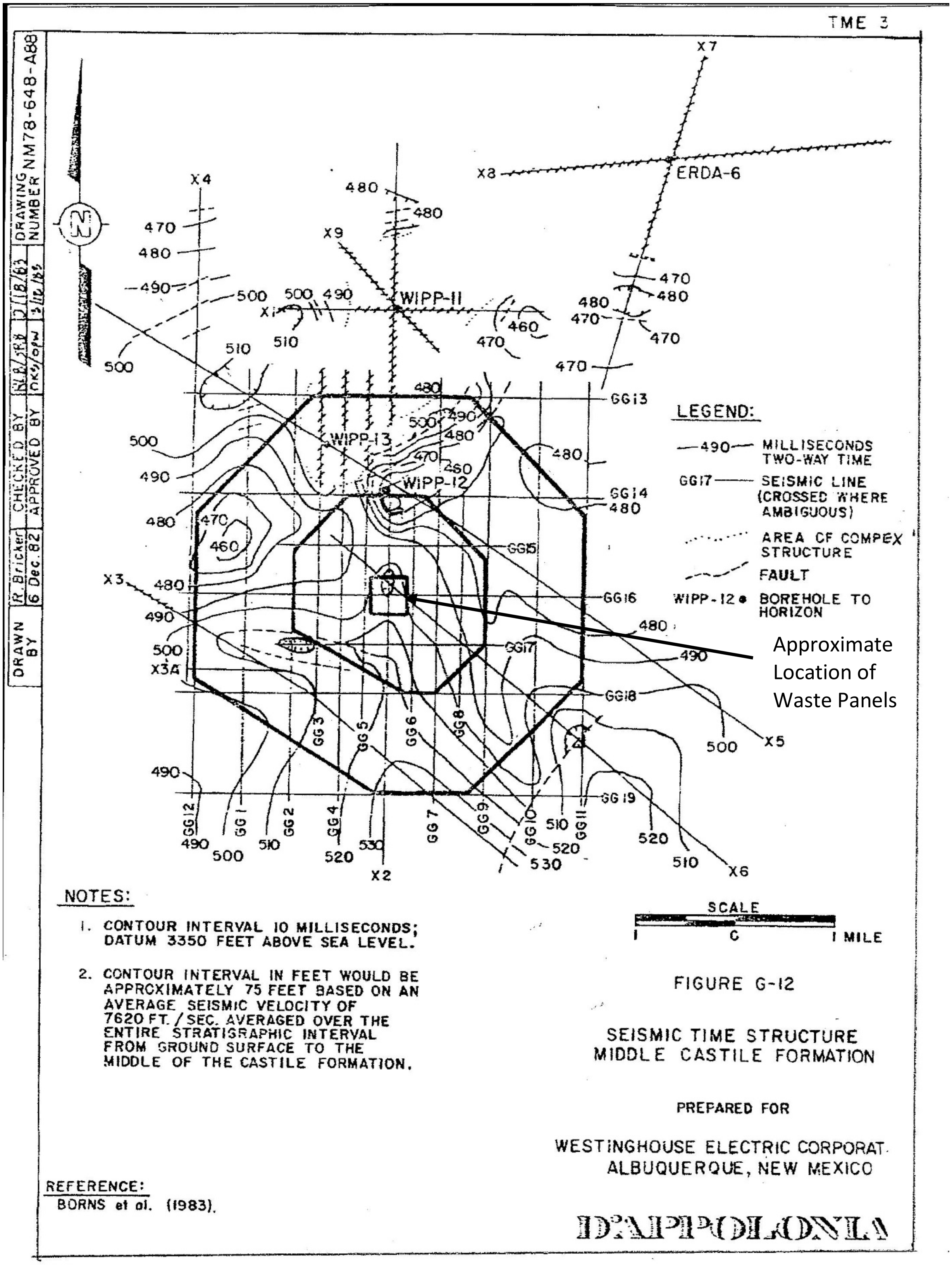

Figure 15. Seismic time structure for the middle Castile Formation (modified from Popielak et al. 1983, Figure G-12).

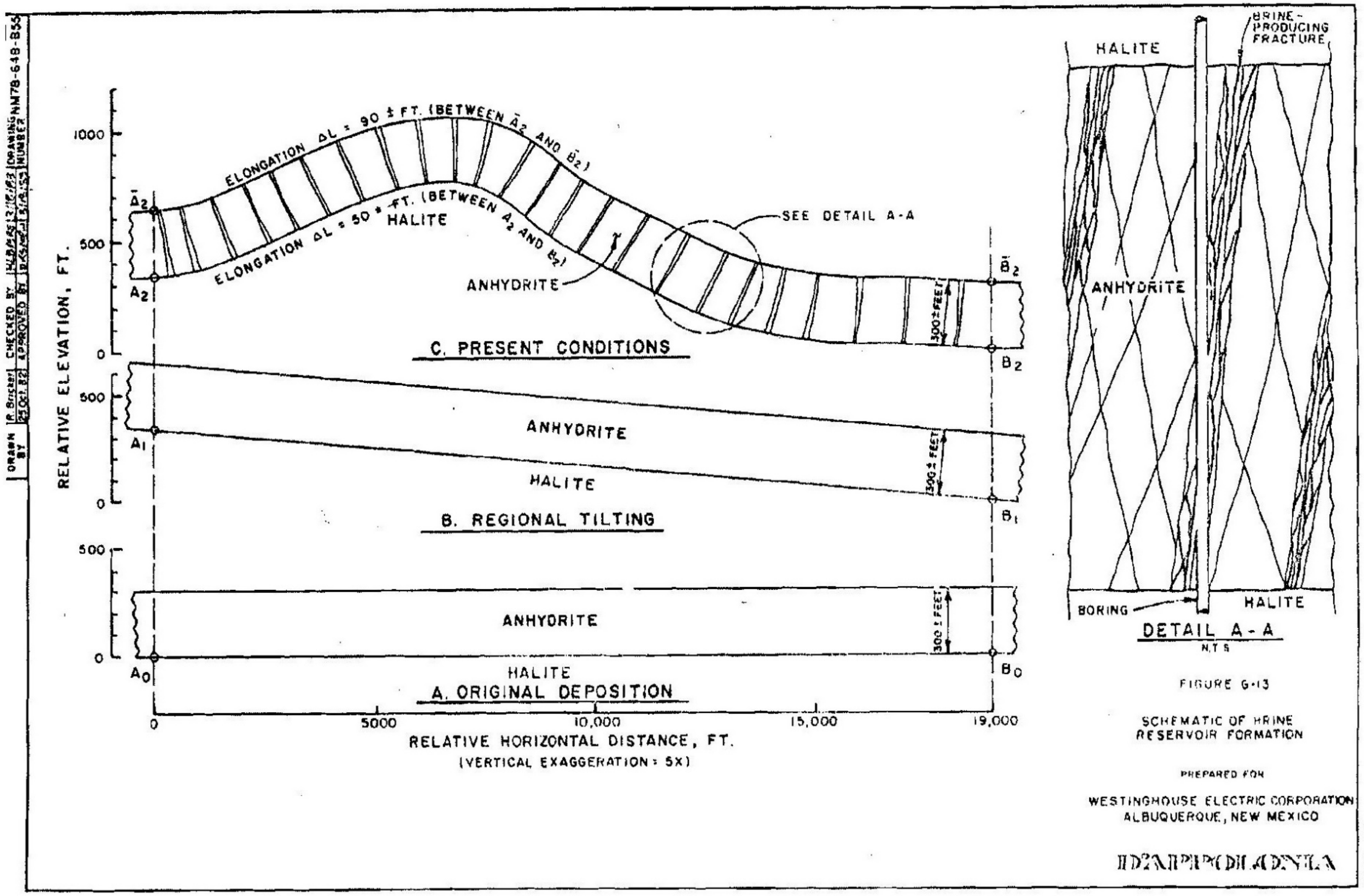

Figure 16. Historic conceptualization of simple direct tensile fracturing of elongated anhydrite bed in the Castile Formation (from Popielak et al. 1983, Figure G-13).

gravity foundering process under the available stresses. Absent such an analysis, foundering at the relatively shallow depths of the Delaware Basin is questionable.

The gravity sliding model involves the downslope sliding of halite over a sloping anhydrite bed. The sliding is likely facilitated by pore pressure increases due to the water generated during the transformation of gypsum to anhydrite. Under this model, the halite moves laterally from a detachment area at the head of the slide where the halite would be thinned to a toe area at the foot of the slide where the slide stops and the halite would be thickened. Thickening in the toe area would uplift and flex the overlying anhydrites causing them to fracture. At locations where the uplift is relatively uniform, anhydrite flexure could result in simple extension and tensile fracturing of the anhydrite beds similar to that illustrated in Figure 16 (Popielak et al., 1983, Section 4.3.3); however, as described below, the fracture systems encountered at both WIPP-12 and ERDA-6 are considerably more complex and do not support the simplification illustrated in this figure.

At locations where the uplift is complex and chaotic, fracturing could also occur under compressive stresses or by shearing, as previously discussed. Borns et al. (1983, p. 89) suggest that gravity sliding could be initiated by basin tilting or by density contrasts within interfingering anhydrite-halite sequences at the reef margins. As noted above, gravity sliding could also be initiated by shear strength reductions on the underlying anhydrite-halite contact due to pore pressure increases during gypsum dehydration. Gypsum dehydration is treated by Borns et al. (1983, Section 4.4) as a separate mechanism resulting in ‘hydraulic weakening’ of the halite. Although Borns et al. (1983, p. 90) did not favor gypsum dehydration and concluded that “…the observable evidence indicates that anhydrite [rather than gypsum] is primary,” gypsum dehydration appears to provide the best explanation for the large volumes of brine found in the Castile reservoirs.

5.4.2 Models for Brine Reservoir Behavior

Detailed hydrologic analyses of the Castile brine reservoirs encountered in boreholes ERDA-6 and WIPP-12 conducted by Popielak et al. (1983) provide insights into the structure of the reservoirs and the nature of the release process. Regardless of the mechanism for fracture development, Popielak et al. (1983, p. G-2) hypothesize that interstitial fluids that were probably already present in the Castile migrated into the developing fractures in the anhydrites due to differential pressure. As discussed in the following paragraphs, Popielak et al. identify significant differences in the fracture networks and hydrological behavior of the brine reservoirs at ERDA-6 and WIPP-12 that support different models for fracture network development in these two reservoirs.

ERDA-6 Fracture Network Model

Popielak et al. envision that Castile brine reservoirs reside in a system of larger fractures within a region of smaller microfractures within the anhydrite beds. Popielak et al.’s (1983, Part III) test results in ERDA-6 supported a conceptualization of a dual, bimodal system of large fractures within a matrix of microfractures, with essentially no intermediate size fractures present. Although this model is less applicable to the WIPP-12 reservoir, Popielak et al. present it as generally applicable it to all Castile brine reservoirs. A summary of this model is reproduced below (Popielak et al. 1983, p. H-59).

> "A limited system of large fractures, designated the local large-fracture group, was intercepted in each borehole. These large fractures serve as high permeability brine collection systems, but comprise only a small portion of the reservoirs' brine storage capacity. The local large-fracture groups can be viewed as extensions of the wells, and are responsible for the initially vigorous production rates and pressure-buildup rates observed at the beginning of each test. "
>
> "The large fractures are intersected by numerous microfractures. The microfractures have relatively low permeabilities, but provide access to the majority of the brine stored in the reservoirs. The majority of the brine in storage may be contained within the microfractures alone, or in other large fracture groups which are only connected to the wellbores by microfractures. After the initially high rates of production and pressure buildup, the major fractures serve mainly as conduits for the brine produced from the microfractures. Production from the microfractures is observed as a prolonged slow production or slow buildup rate."
>
> "The components described above comprise the brine reservoirs as defined for volume determination. These reservoirs are surrounded by intact anhydrite with extremely low permeability which contributes little, if any, brine to the reservoirs."

In describing the fractures encountered at ERDA-6, Popielak et al. (1983, p. G-35) refer to the previous investigation of ERDA-6 by the USGS (Jones 1981) and state:

> "According to Jones, narrow, open fractures lined with anhydrite crystals are present at 2702 feet. The zone between 2709 and 2718 feet is considered to be the main fracture location, with vuggy, porous, recrystallized anhydrite breccia cut by fractures dipping between 45 and 60 degrees (no core was recovered between 2711 and 2718 feet). "
>
> "For the present study, only a small portion of the original core through the reservoir zone was available for study to determine, if possible, any further information on fracture characteristics. … An irregular fracture plane cuts the sample at an angle between 75 and 85 degrees. Adjacent to the fracture planes is porous, vuggy, recrystallized anhydrite containing halite in many of the vugs. Some halite crystals aligned parallel to the fracture are cubic, clear, transparent, up to one inch in length."
>
> "The fracture described above is considerably different from the fractures described at WIPP-12. The ERDA-6 fractures appear to be related to sites of extensive recrystallization, even brecciation, of the host anhydrite. The WIPP-12 fracture known to have produced brine is a relatively clean, smooth fracture with no secondary filling. These differences are apparently related to the degree of structural deformation at each site, ERDA-6 being located on an apparently larger, more intensely deformed feature, four miles closer to the buried Capitan reef margin than WIPP-12."

Popielak et al. (1983, p. G-36) further state:

> "The fractures at ERDA-6 appear to be different than those at WIPP-12 in that there appears to be a concentration of fractures (or some type of voids) over a ten-foot interval (2709 to 2719 feet), whereas the fractures at WIPP-12 are more or less interspersed throughout the reservoir. Not all core was recovered from the fracture zone interval at ERDA-6, however, and therefore the nature of this zone is not well known."

The bimodal fracture model of Popielak et al. (1983, p. H-59) described above is supported by the results of a drill stem pressure buildup test of the Castile brine reservoir at ERDA-6. Those results are presented in Figure 17 and illustrate the components of Popielak et al.'s bimodal model: a relatively rapid pressure buildup due to initial radial flow from large fractures (Popielak et al.'s Region A), a reduction in the pressure buildup rate due to boundary effects of the large fracture network (Popielak et al.'s Region B), and a subsequent, longer term pressure buildup as brine enters the larger fractures from an extensive network of smaller fractures which Popielak et al. call microfractures (Popielak et al.'s Region C). The relatively abrupt changes in slope of the pressure buildup curve from region to region

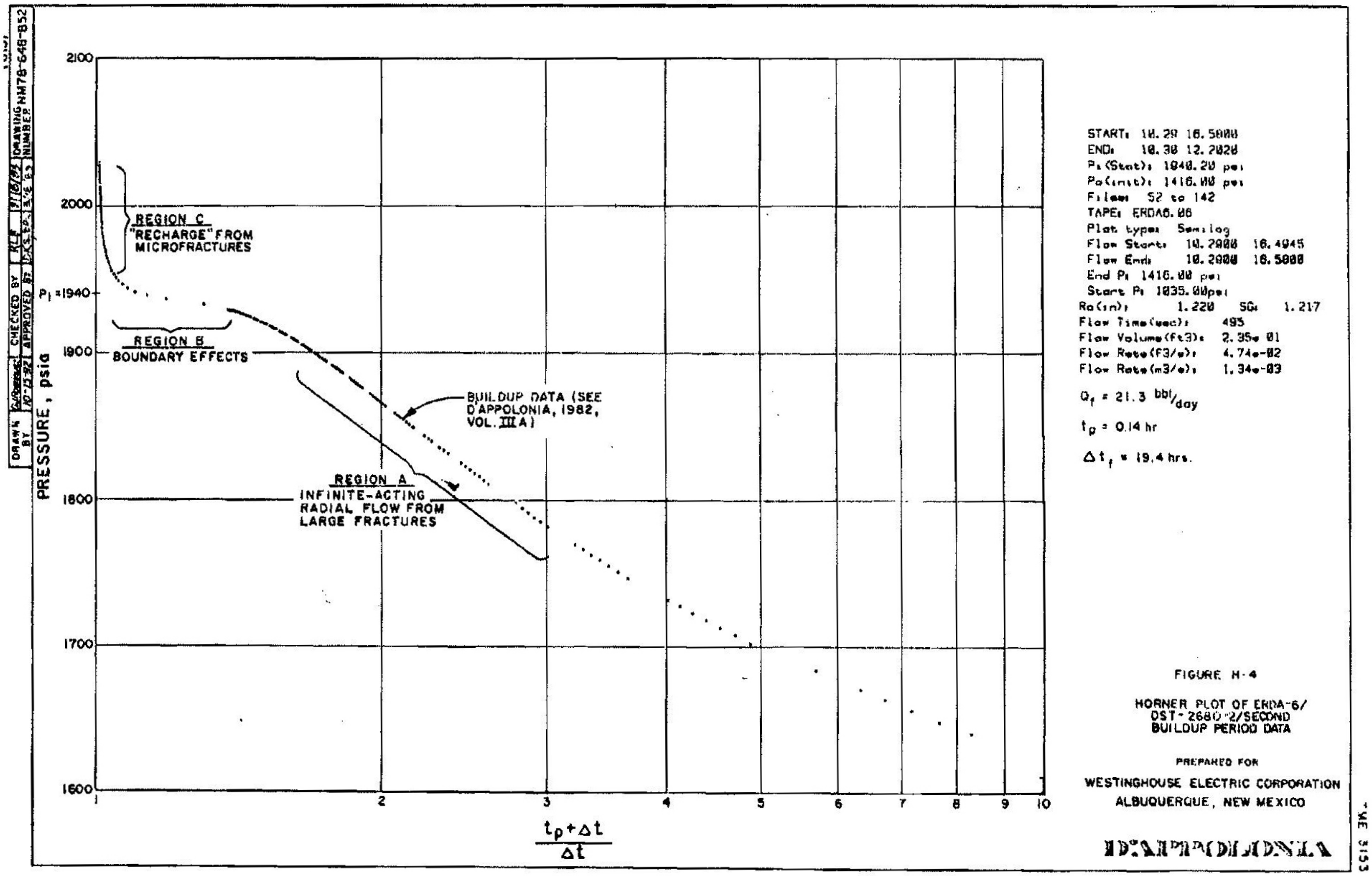

Figure 17. Results of drill stem pressure buildup test in ERDA-6 brine reservoir (from Popielak et al. 1983, Figure H-4).

support the essentially bimodal fracture system model proposed by Popielak et al., with large fractures, small microfractures, and an inconsequential network of intermediate size fractures.

When conducting pressure buildup tests in porous media, the flow or drawdown period should typically be of a similar duration to that of the pressure buildup or recovery period. As shown in Figure 17, in Popielak et al.'s ERDA-6 test the flow period was only 495 seconds or about 8 minutes compared with a pressure buildup period of 19.4 hours, yet the pressure buildup curve for that test shows boundary effects and long-term, low-flow recharge with textbook clarity. Popielak et al's interpretation of the test results is expressed in the foregoing paragraph. The fracture system at ERDA-6 clearly does not behave as a typical porous medium. Instead, Popielak et al. conclude that it behaves as a system of large, transmissive fractures of limited volume that, once partially drained and depressurized, is slowly replenished and repressurized by a large network of low permeability microfractures. In the case of the ERDA-6 reservoir, it took more than 19 hours to restore the pressure drop caused by only 8 minutes of flow from the highly transmissive but limited volume fractures encountered in the borehole. In view of the foregoing evidence for significant structural deformation and fracture filling that could have sealed the smaller fractures at ERDA-6, the Agency considers Popielak et al.'s interpretation of the ERDA-6 test results to be reasonable.

Although the behavior of the ERDA-6 reservoir is similar to the behavior that might be expected from a simplified fractured reservoir of the type shown in Figure 16, the relatively equally spaced set of large fractures normal to the anhydrite bedding plane with generally intact but microfractured anhydrite on either side shown in Figure 16 is nothing like the ten-foot interval of vuggy, porous, recrystallized anhydrite breccia cut by fractures dipping between 45 and 60 degrees found at ERDA-6. The actual fractured reservoir in ERDA-6 has a considerably more complex and different origin than that illustrated in Figure 16.

In summary, the fractures or voids at ERDA-6 appear to be the result of extensive deformation. They appear to have been subjected to intense shearing that has resulted in brecciation, extensive recrystallization, and the formation of secondary fracture fillings. The brecciation, recrystallization, and fillings could have essentially closed smaller aperture fractures that may have been present, making them hydrologically inconsequential. This type of fracture system led to the ERDA-6 test results shown in Figure 17 and the bimodal fracture system model described above, and is quite different from the simple tensile extension model illustrated in Figure 16 and neither is like the fracture system found at WIPP-12.

WIPP-12 Fracture Network Model

The more widely disbursed network of relatively clean, smooth fractures with no secondary filling and a range of orientations and apertures found at WIPP-12 suggest a model of simpler individual fractures but a denser and more diverse fracture network than at ERDA-6. This alternative model is supported by the descriptions of the fractures encountered in WIPP-12 and by the results of hydrologic tests in that borehole.

Ten fractures were identified in the WIPP-12 core and televiewer logs, of which seven were in Anhydrite III (the uppermost anhydrite), two were in an anhydrite interbed in Halite II, and one fracture was in Anhydrite II (Popielak et al. 1983, p. G-26). These were identified by Popielak et al. as fractures A through K (there was no fracture I). The fracture system at WIPP-12 was quite variable:

- The fractures are generally planar and fairly smooth. Wall strength, although not measured, appeared to be unaltered. An exception was the major brine-producing fracture (fracture D) with severely broken and crushed rock in the middle six inches of the fracture interval (Popielak et al. 1983, p. G-27).
- Core fragments across open fractures could be mated together, indicating tensile fractures with little displacement (Popielak et al. 1983, p. G-27).
- Not all fractures were large, although it was the largest aperture fracture, fracture D, that produced the WIPP-12 brine release observed during drilling. Fracture apertures as estimated from cores ranged from zero to less than 0.2 inches (0.0 to less than 5.1 mm; Popielak et al. 1983, Table G.1).
- Not all fractures were transmissive. Fractures H and J were closed with visible halite filling; fracture B was partially filled with halite; fracture G had a gapped appearance; and fractures A, C, D, E, F, and K had no filling (Popielak et al. 1983, p. G-26).
- Not all fractures belonged to the same set, as illustrated in Figure 18. Three of the fractures in each illustration in Figure 18 were from Anhydrite III and ranged in orientation from near north-south to near east-west. Figure 18 illustrates that the fractures in Anhydrite III at WIPP-12 do not belong to a single set; they are diversely oriented and capable of intersecting and creating an interconnected network (Popielak et al. 1983, p. H-16). Fracture D, which produced the WIPP-12 brine release, was in Anhydrite III.
- Evidence of seepage, such as obvious dissolution, dissolution residue, clays, or iron staining, was not readily apparent along any of the fractures, even though fracture D released observable volumes of brine (Popielak et al. 1983, p. G-28).
- Fractures E, F, and G may also have contained brine because of their proximity to the main fracture D, but again no direct evidence of fluid was indicated by their appearance (Popielak et al. 1983, p. G-28).

The attributes of open fractures with variations in aperture, variations in transmissivity, and variations in orientation indicate that the fractures at WIPP-12 would be expected to form a transmissive network that is not bimodal but consists of fractures with a range of sizes and orientations.

A WIPP-12 pressure buildup test from Popielak et al. (1983, Figure H-5) is shown in Figure 19. As compared with the test in ERDA-6 (Figure 17), the pressure buildup in the large fractures at WIPP-12 is less linear and the changes in slope due to boundary effects and long-term recharge are smaller. These effects are consistent with the variability in the fracture system and indicate the presence of a more gradational network of fracture sizes at WIPP-12.

<u>Reservoir Behavior Model Conclusions</u>

The Agency concludes that the foregoing data support two related models of reservoir behavior in the Castile anhydrites. One is the bimodal model proposed by Popielak et al. (1983, p. H-59) and evident in the fracture data and test results at ERDA-6. Fracture networks of this type would most likely be found in highly disturbed areas. The other is the graded network model evident in the fracture data and test results at WIPP-12 and would most likely be found is less disturbed areas. In both models it is the high permeability, continuous large aperture fractures that supply the brine releases noticed and logged by drillers but those fractures are relatively quickly depleted. Releases from the smaller, lower permeability fractures and microfractures that may not be noticed or logged by drillers support the slow, long-term releases that are found in the drill stem test results. This reservoir behavior is consistent with many fractured reservoirs, in that a few rare but high aperture, high permeability fractures account for most of the reservoir's initial yield while the subsidiary networks of smaller fractures ranging in size down to microfractures supply most of the reservoir's storage.

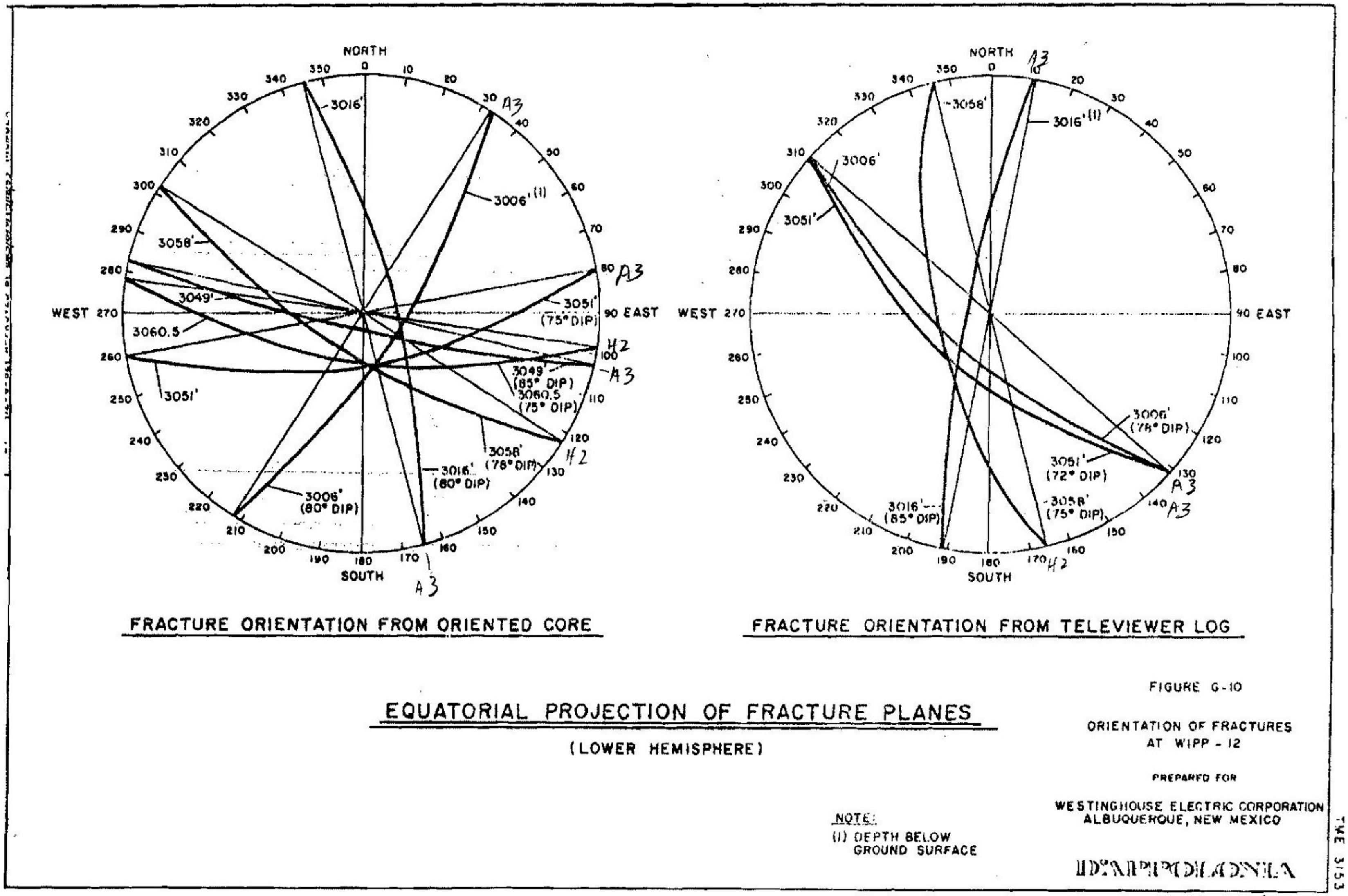

Figure 18. Fracture orientations in WIPP-12 (from Popielak et al. 1983, Figure G-10).

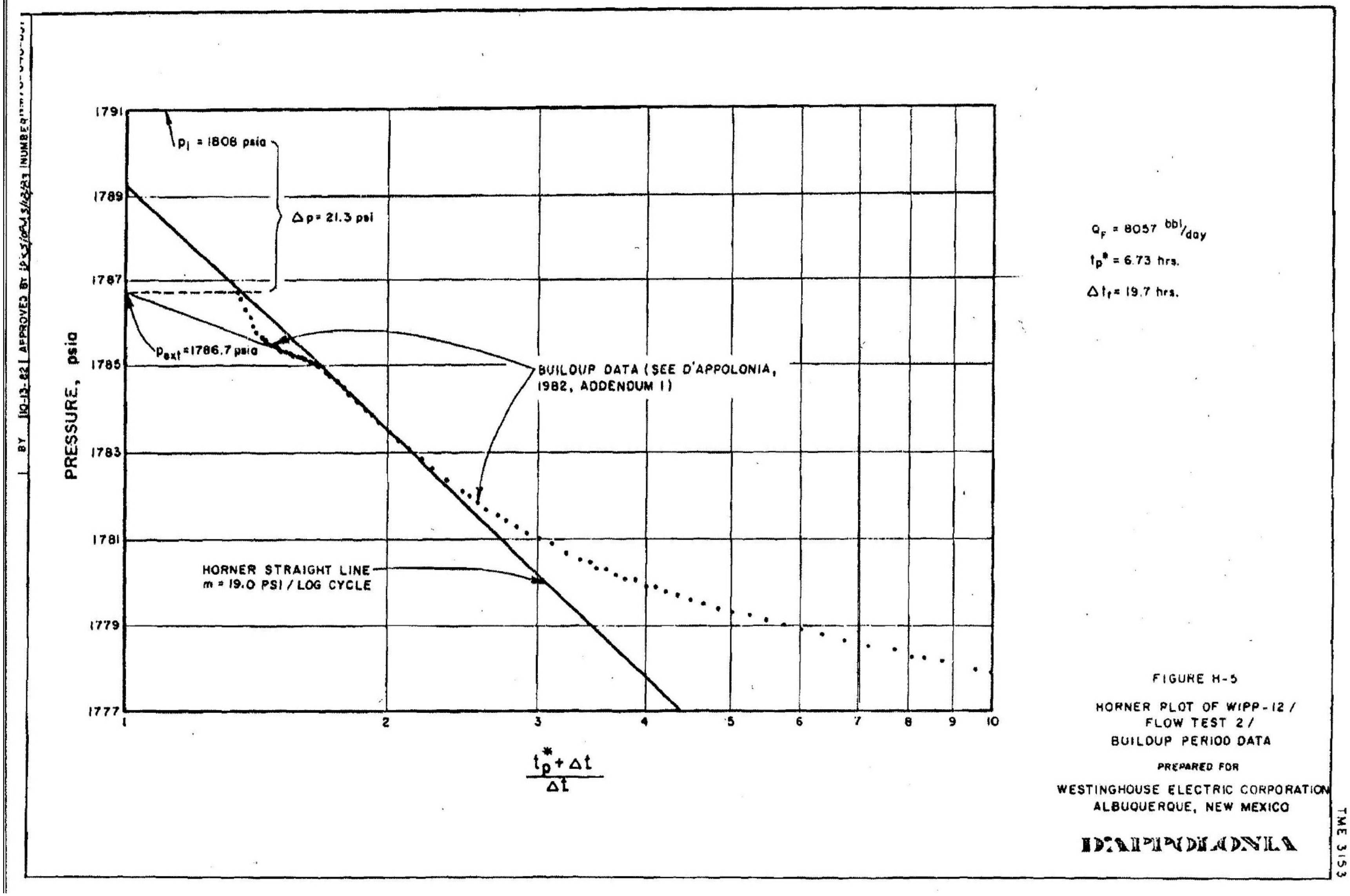

Figure 19. Results of drill stem pressure buildup test in WIPP-12 brine reservoir (from Popielak et al. 1983, Figure H-5).

5.5 Presence of Castile Brine Beneath the WIPP Waste Panels

5.5.1 Uncertainty in Geologic Conditions in the Castile beneath the WIPP Site

Most brine encounters identified during drilling have been in Castile anhydrite beds in areas where the Castile is deformed. Due to the aforementioned lack of drilling data, the degree of deformation in the Castile beneath the WIPP waste panels is uncertain. Powers et al. (1996, p. 1) state that the Castile is deformed at WIPP-12, which is located one mile north and yielded the nearest brine encounter to the WIPP waste panels. However, Powers et al. (1996, p. 3) also state that "…structure data for the WIPP site are meager for the Castile, though it appears that the area of the waste panel is not significantly deformed." However, Powers et al. (1996, p. 16) also warn that "…structure and isopachs can vary over short distances…" At a distance of only one mile north of the WIPP waste panels, the structure and associated Castile brine reservoir at WIPP-12 may also affect the Castile beneath the WIPP site.

A contour map of the top of the Castile prepared by Powers et al. (1996, Figure 5.2-3) clearly shows areas of significant Castile deformation in the vicinity of the WIPP site and is included in this report as Figure 14. The Agency has added the WIPP site boundary and the approximate surface projection of the WIPP waste panels to this figure to provide perspective. Areas of significant deformation to the northeast of the WIPP site are clearly evident on the figure but areas of possibly more localized deformation are also shown directly north of the WIPP waste panels, to the northwest of the panels, to the southwest of the panels, and also to the south. The relative lack of structure identified within the WIPP site boundary could be directly related to the relative scarcity of deep drilling data within that boundary. Because of this scarcity, the aforementioned observation of Powers et al. (1996) that structure in the Castile can vary over short distances, and the widespread occurrence of apparently localized structural deformation around the WIPP site, it is not at all clear that the presence or lack of deformation at the WIPP site can be concluded with any certainty.

5.5.2 Site-Specific Information from WIPP-12

In considering the possibility that the WIPP-12 reservoir may affect the WIPP site, the Agency notes the following observation from Popielak et al. (1983, p. H-60):

> "The total brine storage in the WlPP-12 reservoir was estimated to be 1.7 x 10^7 barrels, with approximately one million barrels stored in large fractures. The ERDA-6 reservoir is significantly smaller. It is estimated to hold about 630,000 barrels, 30,000 of which are stored in large fractures."

A plot showing Popielak et al.'s WIPP-12 volume estimate and its associated uncertainty as a function of average reservoir effective porosity is shown in Figure 20. Their representative estimated volume of the WIPP-12 reservoir is huge, amounting to 2.7 million cubic meters (713 million gallons or 2,200 acre-feet), of which about 94% or 670 million gallons are estimated to be stored in the smaller fractures that may not be noticed by a driller but are potentially important to WIPP performance (Popielak et al. 1983, p. H-60). By comparison, the initial volume of an intruded waste panel, not including the DRZ or pillars between rooms and considering a filled waste panel initial porosity of 0.848 (DOE 2014, Appendix PA, Table PA-3), is about 40,000 cubic meters.

The relative areal extent of a brine reservoir can be expressed by the radius of an equivalent cylinder about the intruding well. Popielak et al. (1983, p. H-55) estimated the average effective porosity of the fractured WIPP-12 reservoir from laboratory and geophysical data to be 0.5%. Based on their estimated reservoir thickness of 18.6 m corresponding to the thickness of the hydrologically tested fractured zone,

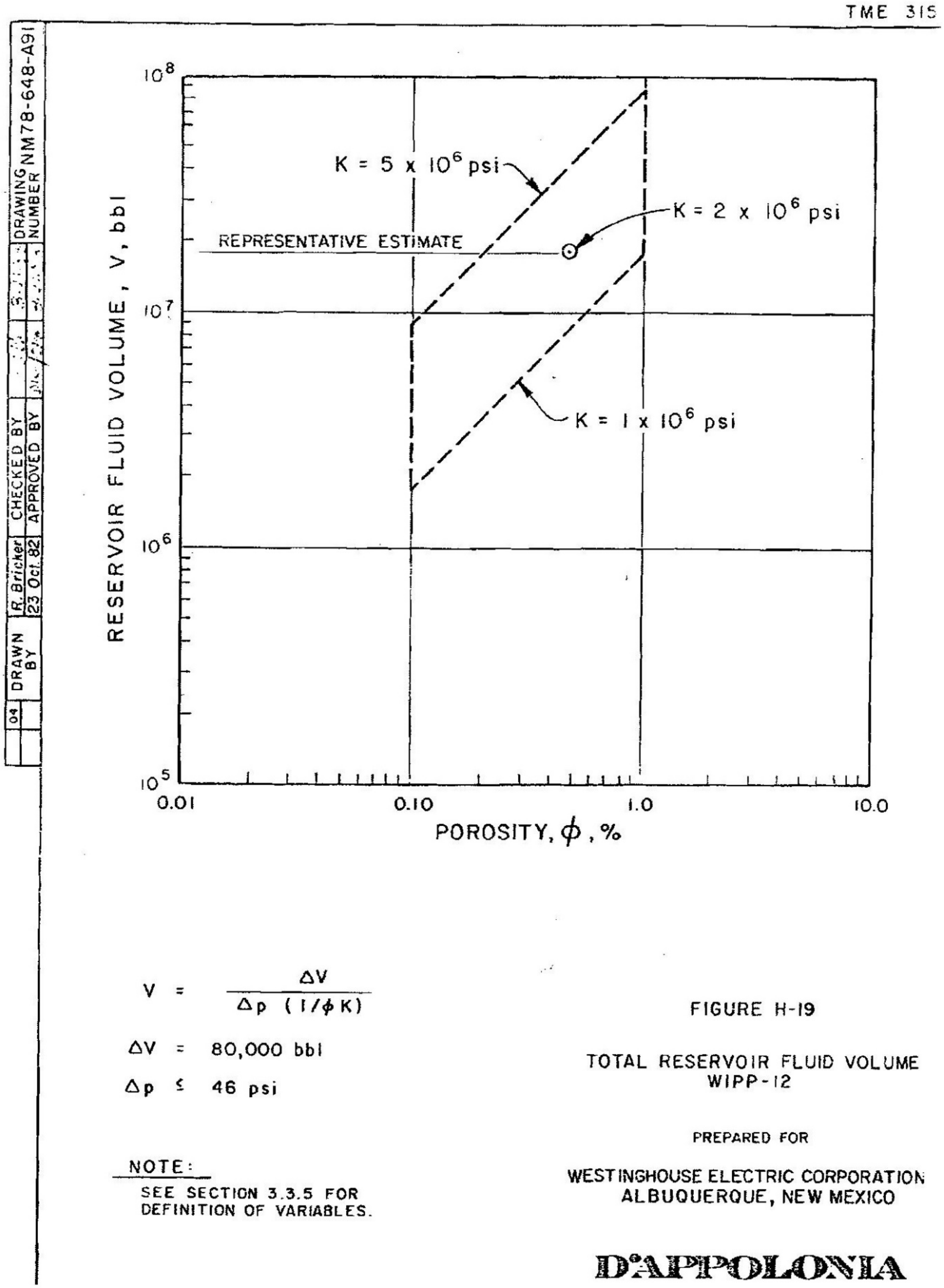

Figure 20. Estimated total fluid volume in WIPP-12 reservoir (from Popielak et al. 1983, Figure H-19)

the equivalent radius of the WIPP-12 reservoir is over 3,000 m or nearly 2 miles. By comparison, the equivalent radius of the ERDA-6 reservoir is about 430 m and the equivalent radii assumed by Kirchner et al. (2012, p. 10) for brine reservoirs northeast of the WIPP site was 500 m. While Castile brine reservoirs are highly unlikely to be circular and there is considerable uncertainty in all such estimates of reservoir size, the sheer magnitude of the estimated rock volume encompassing the brine reservoir penetrated by WIPP-12 suggests that at least part of that reservoir could easily underlie the WIPP waste panels.

5.5.3 Site-Specific Information from Seismic Geophysical Data

A seismic time structure map of the middle Castile Formation taken from Popielak et al. (1983, Figure G-12) is presented in this report as Figure 15. The contours indicate return (2-way) times for the reflected seismic waves. Changes in return times can be interpreted either as differences in the depth of a target horizon (with longer return times indicating deeper structures), or as differences in the average density of the stratigraphic interval from ground surface to target horizon (with longer return times indicating a lower average density), or as a combination of depth and density contrasts. Precise quantitative evaluation of this seismic data is not possible due to a lack of detailed information on seismic velocities in geologic strata beneath the WIPP site down to and including the middle Castile Formation.

The seismic reflection data in Figure 15 was interpreted by Borns et al. (1983, Section 3.2.2), Popielak et al. (1983, p. G-10), and Barrows et al. (1983, Section 1.2.2) as indicating structural deformation of the target horizon in the middle Castile and specifically at WIPP-12. As noted on the figure, for an average seismic velocity of 7620 ft/sec, the time contour (seismic isochron) intervals of 10 milliseconds represent depth intervals of approximately 75 feet. At 3 to 4 contour intervals high, the seismic data indicate that the antiform at WIPP-12 has abruptly risen between 225 and 300 feet above its base. Northwest of WIPP-12, in the vicinity of WIPP-11 and WIPP-13, is an unmapped area identified on the figure as having complex structure. As previously noted, Barrows et al. (1983, p. 19) state that structural deformation in this area is intense and too complex to map with the seismic data. It is interesting that WIPP-11 was drilled in this area of intense structural deformation through the Castile and into the underlying Bell Canyon but no brine encounters in the Castile were logged by the driller. Although this area could provide much of the fracture and pore volume for the brine reservoir penetrated at WIPP-12, Popielak et al. (1983, p. G-39) state "Nevertheless, the seismic isochrons appear to indicate that the structure at WIPP-12 is separate and distinct from the structure at WIPP-11."

Looking due south of WIPP-12 in Figure 15 toward the center of the WIPP site (indicated by the solid black octagons as envisioned in 1983), the seismic isochrons indicate a broad synclinal structure or synform with an axis extending north-south. The axis of this structure is up to 3 contour intervals or about 225 feet below the general structural surface with the deepest part lying directly beneath the center of the WIPP site. A structure of this type responding to thinning of the halite would be expected in a source area for the WIPP-12 antiform. However, regardless of its possible structural association with the WIPP-12 antiform, a structural interpretation of the seismic data does indicate significant structural deformation beneath the WIPP site, which at its deepest part may be locally as abrupt (potentially dropping over 75 feet in a horizontal distance of about 450 feet) as the rise in the WIPP-12 antiform. A similar structure is evident approximately one mile to the southwest which Barrows et al. (1983, p. 19) identify as a possibly faulted syncline or perhaps a graben. Curiously, Barrows et al. (1983) do not mention the similar structure that underlies the center of the WIPP site. Synclinal deformation of this type would lead to local deformation of the anhydrite beds as significant as that found in the larger anticlinal structures. The associated fracturing of the anhydrite beds would support the possible presence of increased brine content beneath the waste panels.

An alternate interpretation of the seismic data relates it not to physical structure but rather to differences in rock density or rigidity. Less dense, more porous rock would have longer return times and look like deeper structures, while shorter return times for denser, less porous rock would look like shallower structures. Although such an interpretation is unlikely to be entirely correct, because the presence of a structural antiform at WIPP-12 is consistent with the correlation of antiforms with brine reservoirs elsewhere in the Delaware Basin, it is possible that density differences have to some extent affected the seismic results. If such effects are significant, they would indicate less dense, more porous rock beneath the center of the WIPP site than in the vicinity of WIPP-12, which would also be indicative of increased brine content and consistent with the TDEM results.

In summary, the seismic data may be best interpreted as did Barrows et al. (1983, Section 1.2.2), to primarily indicate structural deformation. As such, the data show abrupt synformal structural deformation beneath the center of the WIPP site that would likely lead to flexing and fracturing of the anhydrite beds and to conditions favoring the presence of brine reservoirs in the Castile. Alternatively, the seismic data may be interpreted, at least in part, as indicating more porous rocks beneath the center of the WIPP site, which also favor the presence of elevated brine content in the Castile.

5.5.4 Site-Specific Information from Gravity Geophysical Data

A detailed gravity survey performed at the WIPP site was documented by Barrows et al. (1983) and much of the following information was taken from that source. The gravity method is based on the measurement and interpretation of small variations in the earth's gravity field. These variations (or anomalies) result from lateral variations in the subsurface distribution of mass or rock density. The WIPP gravity survey was originally planned to resolve anomalies originating within the area of complex structure northeast of the WIPP site identified in the seismic data and to help assure that additional structures are not present beneath the site. However, the density structure of the underlying strata was found to differ substantially from that anticipated. Instead of measuring gravity anomalies originating within complex structures of the Castile Formation, the gravity field was found to be dominated by effects of lateral density variations within shallower and relatively flat-lying strata above the Castile, and was not considered to provide valid information relevant to Castile brine reservoirs beneath the WIPP waste panels (Barrows et al. 1983, p. 26). The structures within the Castile were unfortunately found to be an inconsequential part of the interpretation.

5.5.5 Site-Specific Information from TDEM Geophysical Data

The TDEM survey performed at the WIPP site was documented by The Earth Technology Corporation (1987) and much of the following information was taken from that source. The TDEM survey was conducted several years after the seismic and gravity surveys "…to determine the occurrence and depth of brine in the geologic formations above and below the waste panels." (The Earth Technology Corporation 1987, p. 1). TDEM is a geophysical technique performed at the ground surface that identifies stratigraphic horizons in the subsurface from surface-based resistivity measurements. Because horizons containing elevated volumes of brine would have low electrical resistivities compared to the bedded salts of the host rock, they were considered good targets for electrical exploration because there are no other likely causes of electrical resistivities as low as about 1 ohm-m beneath the WIPP site. By comparison, the resistivities of the bedded salts were significantly higher, on the order of 120 ohm-m, and provided good contrasts (The Earth Technology Corporation 1987, p. 5). Electrical conductivity is the reciprocal of electrical resistivity, so a low resistivity is indicative of a high conductivity.

All but two of the 38 TDEM soundings were located in or near a 1.5 x 1 km grid directly over the WIPP waste panels. The two remaining soundings were made near boreholes WIPP-12 and DOE #1 to correlate the survey results with borehole geological and geophysical data. Also, one borehole (ERDA-9) at the northern boundary of the survey grid was used for calibration of strata above the Castile. The TDEM survey results were found to compare well with geologic and geophysical data from the three drill holes (The Earth Technology Corporation 1987, Section 3.0).

A single sounding was made about 580 m northeast of WIPP-12 to corroborate the TDEM soundings with a known depth of brine occurrence. A high electrical conductivity zone indicative of the presence of brine was found at the WIPP-12 sounding location between depths of about 800 to 1,000 m (The Earth Technology Corporation 1987, Figure 3-7). The 200 m thickness of this zone completely encompassed the uppermost anhydrite layer (Anhydrite III – IV) in the Castile, which was encountered at WIPP-12 during drilling in the depth interval of 2725.3 to 3053.9 feet (831 to 931 m) (Popielak et al. 1983, p. G-16). The major WIPP-12 brine release reported during drilling occurred within this anhydrite layer at a depth of 3017 feet (920 m; Popielak et al. 1983, p. G-28). The fact that the TDEM high electrical conductivity zone encompassed the entire thickness of this anhydrite layer suggests that the entire layer has an elevated brine content. The precise TDEM sounding depth to the top of this high electrical conductivity zone was 802 m (The Earth Technology Corporation 1987, p. 9). If the top of this zone does coincide with the top of the anhydrite layer and the top of the layer is at the same depth at the sounding location as at the WIPP-12 borehole, the depth error in the TDEM sounding would be about 831-802 or 29 m. Similarly, the TDEM depth error for the bottom of the high electrical conductivity zone would be about 1,000-931 or 69 m. The Earth Technology Corporation considered these results as corroborating the TDEM sounding depth data and also as validating the interpretation of high electrical conductivity as indicating the enhanced presence of brine.

Borehole DOE #1 was drilled in the southeast part of the WIPP site to the top of Anhydrite I in the Castile. The TDEM sounding near DOE #1 showed no evidence of shallow occurrence of brine, and none was encountered during drilling. However, the sounding did show evidence of deep brine, at a depth of over 1200 m and potentially in the Bell Canyon Formation (The Earth Technology Corporation 1987, Figure 3-9).

The results of the TDEM survey show brine occurrences everywhere beneath the waste panels. Some were at depths corresponding to the Castile Formation while others were at depths corresponding to the Bell Canyon Formation. The report further states "The 36 soundings in the 1.5 by 1 km area over the waste storage panels show a continuous brine layer within the Bell Canyon Formation (1200 m depth)." (The Earth Technology Corporation 1987, p. 1). It is not clear to the Agency how this conclusion was reached because shallower brine occurrences in the Castile would mask deeper underlying occurrences in the Bell Canyon. There was no evidence in the data for brine reservoirs in the Salado or in other formations above the waste storage panels. This interpretation was consistent with geologic and geophysical information from ERDA-9, which penetrated the Castile only to the top of Anhydrite III (The Earth Technology Corporation 1987, p. 1).

The aforementioned uncertainties in the depths of the TDEM high conductivity horizons, in the depth of the Castile – Bell Canyon contact, and in the Castile stratigraphy beneath the WIPP site did not allow the TDEM data to be correlated with specific strata in the Castile beneath the waste panels. However, because brine releases during drilling have occurred from intercalated halite units and halite-anhydrite contacts as well as from the Castile anhydrite beds (Powers et al. 1996, Table 4.2-2), the Agency conservatively accepted that brine releases could occur from any depth within the Castile.

Based on the foregoing site-specific information, the Agency concludes that the potential size of the WIPP-12 reservoir and the results of the TDEM soundings make the presence of horizons with elevated brine content beneath the waste panels likely. In addition, the abrupt synformal structure evident in the seismic data directly beneath the waste panels supports the presence of deformation associated with brine encounters that have occurred during drilling in other parts of the Delaware Basin.

5.6 Drilling Information on Brine Encounters

Drillers' reports of encounters with high volume, high yield brine reservoirs in the Delaware Basin during exploratory drilling for oil and gas have been proposed by DOE as the sole source of information used to estimate the value of PBRINE (Kirchner et al. 2012). Basing the expected value of PBRINE only on drilling data has the drawbacks of ignoring lower-yield brine reservoirs that are important to WIPP performance but would not have been noticed and logged by drillers, ignoring available site-specific data that could be used to improve estimates of brine encounters beneath the WIPP waste panels, and relying on reports of brine encounters that were noticed by drillers only incidental to reporting their drilling activities and were not documented for the purpose of estimating the frequency of brine encounters.

Information on drilling encounters with high volume, high yield sources of brine were obtained by DOE from reviews of driller's logs, survey questionnaires sent to drillers, and interviews with drillers. Such encounters might only have been noticed and/or logged if they were large enough to affect drilling rates or cause mud pits to overflow. Any non-reports of actual encounters would result in underestimating the frequency of high volume, high yield brine flows, would provide no information on lower yield brine flows that were too small to be noticed, and would therefore lead to underestimating the value of PBRINE. In recognizing the potential weaknesses of such sources of information, Powers et al. (1996, p. 5) state:

> "There is no requirement that all brine intercepts be reported. Some of the earliest known reports of brine came before modern drilling practices and resulted in loss of control of the drillhole and substantial surface flows. We cannot know if some drillholes intercepted a brine reservoir that went undetected because substantial pressure was depleted by other drillholes. Some companies declined to respond to Silva's survey. Other intercepts may have been quickly controlled, and no report was made or required. We accept the reports accumulated as a reasonable representation of the actual history of brine intercepts."

The results of Silva's survey, mentioned in the foregoing quotation, are included in an unpublished SNL document (Silva 1996).

DOE's most recent proposal to estimate the value of PBRINE based only on drilling data was documented by Kirchner et al. (2012), who provided updated information on the frequency of reported drilling encounters with brine reservoirs in the Castile. Such information was documented by Kirchner et al. on a regional basis and also on a local basis for a geologically disturbed area to the northeast of the WIPP site.

On a regional basis, Kirchner et al. (2012, p. 2) state:

> "The number of Castile brine encounters within a geologically similar area surrounding the WIPP site is reported periodically. The data as of November 1, 2012 show 34 brine pocket intrusions out of 678 wells drilled (Fig. 1)."

On a regional basis, the updated frequency of brine encounters reported by drillers as documented by Kirchner et al. (2012, p. 2) is 34/678 = 0.0501. Kirchner et al.'s Fig. 1 cited in the above quotation is reproduced in this report as Figure 21. This figure shows brine reservoir encounters within an area of some 400 square miles in and around the WIPP site. The Agency questions Kirchner et al.'s assertion

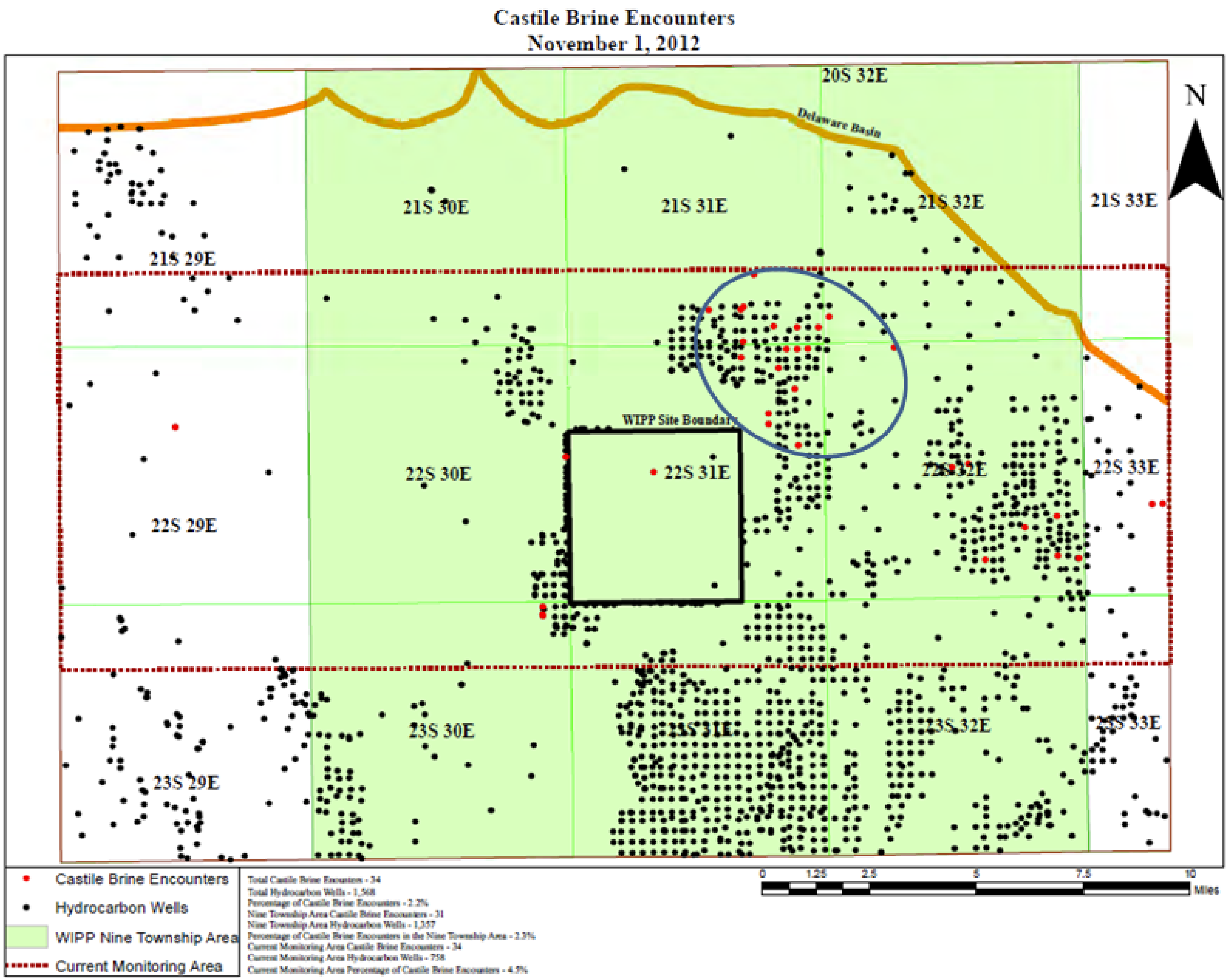

Figure 21. Castile brine encounters during drilling in the region around the WIPP site (from Kirchner et al. 2012, Figure 1).

that this large area is 'geologically similar' to and therefore representative of the WIPP site because of the uncertainty concerning geological conditions in the Castile at the WIPP site (see Section 5.5.1). The Agency does consider that geological conditions in the 400 square mile area are likely to include the range of conditions that could underlie the WIPP waste panels. Most importantly, this drilling information demonstrates that geological conditions in the northern Delaware Basin are quite variable as evidenced in the geologic section in Figure 9 and by the localized areas of deformation in Figure 14.

On a local basis, Kirchner et al. (2012, p.5) identify a geologically disturbed area northeast of the WIPP site that "…has a higher frequency of brine pocket hits than any other area adjacent to the WIPP site." This area is contained within the blue ellipse in Figure 21 and includes ERDA-6. It has a reported frequency of 19 brine reservoir intrusions out of 150 wells drilled, or a frequency of 19/150 = 0.127. Kirchner et al. (2102, p. 5) attribute this higher frequency to a degree of deformation greater than that exhibited at the WIPP site and also greater than that generally found in the northern Delaware Basin.

The Agency concludes that the drilling data rely on incomplete records of brine encounters because some brine encounters may not be documented by drillers. Sole reliance on drilling data would therefore result in values of PBRINE that are too low. Although drilling data alone do not provide an acceptable basis for estimating PBRINE, they can be used to develop a lower bound of the range of uncertainty for PBRINE. The range of a distribution should be inclusive of all likely values of the distributed parameter and by definition the lower bound of the distribution should be demonstrated to be a possible value that is slightly lower than or equal to the lowest potential value. The tendency of drilling data to underestimate the frequency of brine encounters makes it an appropriate basis for establishing a lower bound for the distribution of PBRINE.

5.7 Encountering Brine within a High Electrical Conductivity Zone

Section 4.0 provided detailed supporting information for the calculation of the probability *pHCZ* of hitting a high electrical conductivity zone within the Castile beneath the waste panels. The foregoing discussions in Section 5.0 provide the conceptual and numerical bases for determining the bounding values for the conditional probability *p[BRINE|HCZ]* of encountering brine yields potentially important to repository performance within a high electrical conductivity zone. As stated in Section 3.0, this conditional probability is assumed to be uniformly distributed within a range of 0.05 to 1.0. In developing this range it was also assumed that all Castile brine encounters occur within high conductivity zones. The limits of this range were selected as bounding values and the range is intentionally broad. It encompasses what is known and not known about the presence of Castile brine beneath the WIPP waste panels, it encompasses the alternative models of the brine reservoirs and their fracture networks, and it considers the types of brine encounters that could be potentially important to WIPP performance.

The low end of the range (0.05) is based on the updated regional frequency of brine encounters reported by drillers as documented by Kirchner et al. (2012, p. 2). This value was selected based on the consideration that a brine reservoir beneath the waste panels could be of the type encountered at ERDA-6: it could be in an area that is locally highly disturbed and have a fracture network consisting primarily of large, near vertical fractures that would be rarely encountered during exploratory drilling but when encountered would yield flows of sufficient magnitude to be reported by drillers. Such a fracture network would be associated with the type of severe deformation found at ERDA-6. The abrupt synformal deformation directly beneath the repository location evident in the seismic data described in Section 5.5.3 indicates that fracturing similar to the type encountered at ERDA-6 could be locally present beneath the WIPP site. Given the uncertainties in geological conditions in the Castile beneath the repository, the Agency concludes that the low end of the uncertainty range can be best bounded by assuming that deformation beneath the repository could be locally intense and that a fracture network of the type found at ERDA-6 could be present. This assumption can be used to determine a lower bound for the conditional probability distribution *p[BRINE|HCZ]* because drilling data would reflect the low frequency of encounter of an ERDA-6 type reservoir and are therefore relevant to this type of fracture network. Also, because drilling data tend to underestimate the value of PBRINE, they can be used to support the lower bound of the *p[BRINE|HCZ]* distribution because lower values than those provided by drilling data are unlikely.

The regional frequency of encounter discussed in Section 5.6 was selected to represent the lower bound. The alternative of basing this bound on the frequency of encounter in the geologically disturbed area northeast of the WIPP site, also discussed in Section 5.6, was rejected because geological conditions beneath the WIPP site are uncertain and that frequency may be too high and not suitable for determining a lower bound. The alternative of selecting a zero value for the lower bound was also rejected because, although bounding, it is physically incorrect because Castile brine has, in fact, been encountered during drilling within the northern Delaware Basin. A bound lower than the regional average of 0.05 was not adopted because, as discussed in Section 5.6, the drilling data are already biased toward underestimating the frequency of encounter due to incomplete information.

The high end of the range (1.0) considers that a brine reservoir beneath the waste panels could be of the type encountered at WIPP-12: it could have a dense, well dispersed, transmissive fracture network consisting of rare large fractures, a larger number of smaller fractures, and many microfractures. As discussed in Section 5.3, brine yields need not be large to be of potential importance to WIPP performance and such yields could come from smaller as well as larger fractures and be supported long-term by a large array of microfractures. The density of the network could be large enough to support a high probability that a borehole penetrating a high electrical conductivity zone would intersect at least one fracture that would yield sufficient brine to be important to WIPP performance, and as a bounding limit that probability would be the physically possible value of 1.0.

5.8 Alternative Models for Estimating PBRINE

Alternative models for estimating PBRINE have been proposed and several have been mentioned in this report. These models are summarized below along with brief evaluations of their adequacy.

Powers et al. (1996) Geostatistical Model. This was the first model to be proposed by DOE for WIPP PA. It was based on a geostatistical analysis of Castile brine reservoir encounters in the northern Delaware Basin as documented in drillers' logs. It was not accepted by EPA because of the scarcity of data near the WIPP site, its sole reliance on drillers' logs, its proposed use in WIPP PA did not include uncertainty, and it did not consider site-specific TDEM data that suggested a much higher probability of encountering brine. This model is also discussed in Section 2.0.

EPA (1998a) Uniform Model. This model was mandated by EPA for use in WIPP PA as a replacement for the Powers et al. (1996) model. It consisted of a uniform distribution with a lower bound based on drilling data and an upper bound based on site-specific TDEM data. This model is more fully described in Section 2.0 and is intended to be superseded by the more refined model described in this report. EPA's uniform model addressed both the TDEM data and uncertainty, and likely conservatively overestimated the value of PBRINE. This model did not specifically consider hydrogeological information from WIPP-12 and ERDA-6, and did not specifically consider the conditional probability that a high conductivity zone would yield brine to an intersecting borehole.

Kirchner et al. (2012) TDEM Model. This model was explored by DOE as a possible replacement for the EPA (1998a) uniform model. It consisted of a statistical analysis of the TDEM data as well as the conditional probability that a high conductivity zone would yield brine to an intersecting borehole. The conditional probability was based on a statistical analysis of drilling data that assumed a lateral reservoir extent which was considered by Kirchner et al. to be reasonable but was without further justification. This model was rejected by Kirchner et al. (2012) in favor of the drilling data model described below.

Kirchner et al. (2012) Drilling Data Model. This model was proposed by DOE as a replacement for the EPA (1998a) uniform model. It consisted of a statistical analysis of brine encounters in a geologically disturbed part of the Castile Formation where such encounters have been relatively frequent. This model was rejected by EPA in part because of its sole reliance on drillers' logs and because it did not consider site-specific TDEM data that suggested a much higher probability of encountering brine.

Parametric Variations within the EPA TDEM Block Model. Potential variations within the EPA TDEM block model described in this report are discussed in this report and summarized below.

- The adopted statistical interpretation of the reported ±75 m uncertainty in TDEM depth data was to treat this uncertainty as the standard deviation of a normal distribution. The rationale for this decision is discussed in Section 4.2. The alternative of interpreting this uncertainty as two standard deviations instead of one was considered but rejected for the following reasons.
    - If the ±75 m uncertainty range is assumed to represent two standard deviations, it would have to be considered a bounding value encompassing about 95% of the results. If the ±75 m error range is assumed to represent one standard deviation, it would encompass about 68% of the results and would include most of the results but would not be considered a bounding value.

    - The ±75 m error range was developed based on only three out of 36 TDEM soundings and those three were selected because they were typical and not because they were bounding.
    - The ±75 m error range was based on RMS error values which are very similar to the standard deviation. If the expected value and the mean value are the same, as in a normal distribution, the RMS error and the standard deviation are the same.
- The adopted estimates of the depth of the Castile – Bell Canyon contact and its related uncertainty were based on a projection by SNL of the depth of that contact in the two closest wells to a location beneath the WIPP waste panels. The rationale for this decision is discussed in Section 4.3. Alternative estimates of this depth and its uncertainty were also developed by SNL and were considered and rejected by EPA for the following reasons.
    - The alternative estimate is presented in the same report as the adopted estimate but the basis for the alternative estimate is not clearly described, nor is it clear why two estimates of the same parameter are presented in a single report. See Section 4.3 for details.
    - The two estimates are consistent in that the uncertainty range for the adopted estimate lies entirely within the uncertainty range of the alternative estimate.
    - The adopted estimate places more of the TDEM high electrical conductivity zones within the Castile Formation and is therefore slightly more conservative.
- The adopted basis for establishing the lower bound of the conditional probability that a borehole intersecting a high conductivity zone would yield brine is the regional frequency of brine encounters documented in drillers' logs (0.05), as discussed in Section 5.7.
    - The alternative of using the frequency of encounter in the geologically disturbed area northeast of the WIPP site (0.13) was considered but rejected because similar geological conditions may not be present beneath the WIPP site and the actual frequency beneath the site may be lower.
    - The alternative of selecting a zero value for the lower bound was considered but rejected because, although bounding, it is physically incorrect because Castile brine has, in fact, been encountered during drilling within the northern Delaware Basin.
    - A bound lower than the regional average of 0.05 was considered but not adopted because the drilling data are already biased toward underestimating the frequency of encounter due to incomplete information.

6.0 Summary and Conclusions

In the 1996 Compliance Certification Application (CCA), the DOE proposed a method for determining the probability of encountering Castile brine beneath the WIPP waste panels that using brine encounters reported by drillers during deep exploratory drilling in the northern Delaware Basin. During the CCA review, the Agency expressed concerns over the appropriateness of that approach because it did not incorporate uncertainty and it ignored site-specific geophysical data suggestive of elevated brine content in the Castile Formation beneath the WIPP waste panels. The Agency therefore mandated a revised approach that included uncertainty and was based on both the geophysical data and the drilling data to help bound this uncertainty. The Agency's1996 mandated approach was used by the DOE in the CRAs in 2004 and 2009 but not in CRA-2014. In DOE's CRA-2014, the updated drilling frequency was accompanied by a modification to the assessment of where Castile brine reservoirs could be located that differed from what was calculated in previous PAs.

This report provides an updated method for estimating the value of the parameter GLOBAL:PBRINE. This updated method includes new information on drilling encounters that have occurred since the Agency's mandated uncertainty distribution was quantified in 1998. The updated method meets the following criteria:

<u>Consistency with available geologic and hydrologic information.</u> Available geologic and hydrologic information are reviewed in Sections 4.0 and 5.0, and the updated PBRINE calculations are consistent with this information. Uncertainties are identified and addressed through identification of ranges of uncertainty and bounding values, which were incorporated in the statistical sampling.

<u>Consistency with models of reservoir development and behavior.</u> A detailed evaluation of information on the only two Castile brine reservoirs that have been scientifically analyzed, WIPP-12 and ERDA-6, has found those reservoirs to be very different from one another and from the simplified fractured reservoir model that has been previously proposed. Two new models of fractured reservoirs are described and used to develop bounding values for the probability of brine releases from TDEM high electrical conductivity zones.

<u>Consistency with the use and importance of the data in WIPP PA.</u> The approach used to model Castile brine releases in WIPP PA indicates that repository performance can be sensitive not only to high-yield releases that would be noticed and logged by a driller but also to low-yield releases that are not likely to be noticed but could, over time, completely saturate a waste panel. Low-yield releases are also likely to be more common and therefore more probable than high-yield releases because they would emanate from the more common, smaller fractures in a reservoir that are more likely to be intersected by a borehole. The moderately deformed WIPP-12 reservoir provides an example of this type of fracture system. These considerations were incorporated in developing upper bound values for the probability of brine releases from TDEM high electrical conductivity zones.

<u>Consistency with available-site specific data.</u> Site-specific information on conditions in the Castile beneath the repository waste panels is available from a TDEM survey, from a seismic survey, and from the characteristics of the large brine reservoir encountered in nearby borehole WIPP-12. This information strongly indicates the presence of horizons of elevated brine content in the Castile directly beneath the waste panels; it indicates the possible presence of a small but sharp synformal structure beneath the waste panels suggesting deformation of the type associated with brine encounters that are noticed and logged by drillers; and it suggests that brine volumes beneath the waste panels could be significant if linked with the WIPP-12 reservoir. This information was incorporated in developing an upper bound value for the probability of brine releases from TDEM high electrical conductivity zones.

Consistency with drilling information on brine encounters. Drilling information on Castile brine encounters is limited to high-yield releases that would be noticed and logged during borehole drilling. The fracture characteristics of the highly deformed ERDA-6 reservoir support a model where rare, high-yield releases would predominate and lower-yield releases from smaller fractures would not be significant because such fractures would be filled and non-transmissive. Information on the regional frequency of brine encounters during drilling was used in developing a lower bound value for the probability of brine releases from TDEM high electrical conductivity zones.

The uncertainty distribution for GLOBAL:PBRINE developed using this updated approach is shown as a CDF in Figure 5 and in the form of a histogram in Figure 6. The density in the histogram is irregular, as would be expected from a developed distribution, and is bimodal. The histogram reflects the different characteristics of the TDEM high electrical conductivity zones beneath the individual waste panels. The principal mode of the distribution is 0.13, toward the low end of the range, with a secondary mode at 0.41. The principal mode reflects the aforementioned cluster of four waste panels with low probabilities of intersecting high conductivity zones. The median is 0.25. The long tail to the right reflects the increasing probability of intersecting high conductivity zones beneath the six remaining waste panels. EPA's 1996 currently mandated uniform distribution of PBRINE is shown in Figure 6 for comparison. The minimum (0.04) and maximum (0.57) values for PBRINE in the updated model are almost identical with the minimum (0.01) and maximum (0.60) values of the currently mandated distribution. This updated distribution spans essentially the full range of the current distribution. In DOE's CRA-2014 approach the normal approximation of the distribution of PBRINE (mean=0.127, SD=0.0272) will result in simulated frequencies of brine intrusions that cover the same range as that produced using the uniform distribution ([0.01, 0.60]) but showing a greater degree of positive skewness, i.e. showing a mode that is shifted to the left.

The updated distribution in Figure 6 was compared with several standard distribution functions, including gamma, beta, and lognormal distributions, but none adequately represented the length and abrupt truncation of the right tail. As explained above, this tail is a reflection of the TDEM data and should be retained during sampling. The Agency therefore concludes that the value of GLOBAL:PBRINE used by DOE in performance assessments is to be sampled directly from the actual, derived CDF shown in Figure 5 or from a curve fitted to that distribution. A continuous CDF with piecewise-linear segments between adjacent discrete values could be constructed for ease of implementation. Other continuous approximations to the discrete distribution also are possible, including spline techniques. The only requirement is that the approximating continuous distribution passes through all points on the empirical CDF of the discrete distribution. The ranked values of PBRINE used to develop this CDF are tabulated in Appendix B, Table B-1, for DOE's use in performance assessment. Tables B-2 through B-11 tabulate CDFs of the probability of encountering a HCZ for each panel, and Tables B-12 through B-21 tabulate CDFs of the probability of encountering brine for each panel.

The uncertainty in PBRINE is closely related to the repository geometry, the geometry of the underlying zones of high electrical conductivity, and to uncertainties in the depths of those zones and in the depth of the Castile – Bell Canyon contact beneath the waste panels. The uncertainty is also related to the conditions in the Castile beneath the waste panels and to the applicability of alternative models describing those conditions. Significant changes in any of this information could affect the uncertainty in PBRINE and require a reevaluation of that uncertainty. At this time, EPA is specifying that DOE use EPA's updated probability distribution for PBRINE in future performance assessments. EPA will evaluate alternative approaches proposed by DOE.

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Appendix A. Steps in the Statistical Estimation of PBRINE

A.1 Statistical Model Assumptions

The assumed parameter values are given in Section A.3.

1) The measurement error for the depth to first conductor (*Z*) has a normal distribution with standard deviation: *S*

   Basis for Assumption: The normal distribution is commonly used as a probability model for measurement error. Random errors in measurements are caused by unpredictable changes that may occur in the manner of use of a measuring instrument, within the instrument itself, in the local environmental conditions, or as electronic noise in the circuit of electrical instruments. Since measurement error is the sum of many different types of error, the random errors around the mean of a set of measurements often have a normal distribution. Mathematically, this is a result of the Central Limit Theorem.

2) Uncertainty in the depth of the base of the Castile (*C*) is expressed as a uniform distribution with lower bound *L* and upper bound *U* : C~ *Uniform*[*L*, *U*].

   Basis for Assumption: A uniform distribution was selected because it is the maximum entropy distribution when little is known about a parameter except for its range.

3) The conditional probability of encountering brine within a TDEM-identified high electrical conductivity zone (HCZ) : *p*[brine | HCZ] ~ *Uniform*[0.05,1.0]

   Basis for Assumption: The rationale for this distribution is described in Section 3.0 and in more detail in Section 5.7.

A.2 Statistical Algorithm

The statistical simulation is based only on the data described above and contains the following steps:

1. Choose a random value for the depth of the base of the Castile (*C*).

   [See Step 7 for more details.]

2. For the waste disposal area of the first waste panel, randomly select 100 borehole locations and determine which TDEM block each borehole is in.

   [With 100 intrusions per panel, 10 panels, and 100 values for the base of Castile, the simulation comprises 100,000 intrusions. This value is typical of WIPP performance assessment models which range from 10,000 to 1,000,000 realizations.]

3. For each intrusion, choose a random value (*Z*) for the measured depth of the high electrical conductivity zone encountered beneath the waste panel.

   [This depth is selected from the appropriate measurement error distribution for the TDEM block identified in Step 2. The appropriate measurement error distribution is a normal distribution with standard deviation *S* and a mean equal to the depth reported for that block from the TDEM survey results (see Figure 8).]

4. Compare Z (from Step 3) to C (from Step 1). If $Z < C$, count this intrusion as a hit of a high electrical conductivity zone above the base of the Castile.

   For each intrusion identified as hitting a high electrical conductivity zone above the base of the Castile, determine the conditional probability that a brine release occurs by selecting a conditional probability (P) from the *Uniform* [0.05, 1.0] distribution. Now select a second random value (X) from the standard *Uniform* [0, 1] distribution. If $X \leq P$, count this intrusion as releasing brine from a high electrical conductivity zone above the base of the Castile.

   [‘X’ is a variable used to sample the conditional probability distribution *p*[brine | HCZ] ~ *Uniform* [0.05,1.0] consistent with the properties of that distribution. It acts as a switch to determine either yes, the borehole that hit a high electrical conductivity zone did yield brine, or no, the borehole did not yield brine. Assume, for example, that for a given borehole that hit a high electrical conductivity zone the conditional probability P is sampled to be 0.4. The probability that that borehole also yields brine is therefore 40%. In the standard *Uniform* [0, 1] distribution, 40% of the values are ≤ 0.4. Therefore, if $X \leq 0.4$ the borehole is determined to yield brine. If not, the borehole does not yield brine.]

5. Calculate the percentage of the 100 intrusions into this panel that release brine from a high electrical conductivity zone above the base of the Castile (PBRINE).

   [PBRINE represents the probability that an intrusion will release brine from a high electrical conductivity zone above the base of the Castile in quantities that are important to WIPP performance, and is based on 100 borehole locations.]

6. Repeat Steps 2 thru 5 for each of the 10 waste panels giving one value of PBRINE for each waste panel.

7. Repeat Steps 1 to 6 for 100 random depths for the base of the Castile.

   [This gives 100 sampled values of PBRINE for each panel, for a total of 1,000 estimates. Because the panels are not all the same size, the larger panels 1 through 8 were assigned higher weights and the smaller panels 9 and 10 were assigned lower weights to compensate for the different probabilities of random borehole intersections. A detailed description of the weighting methodology is provided in Appendix C.]

8. Calculate the CDF of PBRINE for the repository using the 1,000 estimates of PBRINE (Figure 5).

   [The density function of PBRINE is shown as a histogram in Figure 6. Since all estimates of PBRINE are calculated as a count of the number of “hits” out of 100 intrusions, the estimates of PBRINE are restricted to be a whole number percentage: 4%, 5%, 6%, etc. … up to a maximum of 57%. The probability that PBRINE attains each of these values is shown In Table B-1 of Appendix B.]

A.3 Assumed Parameter Values

- Measurement error in depth to first conductor: Normal with standard deviation (*S*) = ±75m; see Section 4.2.
- Depth to base of Castile: Uniform with lower bound = 1,238 m; upper bound = 1,268 m; see Section 4.3.
- *P* = Probability [brine | HCZ] ~ Uniform with lower bound = 0.05; upper bound = 1.0; see Section 5.7.

Appendix B. Frequency Distribution of PBRINE

Table B-1 provides the data used to develop the CDF for PBRINE in Figure 5 and the histogram in Figure 6. The value of GLOBAL:PBRINE is to be sampled by DOE for use in WIPP PA from the ranked values in this table or from a curve fitted to that distribution. A continuous CDF with piecewise-linear segments between adjacent discrete values could be constructed for ease of implementation. Other continuous approximations to the discrete distribution also are possible, including spline techniques. The only requirement is that the approximating continuous distribution passes through all points on the empirical CDF of the discrete distribution. The probability that the discrete random variable PBRINE attains each of the estimated values is shown in the table. For example, the probability that PBRINE equals 0.10 (10%) is 0.037 (that is, 37 out of 1,000 realizations occurred with PBRINE equal to 10%). Similarly we see that 2 realizations out of 1,000 had the minimum value of PBRINE equal to 0.04 (4%), while only 1 realization out of 1,000 had the maximum value for PBRINE of 0.57 (57%).

Tables B-2 through B-11 tabulate the frequency distribution and CDF for the probability of encountering a high conductivity zone (pHCZ) in each of the ten panels. Each of the 10 waste panels is assigned the same number of ranks (81) to span all realized values of pHCZ in the 10 panels and facilitate developing the combined distribution in Table B-1. Each rank represents a bin containing the number of realizations of a given sampled value of pHCZ. A total of 81 such bins were found to be required to span all realized values of pHCZ in the 10 waste panels.

Rank 1 corresponds to pHCZ equal to 0.12, which is the lowest value of this parameter realized in any waste panel. This low value was realized only in Panels 6 and 7 because only these two panels have non-zero probabilities of pHCZ equal to 0.12. The probability of sampling a value of pHCZ less than 0.12 is zero for all 10 panels. As an example, the next lowest sampled value of pHCZ is 0.14. This value was only found in Panel 5 and is assigned a rank of 2. Although 100 samples of pHCZ were taken in each panel, some duplicate values occurred. In Panel 6, for example, a pHCZ value of 0.12 was realized twice, thus the probability of sampling pHCZ = 0.12 in Panel 6 is 0.02. In Panel 7, a pHCZ value of 0.12 was realized only once, thus the probability of sampling pHCZ = 0.12 in Panel 7 is 0.01.

Rank 81 corresponds to pHCZ equal to 0.93, which is the highest value of this parameter that was realized in any waste panel. This value was realized once in Panel 1 and twice in Panel 8. The frequency distribution for pHCZ achieved its maximum value at lower ranks in the other panels. The probability of realizing a value of pHCZ higher than 0.93 is zero in all panels. The results in these tables indicate that the probability of encountering a high conductivity zone is greatest in the northernmost Panels 1 and 8, and lowest in the southern and western Panels 5, 6, 7, and 9.

Tables B-12 through B-21 tabulate the frequency distribution and CDF for PBRINE in each of the ten waste panels. As for the foregoing tables of pHCZ, each of the 10 waste panels is assigned the same number of ranks (54) to span all realized values of PBRINE in the 10 panels and facilitate developing the combined distribution in Table B-1. Rank 1 corresponds to the lowest value of PBRINE (0.04) realized in any waste panel. This low value was realized once in Panel 6 and once in Panel 7. The probability of sampling a value of PBRINE less than 0.04 is zero for all 10 panels. Although 100 samples of PBRINE were taken in each panel, some duplicate values again occurred. This duplication reduced the total number of rank bins needed to span all realized values from 100 to 54. The highest value of PBRINE realized in any waste panel was 0.57 and this value occurred only once, in Panel 1.

Table B-1. Discrete Probability Function for Sampling PBRINE in WIPP PA

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.002	0.002	28	0.31	0.016	0.609
2	0.05	0.002	0.004	29	0.32	0.024	0.633
3	0.06	0.002	0.006	30	0.33	0.020	0.653
4	0.07	0.008	0.014	31	0.34	0.020	0.673
5	0.08	0.009	0.023	32	0.35	0.016	0.689
6	0.09	0.020	0.043	33	0.36	0.023	0.713
7	0.1	0.037	0.080	34	0.37	0.023	0.735
8	0.11	0.029	0.109	35	0.38	0.024	0.759
9	0.12	0.031	0.139	36	0.39	0.015	0.774
10	0.13	0.046	0.185	37	0.4	0.022	0.796
11	0.14	0.038	0.223	38	0.41	0.029	0.825
12	0.15	0.042	0.264	39	0.42	0.027	0.851
13	0.16	0.030	0.294	40	0.43	0.023	0.875
14	0.17	0.035	0.330	41	0.44	0.015	0.890
15	0.18	0.033	0.363	42	0.45	0.018	0.908
16	0.19	0.023	0.385	43	0.46	0.019	0.927
17	0.2	0.028	0.414	44	0.47	0.012	0.939
18	0.21	0.016	0.429	45	0.48	0.013	0.953
19	0.22	0.025	0.455	46	0.49	0.012	0.964
20	0.23	0.023	0.478	47	0.5	0.012	0.976
21	0.24	0.009	0.487	48	0.51	0.006	0.982
22	0.25	0.024	0.512	49	0.52	0.004	0.986
23	0.26	0.021	0.533	50	0.53	0.006	0.993
24	0.27	0.013	0.546	51	0.54	0.004	0.997
25	0.28	0.017	0.563	52	0.55	0.001	0.998
26	0.29	0.014	0.577	53	0.56	0.001	0.999
27	0.3	0.016	0.593	54	0.57	0.001	1.000

Table B-2. Discrete Probability Function for pHCZ in PANEL 1

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.000	0.000	42	0.54	0.000	0.000
2	0.14	0.000	0.000	43	0.55	0.000	0.000
3	0.15	0.000	0.000	44	0.56	0.000	0.000
4	0.16	0.000	0.000	45	0.57	0.000	0.000
5	0.17	0.000	0.000	46	0.58	0.000	0.000
6	0.18	0.000	0.000	47	0.59	0.000	0.000
7	0.19	0.000	0.000	48	0.6	0.000	0.000
8	0.2	0.000	0.000	49	0.61	0.000	0.000
9	0.21	0.000	0.000	50	0.62	0.000	0.000
10	0.22	0.000	0.000	51	0.63	0.000	0.000
11	0.23	0.000	0.000	52	0.64	0.000	0.000
12	0.24	0.000	0.000	53	0.65	0.000	0.000
13	0.25	0.000	0.000	54	0.66	0.000	0.000
14	0.26	0.000	0.000	55	0.67	0.000	0.000
15	0.27	0.000	0.000	56	0.68	0.000	0.000
16	0.28	0.000	0.000	57	0.69	0.010	0.010
17	0.29	0.000	0.000	58	0.7	0.000	0.010
18	0.3	0.000	0.000	59	0.71	0.000	0.010
19	0.31	0.000	0.000	60	0.72	0.000	0.010
20	0.32	0.000	0.000	61	0.73	0.010	0.020
21	0.33	0.000	0.000	62	0.74	0.000	0.020
22	0.34	0.000	0.000	63	0.75	0.000	0.020
23	0.35	0.000	0.000	64	0.76	0.030	0.050
24	0.36	0.000	0.000	65	0.77	0.020	0.070
25	0.37	0.000	0.000	66	0.78	0.050	0.120
26	0.38	0.000	0.000	67	0.79	0.050	0.170
27	0.39	0.000	0.000	68	0.8	0.020	0.190
28	0.4	0.000	0.000	69	0.81	0.110	0.300
29	0.41	0.000	0.000	70	0.82	0.070	0.370
30	0.42	0.000	0.000	71	0.83	0.090	0.460
31	0.43	0.000	0.000	72	0.84	0.040	0.500
32	0.44	0.000	0.000	73	0.85	0.080	0.580
33	0.45	0.000	0.000	74	0.86	0.130	0.710
34	0.46	0.000	0.000	75	0.87	0.060	0.770
35	0.47	0.000	0.000	76	0.88	0.070	0.840
36	0.48	0.000	0.000	77	0.89	0.060	0.900
37	0.49	0.000	0.000	78	0.9	0.030	0.930
38	0.5	0.000	0.000	79	0.91	0.030	0.960
39	0.51	0.000	0.000	80	0.92	0.030	0.990
40	0.52	0.000	0.000	81	0.93	0.010	1.000
41	0.53	0.000	0.000				

Table B-3. Discrete Probability Function for pHCZ in PANEL 2

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.000	0.000	42	0.54	0.000	0.000
2	0.14	0.000	0.000	43	0.55	0.000	0.000
3	0.15	0.000	0.000	44	0.56	0.000	0.000
4	0.16	0.000	0.000	45	0.57	0.010	0.010
5	0.17	0.000	0.000	46	0.58	0.010	0.020
6	0.18	0.000	0.000	47	0.59	0.030	0.050
7	0.19	0.000	0.000	48	0.6	0.010	0.060
8	0.2	0.000	0.000	49	0.61	0.030	0.090
9	0.21	0.000	0.000	50	0.62	0.020	0.110
10	0.22	0.000	0.000	51	0.63	0.030	0.140
11	0.23	0.000	0.000	52	0.64	0.010	0.150
12	0.24	0.000	0.000	53	0.65	0.080	0.230
13	0.25	0.000	0.000	54	0.66	0.060	0.290
14	0.26	0.000	0.000	55	0.67	0.130	0.420
15	0.27	0.000	0.000	56	0.68	0.110	0.530
16	0.28	0.000	0.000	57	0.69	0.050	0.580
17	0.29	0.000	0.000	58	0.7	0.090	0.670
18	0.3	0.000	0.000	59	0.71	0.080	0.750
19	0.31	0.000	0.000	60	0.72	0.040	0.790
20	0.32	0.000	0.000	61	0.73	0.070	0.860
21	0.33	0.000	0.000	62	0.74	0.020	0.880
22	0.34	0.000	0.000	63	0.75	0.050	0.930
23	0.35	0.000	0.000	64	0.76	0.010	0.940
24	0.36	0.000	0.000	65	0.77	0.030	0.970
25	0.37	0.000	0.000	66	0.78	0.010	0.980
26	0.38	0.000	0.000	67	0.79	0.010	0.990
27	0.39	0.000	0.000	68	0.8	0.000	0.990
28	0.4	0.000	0.000	69	0.81	0.010	1.000
29	0.41	0.000	0.000	70	0.82	0.000	1.000
30	0.42	0.000	0.000	71	0.83	0.000	1.000
31	0.43	0.000	0.000	72	0.84	0.000	1.000
32	0.44	0.000	0.000	73	0.85	0.000	1.000
33	0.45	0.000	0.000	74	0.86	0.000	1.000
34	0.46	0.000	0.000	75	0.87	0.000	1.000
35	0.47	0.000	0.000	76	0.88	0.000	1.000
36	0.48	0.000	0.000	77	0.89	0.000	1.000
37	0.49	0.000	0.000	78	0.9	0.000	1.000
38	0.5	0.000	0.000	79	0.91	0.000	1.000
39	0.51	0.000	0.000	80	0.92	0.000	1.000
40	0.52	0.000	0.000	81	0.93	0.000	1.000
41	0.53	0.000	0.000				

Table B-4. Discrete Probability Function for pHCZ in PANEL 3

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.000	0.000	42	0.54	0.070	0.610
2	0.14	0.000	0.000	43	0.55	0.050	0.660
3	0.15	0.000	0.000	44	0.56	0.040	0.700
4	0.16	0.000	0.000	45	0.57	0.070	0.770
5	0.17	0.000	0.000	46	0.58	0.060	0.830
6	0.18	0.000	0.000	47	0.59	0.050	0.880
7	0.19	0.000	0.000	48	0.6	0.020	0.900
8	0.2	0.000	0.000	49	0.61	0.020	0.920
9	0.21	0.000	0.000	50	0.62	0.030	0.950
10	0.22	0.000	0.000	51	0.63	0.010	0.960
11	0.23	0.000	0.000	52	0.64	0.010	0.970
12	0.24	0.000	0.000	53	0.65	0.020	0.990
13	0.25	0.000	0.000	54	0.66	0.010	1.000
14	0.26	0.000	0.000	55	0.67	0.000	1.000
15	0.27	0.000	0.000	56	0.68	0.000	1.000
16	0.28	0.000	0.000	57	0.69	0.000	1.000
17	0.29	0.000	0.000	58	0.7	0.000	1.000
18	0.3	0.000	0.000	59	0.71	0.000	1.000
19	0.31	0.000	0.000	60	0.72	0.000	1.000
20	0.32	0.000	0.000	61	0.73	0.000	1.000
21	0.33	0.000	0.000	62	0.74	0.000	1.000
22	0.34	0.000	0.000	63	0.75	0.000	1.000
23	0.35	0.000	0.000	64	0.76	0.000	1.000
24	0.36	0.000	0.000	65	0.77	0.000	1.000
25	0.37	0.000	0.000	66	0.78	0.000	1.000
26	0.38	0.000	0.000	67	0.79	0.000	1.000
27	0.39	0.000	0.000	68	0.8	0.000	1.000
28	0.4	0.020	0.020	69	0.81	0.000	1.000
29	0.41	0.000	0.020	70	0.82	0.000	1.000
30	0.42	0.010	0.030	71	0.83	0.000	1.000
31	0.43	0.020	0.050	72	0.84	0.000	1.000
32	0.44	0.040	0.090	73	0.85	0.000	1.000
33	0.45	0.040	0.130	74	0.86	0.000	1.000
34	0.46	0.080	0.210	75	0.87	0.000	1.000
35	0.47	0.070	0.280	76	0.88	0.000	1.000
36	0.48	0.020	0.300	77	0.89	0.000	1.000
37	0.49	0.010	0.310	78	0.9	0.000	1.000
38	0.5	0.060	0.370	79	0.91	0.000	1.000
39	0.51	0.050	0.420	80	0.92	0.000	1.000
40	0.52	0.060	0.480	81	0.93	0.000	1.000
41	0.53	0.060	0.540				

Table B-5. Discrete Probability Function for pHCZ in PANEL 4

Rank	pHCZ	Probability of Sampling pHCZ	Cumulative Distribution Function (CDF) Value	Rank	pHCZ	Probability of Sampling pHCZ	Cumulative Distribution Function (CDF) Value
1	0.12	0.000	0.000	42	0.54	0.060	0.920
2	0.14	0.000	0.000	43	0.55	0.020	0.940
3	0.15	0.000	0.000	44	0.56	0.030	0.970
4	0.16	0.000	0.000	45	0.57	0.020	0.990
5	0.17	0.000	0.000	46	0.58	0.000	0.990
6	0.18	0.000	0.000	47	0.59	0.000	0.990
7	0.19	0.000	0.000	48	0.6	0.000	0.990
8	0.2	0.000	0.000	49	0.61	0.000	0.990
9	0.21	0.000	0.000	50	0.62	0.010	1.000
10	0.22	0.000	0.000	51	0.63	0.000	1.000
11	0.23	0.000	0.000	52	0.64	0.000	1.000
12	0.24	0.000	0.000	53	0.65	0.000	1.000
13	0.25	0.000	0.000	54	0.66	0.000	1.000
14	0.26	0.000	0.000	55	0.67	0.000	1.000
15	0.27	0.000	0.000	56	0.68	0.000	1.000
16	0.28	0.000	0.000	57	0.69	0.000	1.000
17	0.29	0.000	0.000	58	0.7	0.000	1.000
18	0.3	0.010	0.010	59	0.71	0.000	1.000
19	0.31	0.000	0.010	60	0.72	0.000	1.000
20	0.32	0.000	0.010	61	0.73	0.000	1.000
21	0.33	0.020	0.030	62	0.74	0.000	1.000
22	0.34	0.000	0.030	63	0.75	0.000	1.000
23	0.35	0.020	0.050	64	0.76	0.000	1.000
24	0.36	0.030	0.080	65	0.77	0.000	1.000
25	0.37	0.030	0.110	66	0.78	0.000	1.000
26	0.38	0.020	0.130	67	0.79	0.000	1.000
27	0.39	0.080	0.210	68	0.8	0.000	1.000
28	0.4	0.060	0.270	69	0.81	0.000	1.000
29	0.41	0.040	0.310	70	0.82	0.000	1.000
30	0.42	0.060	0.370	71	0.83	0.000	1.000
31	0.43	0.050	0.420	72	0.84	0.000	1.000
32	0.44	0.070	0.490	73	0.85	0.000	1.000
33	0.45	0.030	0.520	74	0.86	0.000	1.000
34	0.46	0.050	0.570	75	0.87	0.000	1.000
35	0.47	0.030	0.600	76	0.88	0.000	1.000
36	0.48	0.070	0.670	77	0.89	0.000	1.000
37	0.49	0.070	0.740	78	0.9	0.000	1.000
38	0.5	0.040	0.780	79	0.91	0.000	1.000
39	0.51	0.010	0.790	80	0.92	0.000	1.000
40	0.52	0.010	0.800	81	0.93	0.000	1.000
41	0.53	0.060	0.860				

Table B-6. Discrete Probability Function for pHCZ in PANEL 5

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.000	0.000	42	0.54	0.000	1.000
2	0.14	0.020	0.020	43	0.55	0.000	1.000
3	0.15	0.010	0.030	44	0.56	0.000	1.000
4	0.16	0.020	0.050	45	0.57	0.000	1.000
5	0.17	0.010	0.060	46	0.58	0.000	1.000
6	0.18	0.020	0.080	47	0.59	0.000	1.000
7	0.19	0.020	0.100	48	0.6	0.000	1.000
8	0.2	0.030	0.130	49	0.61	0.000	1.000
9	0.21	0.070	0.200	50	0.62	0.000	1.000
10	0.22	0.060	0.260	51	0.63	0.000	1.000
11	0.23	0.040	0.300	52	0.64	0.000	1.000
12	0.24	0.100	0.400	53	0.65	0.000	1.000
13	0.25	0.040	0.440	54	0.66	0.000	1.000
14	0.26	0.070	0.510	55	0.67	0.000	1.000
15	0.27	0.060	0.570	56	0.68	0.000	1.000
16	0.28	0.090	0.660	57	0.69	0.000	1.000
17	0.29	0.060	0.720	58	0.7	0.000	1.000
18	0.3	0.020	0.740	59	0.71	0.000	1.000
19	0.31	0.050	0.790	60	0.72	0.000	1.000
20	0.32	0.000	0.790	61	0.73	0.000	1.000
21	0.33	0.060	0.850	62	0.74	0.000	1.000
22	0.34	0.040	0.890	63	0.75	0.000	1.000
23	0.35	0.050	0.940	64	0.76	0.000	1.000
24	0.36	0.020	0.960	65	0.77	0.000	1.000
25	0.37	0.020	0.980	66	0.78	0.000	1.000
26	0.38	0.000	0.980	67	0.79	0.000	1.000
27	0.39	0.010	0.990	68	0.8	0.000	1.000
28	0.4	0.000	0.990	69	0.81	0.000	1.000
29	0.41	0.000	0.990	70	0.82	0.000	1.000
30	0.42	0.000	0.990	71	0.83	0.000	1.000
31	0.43	0.010	1.000	72	0.84	0.000	1.000
32	0.44	0.000	1.000	73	0.85	0.000	1.000
33	0.45	0.000	1.000	74	0.86	0.000	1.000
34	0.46	0.000	1.000	75	0.87	0.000	1.000
35	0.47	0.000	1.000	76	0.88	0.000	1.000
36	0.48	0.000	1.000	77	0.89	0.000	1.000
37	0.49	0.000	1.000	78	0.9	0.000	1.000
38	0.5	0.000	1.000	79	0.91	0.000	1.000
39	0.51	0.000	1.000	80	0.92	0.000	1.000
40	0.52	0.000	1.000	81	0.93	0.000	1.000
41	0.53	0.000	1.000				

Table B-7. Discrete Probability Function for pHCZ in PANEL 6

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.020	0.020	42	0.54	0.000	1.000
2	0.14	0.010	0.030	43	0.55	0.000	1.000
3	0.15	0.030	0.060	44	0.56	0.000	1.000
4	0.16	0.010	0.070	45	0.57	0.000	1.000
5	0.17	0.030	0.100	46	0.58	0.000	1.000
6	0.18	0.020	0.120	47	0.59	0.000	1.000
7	0.19	0.040	0.160	48	0.6	0.000	1.000
8	0.2	0.030	0.190	49	0.61	0.000	1.000
9	0.21	0.030	0.220	50	0.62	0.000	1.000
10	0.22	0.030	0.250	51	0.63	0.000	1.000
11	0.23	0.050	0.300	52	0.64	0.000	1.000
12	0.24	0.080	0.380	53	0.65	0.000	1.000
13	0.25	0.030	0.410	54	0.66	0.000	1.000
14	0.26	0.050	0.460	55	0.67	0.000	1.000
15	0.27	0.100	0.560	56	0.68	0.000	1.000
16	0.28	0.090	0.650	57	0.69	0.000	1.000
17	0.29	0.030	0.680	58	0.7	0.000	1.000
18	0.3	0.040	0.720	59	0.71	0.000	1.000
19	0.31	0.060	0.780	60	0.72	0.000	1.000
20	0.32	0.010	0.790	61	0.73	0.000	1.000
21	0.33	0.040	0.830	62	0.74	0.000	1.000
22	0.34	0.060	0.890	63	0.75	0.000	1.000
23	0.35	0.030	0.920	64	0.76	0.000	1.000
24	0.36	0.020	0.940	65	0.77	0.000	1.000
25	0.37	0.030	0.970	66	0.78	0.000	1.000
26	0.38	0.010	0.980	67	0.79	0.000	1.000
27	0.39	0.010	0.990	68	0.8	0.000	1.000
28	0.4	0.010	1.000	69	0.81	0.000	1.000
29	0.41	0.000	1.000	70	0.82	0.000	1.000
30	0.42	0.000	1.000	71	0.83	0.000	1.000
31	0.43	0.000	1.000	72	0.84	0.000	1.000
32	0.44	0.000	1.000	73	0.85	0.000	1.000
33	0.45	0.000	1.000	74	0.86	0.000	1.000
34	0.46	0.000	1.000	75	0.87	0.000	1.000
35	0.47	0.000	1.000	76	0.88	0.000	1.000
36	0.48	0.000	1.000	77	0.89	0.000	1.000
37	0.49	0.000	1.000	78	0.9	0.000	1.000
38	0.5	0.000	1.000	79	0.91	0.000	1.000
39	0.51	0.000	1.000	80	0.92	0.000	1.000
40	0.52	0.000	1.000	81	0.93	0.000	1.000
41	0.53	0.000	1.000				

Table B-8. Discrete Probability Function for pHCZ in PANEL 7

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.010	0.010	42	0.54	0.000	1.000
2	0.14	0.010	0.020	43	0.55	0.000	1.000
3	0.15	0.010	0.030	44	0.56	0.000	1.000
4	0.16	0.010	0.040	45	0.57	0.000	1.000
5	0.17	0.020	0.060	46	0.58	0.000	1.000
6	0.18	0.040	0.100	47	0.59	0.000	1.000
7	0.19	0.040	0.140	48	0.6	0.000	1.000
8	0.2	0.050	0.190	49	0.61	0.000	1.000
9	0.21	0.030	0.220	50	0.62	0.000	1.000
10	0.22	0.050	0.270	51	0.63	0.000	1.000
11	0.23	0.100	0.370	52	0.64	0.000	1.000
12	0.24	0.020	0.390	53	0.65	0.000	1.000
13	0.25	0.040	0.430	54	0.66	0.000	1.000
14	0.26	0.090	0.520	55	0.67	0.000	1.000
15	0.27	0.050	0.570	56	0.68	0.000	1.000
16	0.28	0.080	0.650	57	0.69	0.000	1.000
17	0.29	0.050	0.700	58	0.7	0.000	1.000
18	0.3	0.050	0.750	59	0.71	0.000	1.000
19	0.31	0.060	0.810	60	0.72	0.000	1.000
20	0.32	0.060	0.870	61	0.73	0.000	1.000
21	0.33	0.030	0.900	62	0.74	0.000	1.000
22	0.34	0.040	0.940	63	0.75	0.000	1.000
23	0.35	0.010	0.950	64	0.76	0.000	1.000
24	0.36	0.010	0.960	65	0.77	0.000	1.000
25	0.37	0.030	0.990	66	0.78	0.000	1.000
26	0.38	0.000	0.990	67	0.79	0.000	1.000
27	0.39	0.010	1.000	68	0.8	0.000	1.000
28	0.4	0.000	1.000	69	0.81	0.000	1.000
29	0.41	0.000	1.000	70	0.82	0.000	1.000
30	0.42	0.000	1.000	71	0.83	0.000	1.000
31	0.43	0.000	1.000	72	0.84	0.000	1.000
32	0.44	0.000	1.000	73	0.85	0.000	1.000
33	0.45	0.000	1.000	74	0.86	0.000	1.000
34	0.46	0.000	1.000	75	0.87	0.000	1.000
35	0.47	0.000	1.000	76	0.88	0.000	1.000
36	0.48	0.000	1.000	77	0.89	0.000	1.000
37	0.49	0.000	1.000	78	0.9	0.000	1.000
38	0.5	0.000	1.000	79	0.91	0.000	1.000
39	0.51	0.000	1.000	80	0.92	0.000	1.000
40	0.52	0.000	1.000	81	0.93	0.000	1.000
41	0.53	0.000	1.000				

Table B-9. Discrete Probability Function for pHCZ in PANEL 8

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.000	0.000	42	0.54	0.000	0.000
2	0.14	0.000	0.000	43	0.55	0.000	0.000
3	0.15	0.000	0.000	44	0.56	0.000	0.000
4	0.16	0.000	0.000	45	0.57	0.000	0.000
5	0.17	0.000	0.000	46	0.58	0.000	0.000
6	0.18	0.000	0.000	47	0.59	0.000	0.000
7	0.19	0.000	0.000	48	0.6	0.000	0.000
8	0.2	0.000	0.000	49	0.61	0.000	0.000
9	0.21	0.000	0.000	50	0.62	0.000	0.000
10	0.22	0.000	0.000	51	0.63	0.000	0.000
11	0.23	0.000	0.000	52	0.64	0.000	0.000
12	0.24	0.000	0.000	53	0.65	0.000	0.000
13	0.25	0.000	0.000	54	0.66	0.000	0.000
14	0.26	0.000	0.000	55	0.67	0.000	0.000
15	0.27	0.000	0.000	56	0.68	0.000	0.000
16	0.28	0.000	0.000	57	0.69	0.000	0.000
17	0.29	0.000	0.000	58	0.7	0.000	0.000
18	0.3	0.000	0.000	59	0.71	0.000	0.000
19	0.31	0.000	0.000	60	0.72	0.000	0.000
20	0.32	0.000	0.000	61	0.73	0.000	0.000
21	0.33	0.000	0.000	62	0.74	0.010	0.010
22	0.34	0.000	0.000	63	0.75	0.010	0.020
23	0.35	0.000	0.000	64	0.76	0.020	0.040
24	0.36	0.000	0.000	65	0.77	0.010	0.050
25	0.37	0.000	0.000	66	0.78	0.040	0.090
26	0.38	0.000	0.000	67	0.79	0.060	0.150
27	0.39	0.000	0.000	68	0.8	0.040	0.190
28	0.4	0.000	0.000	69	0.81	0.100	0.290
29	0.41	0.000	0.000	70	0.82	0.040	0.330
30	0.42	0.000	0.000	71	0.83	0.080	0.410
31	0.43	0.000	0.000	72	0.84	0.030	0.440
32	0.44	0.000	0.000	73	0.85	0.120	0.560
33	0.45	0.000	0.000	74	0.86	0.080	0.640
34	0.46	0.000	0.000	75	0.87	0.110	0.750
35	0.47	0.000	0.000	76	0.88	0.030	0.780
36	0.48	0.000	0.000	77	0.89	0.110	0.890
37	0.49	0.000	0.000	78	0.9	0.030	0.920
38	0.5	0.000	0.000	79	0.91	0.040	0.960
39	0.51	0.000	0.000	80	0.92	0.020	0.980
40	0.52	0.000	0.000	81	0.93	0.020	1.000
41	0.53	0.000	0.000				

Table B-10. Discrete Probability Function for pHCZ in PANEL 9

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.000	0.000	42	0.54	0.000	1.000
2	0.14	0.000	0.000	43	0.55	0.000	1.000
3	0.15	0.000	0.000	44	0.56	0.000	1.000
4	0.16	0.000	0.000	45	0.57	0.000	1.000
5	0.17	0.010	0.010	46	0.58	0.000	1.000
6	0.18	0.000	0.010	47	0.59	0.000	1.000
7	0.19	0.020	0.030	48	0.6	0.000	1.000
8	0.2	0.030	0.060	49	0.61	0.000	1.000
9	0.21	0.060	0.120	50	0.62	0.000	1.000
10	0.22	0.020	0.140	51	0.63	0.000	1.000
11	0.23	0.080	0.220	52	0.64	0.000	1.000
12	0.24	0.070	0.290	53	0.65	0.000	1.000
13	0.25	0.080	0.370	54	0.66	0.000	1.000
14	0.26	0.050	0.420	55	0.67	0.000	1.000
15	0.27	0.100	0.520	56	0.68	0.000	1.000
16	0.28	0.080	0.600	57	0.69	0.000	1.000
17	0.29	0.070	0.670	58	0.7	0.000	1.000
18	0.3	0.030	0.700	59	0.71	0.000	1.000
19	0.31	0.050	0.750	60	0.72	0.000	1.000
20	0.32	0.060	0.810	61	0.73	0.000	1.000
21	0.33	0.010	0.820	62	0.74	0.000	1.000
22	0.34	0.100	0.920	63	0.75	0.000	1.000
23	0.35	0.040	0.960	64	0.76	0.000	1.000
24	0.36	0.020	0.980	65	0.77	0.000	1.000
25	0.37	0.000	0.980	66	0.78	0.000	1.000
26	0.38	0.010	0.990	67	0.79	0.000	1.000
27	0.39	0.010	1.000	68	0.8	0.000	1.000
28	0.4	0.000	1.000	69	0.81	0.000	1.000
29	0.41	0.000	1.000	70	0.82	0.000	1.000
30	0.42	0.000	1.000	71	0.83	0.000	1.000
31	0.43	0.000	1.000	72	0.84	0.000	1.000
32	0.44	0.000	1.000	73	0.85	0.000	1.000
33	0.45	0.000	1.000	74	0.86	0.000	1.000
34	0.46	0.000	1.000	75	0.87	0.000	1.000
35	0.47	0.000	1.000	76	0.88	0.000	1.000
36	0.48	0.000	1.000	77	0.89	0.000	1.000
37	0.49	0.000	1.000	78	0.9	0.000	1.000
38	0.5	0.000	1.000	79	0.91	0.000	1.000
39	0.51	0.000	1.000	80	0.92	0.000	1.000
40	0.52	0.000	1.000	81	0.93	0.000	1.000
41	0.53	0.000	1.000				

Table B-11. Discrete Probability Function for pHCZ in PANEL 10

Rank	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*pHCZ*	*Probability of Sampling pHCZ*	*Cumulative Distribution Function (CDF) Value*
1	0.12	0.000	0.000	42	0.54	0.000	0.000
2	0.14	0.000	0.000	43	0.55	0.000	0.000
3	0.15	0.000	0.000	44	0.56	0.000	0.000
4	0.16	0.000	0.000	45	0.57	0.000	0.000
5	0.17	0.000	0.000	46	0.58	0.000	0.000
6	0.18	0.000	0.000	47	0.59	0.000	0.000
7	0.19	0.000	0.000	48	0.6	0.000	0.000
8	0.2	0.000	0.000	49	0.61	0.020	0.020
9	0.21	0.000	0.000	50	0.62	0.020	0.040
10	0.22	0.000	0.000	51	0.63	0.030	0.070
11	0.23	0.000	0.000	52	0.64	0.030	0.100
12	0.24	0.000	0.000	53	0.65	0.050	0.150
13	0.25	0.000	0.000	54	0.66	0.040	0.190
14	0.26	0.000	0.000	55	0.67	0.100	0.290
15	0.27	0.000	0.000	56	0.68	0.090	0.380
16	0.28	0.000	0.000	57	0.69	0.090	0.470
17	0.29	0.000	0.000	58	0.7	0.140	0.610
18	0.3	0.000	0.000	59	0.71	0.050	0.660
19	0.31	0.000	0.000	60	0.72	0.040	0.700
20	0.32	0.000	0.000	61	0.73	0.070	0.770
21	0.33	0.000	0.000	62	0.74	0.060	0.830
22	0.34	0.000	0.000	63	0.75	0.040	0.870
23	0.35	0.000	0.000	64	0.76	0.030	0.900
24	0.36	0.000	0.000	65	0.77	0.030	0.930
25	0.37	0.000	0.000	66	0.78	0.010	0.940
26	0.38	0.000	0.000	67	0.79	0.030	0.970
27	0.39	0.000	0.000	68	0.8	0.020	0.990
28	0.4	0.000	0.000	69	0.81	0.000	0.990
29	0.41	0.000	0.000	70	0.82	0.010	1.000
30	0.42	0.000	0.000	71	0.83	0.000	1.000
31	0.43	0.000	0.000	72	0.84	0.000	1.000
32	0.44	0.000	0.000	73	0.85	0.000	1.000
33	0.45	0.000	0.000	74	0.86	0.000	1.000
34	0.46	0.000	0.000	75	0.87	0.000	1.000
35	0.47	0.000	0.000	76	0.88	0.000	1.000
36	0.48	0.000	0.000	77	0.89	0.000	1.000
37	0.49	0.000	0.000	78	0.9	0.000	1.000
38	0.5	0.000	0.000	79	0.91	0.000	1.000
39	0.51	0.000	0.000	80	0.92	0.000	1.000
40	0.52	0.000	0.000	81	0.93	0.000	1.000
41	0.53	0.000	0.000				

Table B-12. Discrete Probability Function for PBRINE in PANEL 1

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.000	0.000	28	0.31	0.000	0.000
2	0.05	0.000	0.000	29	0.32	0.010	0.010
3	0.06	0.000	0.000	30	0.33	0.010	0.020
4	0.07	0.000	0.000	31	0.34	0.000	0.020
5	0.08	0.000	0.000	32	0.35	0.020	0.040
6	0.09	0.000	0.000	33	0.36	0.020	0.060
7	0.1	0.000	0.000	34	0.37	0.020	0.080
8	0.11	0.000	0.000	35	0.38	0.020	0.100
9	0.12	0.000	0.000	36	0.39	0.060	0.160
10	0.13	0.000	0.000	37	0.4	0.040	0.200
11	0.14	0.000	0.000	38	0.41	0.100	0.300
12	0.15	0.000	0.000	39	0.42	0.070	0.370
13	0.16	0.000	0.000	40	0.43	0.080	0.450
14	0.17	0.000	0.000	41	0.44	0.070	0.520
15	0.18	0.000	0.000	42	0.45	0.060	0.580
16	0.19	0.000	0.000	43	0.46	0.070	0.650
17	0.2	0.000	0.000	44	0.47	0.050	0.700
18	0.21	0.000	0.000	45	0.48	0.070	0.770
19	0.22	0.000	0.000	46	0.49	0.050	0.820
20	0.23	0.000	0.000	47	0.5	0.040	0.860
21	0.24	0.000	0.000	48	0.51	0.030	0.890
22	0.25	0.000	0.000	49	0.52	0.020	0.910
23	0.26	0.000	0.000	50	0.53	0.050	0.960
24	0.27	0.000	0.000	51	0.54	0.020	0.980
25	0.28	0.000	0.000	52	0.55	0.010	0.990
26	0.29	0.000	0.000	53	0.56	0.000	0.990
27	0.3	0.000	0.000	54	0.57	0.010	1.000

Table B-13. Discrete Probability Function for PBRINE in PANEL 2

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.000	0.000	28	0.31	0.050	0.160
2	0.05	0.000	0.000	29	0.32	0.050	0.210
3	0.06	0.000	0.000	30	0.33	0.040	0.250
4	0.07	0.000	0.000	31	0.34	0.090	0.340
5	0.08	0.000	0.000	32	0.35	0.060	0.400
6	0.09	0.000	0.000	33	0.36	0.110	0.510
7	0.1	0.000	0.000	34	0.37	0.110	0.620
8	0.11	0.000	0.000	35	0.38	0.080	0.700
9	0.12	0.000	0.000	36	0.39	0.020	0.720
10	0.13	0.000	0.000	37	0.4	0.050	0.770
11	0.14	0.000	0.000	38	0.41	0.070	0.840
12	0.15	0.000	0.000	39	0.42	0.030	0.870
13	0.16	0.000	0.000	40	0.43	0.060	0.930
14	0.17	0.000	0.000	41	0.44	0.020	0.950
15	0.18	0.000	0.000	42	0.45	0.030	0.980
16	0.19	0.000	0.000	43	0.46	0.000	0.980
17	0.2	0.000	0.000	44	0.47	0.020	1.000
18	0.21	0.000	0.000	45	0.48	0.000	1.000
19	0.22	0.000	0.000	46	0.49	0.000	1.000
20	0.23	0.000	0.000	47	0.5	0.000	1.000
21	0.24	0.000	0.000	48	0.51	0.000	1.000
22	0.25	0.000	0.000	49	0.52	0.000	1.000
23	0.26	0.010	0.010	50	0.53	0.000	1.000
24	0.27	0.010	0.020	51	0.54	0.000	1.000
25	0.28	0.040	0.060	52	0.55	0.000	1.000
26	0.29	0.010	0.070	53	0.56	0.000	1.000
27	0.3	0.040	0.110	54	0.57	0.000	1.000

Table B-14. Discrete Probability Function for PBRINE in PANEL 3

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.000	0.000	28	0.31	0.040	0.820
2	0.05	0.000	0.000	29	0.32	0.100	0.920
3	0.06	0.000	0.000	30	0.33	0.030	0.950
4	0.07	0.000	0.000	31	0.34	0.030	0.980
5	0.08	0.000	0.000	32	0.35	0.000	0.980
6	0.09	0.000	0.000	33	0.36	0.010	0.990
7	0.1	0.000	0.000	34	0.37	0.010	1.000
8	0.11	0.000	0.000	35	0.38	0.000	1.000
9	0.12	0.000	0.000	36	0.39	0.000	1.000
10	0.13	0.000	0.000	37	0.4	0.000	1.000
11	0.14	0.000	0.000	38	0.41	0.000	1.000
12	0.15	0.000	0.000	39	0.42	0.000	1.000
13	0.16	0.000	0.000	40	0.43	0.000	1.000
14	0.17	0.010	0.010	41	0.44	0.000	1.000
15	0.18	0.020	0.030	42	0.45	0.000	1.000
16	0.19	0.030	0.060	43	0.46	0.000	1.000
17	0.2	0.040	0.100	44	0.47	0.000	1.000
18	0.21	0.020	0.120	45	0.48	0.000	1.000
19	0.22	0.070	0.190	46	0.49	0.000	1.000
20	0.23	0.110	0.300	47	0.5	0.000	1.000
21	0.24	0.040	0.340	48	0.51	0.000	1.000
22	0.25	0.090	0.430	49	0.52	0.000	1.000
23	0.26	0.110	0.540	50	0.53	0.000	1.000
24	0.27	0.080	0.620	51	0.54	0.000	1.000
25	0.28	0.030	0.650	52	0.55	0.000	1.000
26	0.29	0.050	0.700	53	0.56	0.000	1.000
27	0.3	0.080	0.780	54	0.57	0.000	1.000

Table B-15. Discrete Probability Function for PBRINE in PANEL 4

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.000	0.000	28	0.31	0.010	0.960
2	0.05	0.000	0.000	29	0.32	0.000	0.960
3	0.06	0.000	0.000	30	0.33	0.020	0.980
4	0.07	0.000	0.000	31	0.34	0.010	0.990
5	0.08	0.000	0.000	32	0.35	0.000	0.990
6	0.09	0.000	0.000	33	0.36	0.010	1.000
7	0.1	0.000	0.000	34	0.37	0.000	1.000
8	0.11	0.010	0.010	35	0.38	0.000	1.000
9	0.12	0.000	0.010	36	0.39	0.000	1.000
10	0.13	0.000	0.010	37	0.4	0.000	1.000
11	0.14	0.010	0.020	38	0.41	0.000	1.000
12	0.15	0.000	0.020	39	0.42	0.000	1.000
13	0.16	0.050	0.070	40	0.43	0.000	1.000
14	0.17	0.030	0.100	41	0.44	0.000	1.000
15	0.18	0.070	0.170	42	0.45	0.000	1.000
16	0.19	0.020	0.190	43	0.46	0.000	1.000
17	0.2	0.070	0.260	44	0.47	0.000	1.000
18	0.21	0.090	0.350	45	0.48	0.000	1.000
19	0.22	0.110	0.460	46	0.49	0.000	1.000
20	0.23	0.060	0.520	47	0.5	0.000	1.000
21	0.24	0.040	0.560	48	0.51	0.000	1.000
22	0.25	0.120	0.680	49	0.52	0.000	1.000
23	0.26	0.080	0.760	50	0.53	0.000	1.000
24	0.27	0.030	0.790	51	0.54	0.000	1.000
25	0.28	0.080	0.870	52	0.55	0.000	1.000
26	0.29	0.060	0.930	53	0.56	0.000	1.000
27	0.3	0.020	0.950	54	0.57	0.000	1.000

Table B-16. Discrete Probability Function for PBRINE in PANEL 5

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.000	0.000	28	0.31	0.000	1.000
2	0.05	0.010	0.010	29	0.32	0.000	1.000
3	0.06	0.010	0.020	30	0.33	0.000	1.000
4	0.07	0.040	0.060	31	0.34	0.000	1.000
5	0.08	0.020	0.080	32	0.35	0.000	1.000
6	0.09	0.080	0.160	33	0.36	0.000	1.000
7	0.1	0.080	0.240	34	0.37	0.000	1.000
8	0.11	0.070	0.310	35	0.38	0.000	1.000
9	0.12	0.070	0.380	36	0.39	0.000	1.000
10	0.13	0.080	0.460	37	0.4	0.000	1.000
11	0.14	0.120	0.580	38	0.41	0.000	1.000
12	0.15	0.100	0.680	39	0.42	0.000	1.000
13	0.16	0.030	0.710	40	0.43	0.000	1.000
14	0.17	0.100	0.810	41	0.44	0.000	1.000
15	0.18	0.060	0.870	42	0.45	0.000	1.000
16	0.19	0.050	0.920	43	0.46	0.000	1.000
17	0.2	0.040	0.960	44	0.47	0.000	1.000
18	0.21	0.000	0.960	45	0.48	0.000	1.000
19	0.22	0.000	0.960	46	0.49	0.000	1.000
20	0.23	0.020	0.980	47	0.5	0.000	1.000
21	0.24	0.010	0.990	48	0.51	0.000	1.000
22	0.25	0.010	1.000	49	0.52	0.000	1.000
23	0.26	0.000	1.000	50	0.53	0.000	1.000
24	0.27	0.000	1.000	51	0.54	0.000	1.000
25	0.28	0.000	1.000	52	0.55	0.000	1.000
26	0.29	0.000	1.000	53	0.56	0.000	1.000
27	0.3	0.000	1.000	54	0.57	0.000	1.000

Table B-17. Discrete Probability Function for PBRINE in PANEL 6

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.010	0.010	28	0.31	0.000	1.000
2	0.05	0.010	0.020	29	0.32	0.000	1.000
3	0.06	0.000	0.020	30	0.33	0.000	1.000
4	0.07	0.010	0.030	31	0.34	0.000	1.000
5	0.08	0.020	0.050	32	0.35	0.000	1.000
6	0.09	0.070	0.120	33	0.36	0.000	1.000
7	0.1	0.110	0.230	34	0.37	0.000	1.000
8	0.11	0.040	0.270	35	0.38	0.000	1.000
9	0.12	0.070	0.340	36	0.39	0.000	1.000
10	0.13	0.110	0.450	37	0.4	0.000	1.000
11	0.14	0.080	0.530	38	0.41	0.000	1.000
12	0.15	0.110	0.640	39	0.42	0.000	1.000
13	0.16	0.070	0.710	40	0.43	0.000	1.000
14	0.17	0.060	0.770	41	0.44	0.000	1.000
15	0.18	0.060	0.830	42	0.45	0.000	1.000
16	0.19	0.060	0.890	43	0.46	0.000	1.000
17	0.2	0.080	0.970	44	0.47	0.000	1.000
18	0.21	0.010	0.980	45	0.48	0.000	1.000
19	0.22	0.010	0.990	46	0.49	0.000	1.000
20	0.23	0.010	1.000	47	0.5	0.000	1.000
21	0.24	0.000	1.000	48	0.51	0.000	1.000
22	0.25	0.000	1.000	49	0.52	0.000	1.000
23	0.26	0.000	1.000	50	0.53	0.000	1.000
24	0.27	0.000	1.000	51	0.54	0.000	1.000
25	0.28	0.000	1.000	52	0.55	0.000	1.000
26	0.29	0.000	1.000	53	0.56	0.000	1.000
27	0.3	0.000	1.000	54	0.57	0.000	1.000

Table B-18. Discrete Probability Function for PBRINE in PANEL 7

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.010	0.010	28	0.31	0.000	1.000
2	0.05	0.000	0.010	29	0.32	0.000	1.000
3	0.06	0.010	0.020	30	0.33	0.000	1.000
4	0.07	0.020	0.040	31	0.34	0.000	1.000
5	0.08	0.030	0.070	32	0.35	0.000	1.000
6	0.09	0.030	0.100	33	0.36	0.000	1.000
7	0.1	0.090	0.190	34	0.37	0.000	1.000
8	0.11	0.120	0.310	35	0.38	0.000	1.000
9	0.12	0.070	0.380	36	0.39	0.000	1.000
10	0.13	0.170	0.550	37	0.4	0.000	1.000
11	0.14	0.060	0.610	38	0.41	0.000	1.000
12	0.15	0.110	0.720	39	0.42	0.000	1.000
13	0.16	0.090	0.810	40	0.43	0.000	1.000
14	0.17	0.040	0.850	41	0.44	0.000	1.000
15	0.18	0.050	0.900	42	0.45	0.000	1.000
16	0.19	0.040	0.940	43	0.46	0.000	1.000
17	0.2	0.010	0.950	44	0.47	0.000	1.000
18	0.21	0.000	0.950	45	0.48	0.000	1.000
19	0.22	0.030	0.980	46	0.49	0.000	1.000
20	0.23	0.020	1.000	47	0.5	0.000	1.000
21	0.24	0.000	1.000	48	0.51	0.000	1.000
22	0.25	0.000	1.000	49	0.52	0.000	1.000
23	0.26	0.000	1.000	50	0.53	0.000	1.000
24	0.27	0.000	1.000	51	0.54	0.000	1.000
25	0.28	0.000	1.000	52	0.55	0.000	1.000
26	0.29	0.000	1.000	53	0.56	0.000	1.000
27	0.3	0.000	1.000	54	0.57	0.000	1.000

Table B-19. Discrete Probability Function for PBRINE in PANEL 8

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.000	0.000	28	0.31	0.000	0.010
2	0.05	0.000	0.000	29	0.32	0.010	0.020
3	0.06	0.000	0.000	30	0.33	0.000	0.020
4	0.07	0.000	0.000	31	0.34	0.010	0.030
5	0.08	0.000	0.000	32	0.35	0.010	0.040
6	0.09	0.000	0.000	33	0.36	0.010	0.050
7	0.1	0.000	0.000	34	0.37	0.030	0.080
8	0.11	0.000	0.000	35	0.38	0.070	0.150
9	0.12	0.000	0.000	36	0.39	0.040	0.190
10	0.13	0.000	0.000	37	0.4	0.060	0.250
11	0.14	0.000	0.000	38	0.41	0.050	0.300
12	0.15	0.000	0.000	39	0.42	0.130	0.430
13	0.16	0.000	0.000	40	0.43	0.050	0.480
14	0.17	0.000	0.000	41	0.44	0.040	0.520
15	0.18	0.000	0.000	42	0.45	0.070	0.590
16	0.19	0.000	0.000	43	0.46	0.100	0.690
17	0.2	0.000	0.000	44	0.47	0.040	0.730
18	0.21	0.000	0.000	45	0.48	0.050	0.780
19	0.22	0.000	0.000	46	0.49	0.060	0.840
20	0.23	0.000	0.000	47	0.5	0.070	0.910
21	0.24	0.000	0.000	48	0.51	0.030	0.940
22	0.25	0.010	0.010	49	0.52	0.020	0.960
23	0.26	0.000	0.010	50	0.53	0.010	0.970
24	0.27	0.000	0.010	51	0.54	0.020	0.990
25	0.28	0.000	0.010	52	0.55	0.000	0.990
26	0.29	0.000	0.010	53	0.56	0.010	1.000
27	0.3	0.000	0.010	54	0.57	0.000	1.000

Table B-20. Discrete Probability Function for PBRINE in PANEL 9

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.000	0.000	28	0.31	0.000	1.000
2	0.05	0.000	0.000	29	0.32	0.000	1.000
3	0.06	0.000	0.000	30	0.33	0.000	1.000
4	0.07	0.010	0.010	31	0.34	0.000	1.000
5	0.08	0.020	0.030	32	0.35	0.000	1.000
6	0.09	0.010	0.040	33	0.36	0.000	1.000
7	0.1	0.090	0.130	34	0.37	0.000	1.000
8	0.11	0.050	0.180	35	0.38	0.000	1.000
9	0.12	0.110	0.290	36	0.39	0.000	1.000
10	0.13	0.100	0.390	37	0.4	0.000	1.000
11	0.14	0.120	0.510	38	0.41	0.000	1.000
12	0.15	0.100	0.610	39	0.42	0.000	1.000
13	0.16	0.060	0.670	40	0.43	0.000	1.000
14	0.17	0.130	0.800	41	0.44	0.000	1.000
15	0.18	0.070	0.870	42	0.45	0.000	1.000
16	0.19	0.020	0.890	43	0.46	0.000	1.000
17	0.2	0.040	0.930	44	0.47	0.000	1.000
18	0.21	0.040	0.970	45	0.48	0.000	1.000
19	0.22	0.030	1.000	46	0.49	0.000	1.000
20	0.23	0.000	1.000	47	0.5	0.000	1.000
21	0.24	0.000	1.000	48	0.51	0.000	1.000
22	0.25	0.000	1.000	49	0.52	0.000	1.000
23	0.26	0.000	1.000	50	0.53	0.000	1.000
24	0.27	0.000	1.000	51	0.54	0.000	1.000
25	0.28	0.000	1.000	52	0.55	0.000	1.000
26	0.29	0.000	1.000	53	0.56	0.000	1.000
27	0.3	0.000	1.000	54	0.57	0.000	1.000

Table B-21. Discrete Probability Function for PBRINE in PANEL 10

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.000	0.000	28	0.31	0.070	0.130
2	0.05	0.000	0.000	29	0.32	0.070	0.200
3	0.06	0.000	0.000	30	0.33	0.120	0.320
4	0.07	0.000	0.000	31	0.34	0.070	0.390
5	0.08	0.000	0.000	32	0.35	0.080	0.470
6	0.09	0.000	0.000	33	0.36	0.080	0.550
7	0.1	0.000	0.000	34	0.37	0.060	0.610
8	0.11	0.000	0.000	35	0.38	0.070	0.680
9	0.12	0.000	0.000	36	0.39	0.030	0.710
10	0.13	0.000	0.000	37	0.4	0.080	0.790
11	0.14	0.000	0.000	38	0.41	0.070	0.860
12	0.15	0.000	0.000	39	0.42	0.030	0.890
13	0.16	0.000	0.000	40	0.43	0.040	0.930
14	0.17	0.000	0.000	41	0.44	0.020	0.950
15	0.18	0.000	0.000	42	0.45	0.010	0.960
16	0.19	0.000	0.000	43	0.46	0.020	0.980
17	0.2	0.000	0.000	44	0.47	0.010	0.990
18	0.21	0.000	0.000	45	0.48	0.010	1.000
19	0.22	0.000	0.000	46	0.49	0.000	1.000
20	0.23	0.000	0.000	47	0.5	0.000	1.000
21	0.24	0.000	0.000	48	0.51	0.000	1.000
22	0.25	0.000	0.000	49	0.52	0.000	1.000
23	0.26	0.000	0.000	50	0.53	0.000	1.000
24	0.27	0.010	0.010	51	0.54	0.000	1.000
25	0.28	0.010	0.020	52	0.55	0.000	1.000
26	0.29	0.020	0.040	53	0.56	0.000	1.000
27	0.3	0.020	0.060	54	0.57	0.000	1.000

Appendix C. Documentation of EPA TDEM Block Model for Calculating GLOBAL:PBRINE

C.1 Introduction

Encountering a Castile brine reservoir can impact waste isolation at the WIPP repository. A future exploratory borehole inadvertently drilled through a closed WIPP waste panel could penetrate pressurized brine in the underlying Castile Formation and release that brine into the waste panel. The release could occur during drilling, through open, unplugged portions of the borehole after abandonment, and through slower but longer term seepage through degraded borehole casing and plug materials. The probability of encountering Castile brine in an exploratory borehole in sufficient quantities to affect repository performance is encoded in WIPP performance assessment (PA) by the parameter GLOBAL:PBRINE.

This document describes an updated method for estimating the value of parameter GLOBAL:PBRINE, herein identified simply as PBRINE or *pbrine*. The following section defines the input data sets used by the model. A discussion of the conceptualization and justifications for the probability distributions assigned to uncertain model parameters is presented in Section C.3. The probability distributions, functions and arrays used in the EPA Block Model code are defined in Sections C.4, C.5, and C.6, respectively. The central algorithm used in the model is described in Section C.7. These sections are followed by a discussion of the mathematics for summarizing model results in Section C.8.

Contents of the input files are listed in Attachment A. The output files are listed in Attachment B. A description of all variables used in the model is provided in Attachment C, and the R script is listed in Attachment D. Attachment E contains a listing of the runfile that is created when the program is run in R.

C.2 Input Data

The results of the TDEM survey are described in The Earth Technology Corporation (1987). The Earth Technology Corporation made a total of 38 TDEM soundings at the WIPP site, of which 35 were in a rectangular 1 x 1.5 km grid of soundings spaced 250 m apart, one additional sounding was made off the northeast corner of that grid, and two were made at control sites near existing boreholes WIPP-12 and DOE #1. The measurement grid and sounding locations are shown in Figure C-1. The data points of primary interest in developing the block model were within the grid of 35 soundings. This grid represents an array of point values at different depths within 3-dimensional space, with each point indicating the depth to the uppermost region of high electrical conductivity. Based on the stratigraphic layering of the Castile Formation and the conceptualization of brine reservoirs occurring within those layers, each TDEM sounding result was interpreted to represent a point on a laterally extensive horizon of high electrical conductivity. Such horizons were in turn interpreted to represent horizons of elevated brine content because there were no other likely causes of electrical resistivities as low as about 1 ohm-m beneath the WIPP site (The Earth Technology Corporation 1987, p. 5).

The input data for the EPA TDEM Block Model include three sets of rectangles and the TDEM soundings. The first set of rectangles defines the cells shown in the schematic layout of the repository used in BRAGFLO depicted in Figure C-2. The repository cell layout is represented by a schematic grid shown in Figure C-2. The cell grid was converted to a true-to-scale representation with coded cells representing the waste, pillar, and DRZ areas and planned panel closures for use in the statistical sampling shown in Figure C-5.

The second set of rectangles defines the field measurement design blocks used in the TDEM study, including the sounding depth reported for each block. These data are shown in Figure C-1. These blocks form the basis for the EPA TDEM Block Model, presented originally in EPA 1998. The EPA Block Model interpretation of the TDEM sounding data adapted from that report is shown in Figure C-3.

The third set of rectangles defines the 10 waste panels, as shown in Figure C-4. A description of the three input data files follows. The contents of each file are listed in Attachment A.

C.2.1 Repository Cell Layout

The repository cell layout is described by a set of 1,521 coordinate vectors with the boundaries and characteristics of cell i in panel j:

$$R[i,j] = (x1, y1, x2, y2, t)$$

where $x1, y1, x2$ and $y2$ are the x and y coordinates of the (1) lower-left and (2) upper-right corners of the BRAGFLOW site diagram cells shown in Figure C-2. The cell dimensions for the x and y spacing are shown along the bottom and left borders of the diagram. The symbol t denotes an identifier for the type of cell. Cell types include waste area, closures, disturbed rock zones (DRZs), and halite. The cell types are shown in different colors in Figure C-2. Waste area cells are identified by cell color type “3” in the input file.

Cells were grouped by panel, and the set of all cells for panel j is denoted by $R[:,j]$. The 10 panels contain varying numbers of cells of each type. Cells forming the corridors in Panels 9 and 10 have been slightly widened (and the intervening halite cells correspondingly narrowed) to accommodate the required waste capacity (see discussion in EPA 2015, Section 5.2.2). For purposes of the updated PBRINE analysis, the areas of panel 9 and 10 corridors were increased by about 3%. The rectangle coordinates describing each cell are contained in the input file *cells-by-panel.prn*. This file is listed in Attachment A.

C.2.2 TDEM Blocks

The TDEM “blocks” are defined as the rectangles of equal area with the sounding locations shown in Figure C-1 at the center of each rectangle. The outlines of the digitized versions of the TDEM blocks are shown in Figure C-5 overlaid with the cell layout of the repository. Mathematically the TDEM blocks are rectangles described by a set of 36 coordinate vectors with the boundaries of TDEM block k:

$$B[k] = (x1, y1, x2, y2)$$

where $x1, y1, x2$ and $y2$ are the x and y coordinates of the lower-left and upper-right corners of TDEM block k. The rectangle coordinates describing each block are contained in the input file *Blocks.prn*. This file is listed in Attachment A.

C.2.3 TDEM Sounding Data

Each TDEM block has an associated sounding depth $T[k]$. The sounding depths reported on Figure C-1 are assigned to each block. The sounding values determine the depth to the horizontal upper surfaces of the blocks shown in the view on the left of Figure C-3. These laminar surfaces are illustrated with the vertical walls removed on the right in Figure C-3. Under the EPA Block Model assumptions, the measured sounding depth applies to all points within the upper surface of the TDEM block. The sounding depths for each block are contained in the input file *Blocks.prn*. This file is listed in Attachment A.

C.2.4 Panel Layout

A true-to-scale panel layout is shown in Figure C-5. The two northern panels (1 and 8) are located over the TDEM blocks with the highest elevations (shallowest depth). The four southwestern panels (5, 6, 7 and 9) are located over the TDEM blocks with the lowest elevations (greatest depth). The four remaining intermediate panels (2, 3, 4 and 10) are located between these two groups.

A set of 10 coordinate vectors defines the boundaries of panel j:

$$P[j] = (x1, y1, x2, y2)$$

where $x1, y1, x2,$ and $y2$ are the x and y coordinates of the corners of the smallest rectangle containing all of the waste area and closure cells in panel j. The panel outlines are shown in thin black lines, generally lying between the yellow DRZ and the green waste areas shown in Figure C-5. The lines are best seen using an enlarged view. The repository layout and TDEM blocks are superimposed in this figure. The coordinates of a rectangle describing each panel contained in the input file *Panels1-10.prn*. This file is listed in Attachment A.

C.3 EPA Block Model Probability Distribution Parameter Estimates

This section defines the model input parameters and their uncertainty. Uncertain input parameters include the depth to the base of the Castile Formation, the measurement error in the reported TDEM soundings, and the frequency of encountering brine when a HCZ is penetrated. Area weights used to combine simulation results from the ten panels are also presented.

C.3.1 Uncertainty in the Depth of the Base of Castile (*Cupper, Clower*)

The results of the TDEM survey of the WIPP site are described in a report by The Earth Technology Corporation (1987). The depth to the first electrically conductive horizon beneath the WIPP site was determined at each sounding location by The Earth Technology Corporation from the results of the TDEM survey. The depth of these horizons is important because electrically conductive horizons were found in both the Castile and the underlying Bell Canyon Formations but only horizons in the Castile are important to repository performance.

The Castile – Bell Canyon contact represents the bottom of the Castile Formation and the top of the Bell Canyon Formation. The depth of this contact beneath the waste panels is uncertain because of the understandable lack of borehole information beneath the waste panels. Two different estimates of the uncertainty in the depth of this contact were made for DOE's 1992 WIPP Preliminary Performance Assessment (SNL 1992). The first estimate is documented on a parameter data sheet and indicates that the elevation of this contact is represented by a uniform distribution ranging from -228 m to -198 m above mean sea level (amsl), with a median of -213 m (SNL 1992, Volume 3, p. 2.10). The second estimate was used in a Monte Carlo analysis described in Section 5.1 of the same document with a range from -230 m to -170 m amsl and a median of -200 m.

In preparing the first estimate, SNL states that, due to the lack of boreholes, the elevation of the top of the Bell Canyon and the elevation of the base of Anhydrite III in the Castile Formation directly below the repository "…can only be inferred from a geologic cross section ..." (SNL 1992, p. 2-4). SNL further states (SNL 1992, p. 2-4):

> "The geologic structure is uncomplicated, thus the uncertainty is likely to be small on the regional geologic scale. Because the information is important to evaluating the potential for and size of brine reservoirs under the repository, uncertainty bounds have been placed on these two elevations inferred from the geologic cross section."

Projecting from the two closest wells (Cabin Baby-1 and DOE-2) that provide data for the top of the Bell Canyon, SNL estimated the elevation of the top of the Bell Canyon at the location of borehole ERDA-9 to be -213 m amsl with the foregoing range of -228 m to -198 m amsl. ERDA-9 was only drilled to the top of the Castile but is located immediately north of the repository waste area and was used by SNL as a reference location for the waste panels on the cross section.

In preparing the second estimate of the top of the Bell Canyon, SNL describes the TDEM survey and then states (SNL 1992, p. 5-2):

> "The entire Bell Canyon Formation directly beneath the Castile Formation is a good conductor. However, in several places underneath the WIPP disposal area, the elevation to the first major conducting media detected lay above the top of the Bell Canyon Formation (~ -200 ±30 m [-654 ±100 ft] in the ERDA-9 well but below the bottom of the Salado Formation (178 m [582 ft] in ERDA-9) ..."

Although the foregoing text is not entirely clear, this second estimate is likely a more generalized version of the first estimate. Both estimates refer to the same figure and section of SNL (1992) for further information however that section describes the rationale for the first estimate but not the second. The Agency chose to use the first estimate in determining the uncertainty in PBRINE because of the lack of clarity in the basis for the second estimate and because the first estimate places more of the TDEM high electrical conductivity zones within the Castile Formation and is therefore slightly more conservative.

The TDEM data are given as depths with reference to the ground surface while the data for the top of the Bell Canyon are given as elevations with reference to mean sea level. To be compatible, these two data sets must be expressed relative to the same reference point. To accomplish this, the Agency converted the elevation data to depth beneath the ground surface. The ground surface elevation above the waste panels is required to make this conversion and this elevation must be considered a nominal reference value because the ground surface at the WIPP site is nearly but not completely level. The reference elevation was determined based on the following information. Popielak et al. (1983, p. H-49) state that the floor of the disposal facility at the Experimental Shaft Station is at an elevation above mean sea level of about 1265 feet, which is equivalent to about 385 m amsl, and Hanson (2003, p. 7) states that the WIPP repository is situated at a depth of 655 m below the ground surface. Adding these two gives a nominal ground surface elevation of 1,040 m amsl. The best estimate depth of the Castile – Bell Canyon Contact was therefore determined to be 1,253 m below the ground surface with an uncertainty range of *Cupper*=1,238 m to *Clower*=1,268 m. Because little is known about the shape of this distribution, it was assumed to be uniform consistent with the assigned distribution in DOE's Preliminary Performance Assessment (SNL 1992, Volume 3, p. 2-10).

C.3.2 Parameter for TDEM Measurement Error Uncertainty (*S*)

The results of the TDEM survey of the WIPP site are described in a report by The Earth Technology Corporation (1987). As previously stated, the TDEM sounding locations consist of a regular 5 x 7 array of 35 points, one additional sounding at the northeast corner of the grid, and corroborative soundings near boreholes WIPP-12 and DOE #1. The depth to the first electrically conductive horizon beneath the WIPP site was determined at each sounding location by The Earth Technology Corporation from the TDEM results. The points in the array of sounding locations are spaced 250 m apart.

The Earth Technology Corporation (1987, p. 19) reported an uncertainty of ±75 m in the depths associated with the TDEM soundings but did not associate that uncertainty with a more rigorous statistical definition. In preparing this model for estimating uncertainty in PBRINE, the reported uncertainty of ±75 m was treated as a measurement error of one standard deviation of a normal distribution about each TDEM depth value. The Agency acknowledges that interpreting the reported TDEM depth uncertainty of ±75 m in terms of a more rigorous statistical definition requires judgment. The Earth Technology Corporation (1987, p. 19) states that the ±75 m range was developed based on an evaluation of 'three typical soundings' from the survey area. The TDEM results were evaluated using a 4-layer model. The thicknesses of the two horizons above the salt section (the Dewey Lake and Rustler) were known and held constant while the thickness of the high resistivity salt section (Salado and Castile) above the first conductive horizon was varied. The combination of these three thicknesses gave the depth to the fourth layer, which was the top of the first conductive layer. The Earth Technology Corporation (1987, p. 18) acknowledged that inversions of geophysical data are not unique, but stated that there generally is a range of values for each parameter that matches the observed data with the same error of mismatch. That range of values is called the equivalence of the solution.

The Earth Technology Corporation (1987, Figures 4-4, 4-5, and 4-6) calculated the root mean squared (RMS) error in the thickness of the salt section for the three typical soundings for 15 combinations of parameter values using a forward model. They then plotted those results against the thickness of the salt section, identified the RMS error associated with the equivalence of the solution, and from that they determined the range of uncertainty (or range of equivalence) in the thickness of the salt section. This range of uncertainty is also the range of uncertainty in the depth of the top of the first conductive horizon below the salt section. An example plot is presented in Figure C-6. In the three soundings studied by The Earth Technology Corporation, the validity of the range of uncertainty was corroborated by the results of ridge regression inversions of the apparent resistivity curves determined from the field soundings, each of which lay within the uncertainty range. Figure C-6 shows hand-written scaling performed by the Agency to determine the width of the range of equivalence. In the case of Figure C-6, the range was about 140 m, representing an uncertainty of ±70 m. The results of the other two soundings showed ranges of 106 m, or ±53 m, and 94 m, or ±47 m. Based on these results, The Earth Technology Corporation (1987, p. 19) apparently conservatively selected a potential error of ±75 m and stated that "It can be concluded from Figures 4-4, 4-5, and 4-6 that the accuracy of determining depth to brine is better than 75 m."

The Agency understands how the foregoing conclusion could be reached when based only on results from the three figures. However, the soundings associated with these figures were selected because they were "typical" and not because they were bounding. If all 36 soundings from the survey grid had been similarly evaluated, perhaps a bounding error would have been identified. But only three out of 36 soundings were evaluated and it is unlikely that one of those three represented a bounding error value. The question then remains, how should the ±75 m error range be interpreted in terms of the standard deviation of a normal distribution of measurement error, and more specifically, should this error represent one standard deviation or two standard deviations? The Agency considered the following factors in deciding which approach is most consistent with the data.

- If the ±75 m measurement error is assumed to represent two standard deviations, it would have to be considered a bounding value encompassing about 95% of the results. If the ±75 m error range is assumed to represent one standard deviation, it would encompass a smaller fraction (about 68%) of the results and would include the majority of results but would not be considered a bounding value.
- The ±75 m error range was developed based on only three out of 36 TDEM soundings and those three were selected because they were typical and not because they were bounding.
- The ±75 m error range was based on RMS error values which are very similar to the standard deviation. The RMS error is a measure of the deviation from the expected value of a parameter while the standard deviation is a measure of the deviation from the mean value of a set of data.

Based on the foregoing considerations, a value of *S*=75 m is assigned to represent one standard deviation.

C.3.3 Parameters for Uncertainty in the Probability of Brine in a HCZ *(plower, pupper)*

Two statistical distributions were needed to determine the uncertainty in PBRINE. The first is a distribution of the probability (pHCZ) that a borehole penetrating a waste panel would also penetrate an underlying high electrical conductivity zone (HCZ) in the Castile Formation. This probability is simulated based on the TDEM data, the measurement error parameter *S*, and the depth of the base of the Castile parameters *Cupper* and *Clower* described above. The second is a distribution of the conditional probability that a borehole that intersects a high electrical conductivity zone would also yield brine in sufficient quantity to be important to WIPP performance: *p[brine|HCZ]*. These two distributions are described below.

To develop the distribution of pHCZ, the probability that a borehole penetrating a waste panel would also penetrate an underlying high electrical conductivity zone was separately determined for each waste panel by randomly selecting 100 borehole locations in each panel and determining whether each borehole would intersect a high electrical conductivity zone in the Castile. The frequency of intersection determined from these 100 boreholes provided one estimate of the value of pHCZ. This step was then repeated 100 times to give 100 estimates of pHCZ for each panel. The 100 estimates were used to construct a frequency distribution for PBRINE for each panel using the conditional probability described below. The 10 panel distributions were then combined into a single weighted-average distribution of PBRINE for the repository. Because the panels are not all the same size, the weights assigned for the larger panels were increased, and the weights were reduced for the smaller panels to compensate for the different probabilities of a random intersection in the waste areas of panels 1-8, versus panels 9 and 10. In all, 100 estimates of PBRINE were developed for each panel for a total of 1,000 estimates.

The conditional probability *p[brine|HCZ]* was separately developed as a uniform distribution with a wide range of *plower*=0.05 to *pupper*=1.0. A uniform distribution was again selected because it is the maximum entropy distribution when little is known about a parameter except for its range. The limits of this range were selected as bounding values and the range is intentionally broad. It encompasses what is known and not known about the presence of Castile brine beneath the WIPP waste panels, it encompasses the alternative models of the brine reservoirs and their fracture networks, and it considers the types of brine encounters that could be potentially important to WIPP performance.

The low end of the range (*plower*=0.05) is based on the updated regional frequency of brine encounters reported by drillers as documented by Kirchner et al. (2012, p. 2). Given the uncertainties in geological conditions in the Castile beneath the repository, this uncertainty can be best bounded by conservatively assuming that deformation beneath the repository could be locally intense and that a fracture network of the type found at ERDA-6 could be present. If a fracture network of the type found at ERDA-6 is present beneath the WIPP repository, the associated brine reservoir would only be important to WIPP performance if a borehole inadvertently intersected one or more large fractures. Such fractures would yield enough brine to be noticed and logged by a driller and the low end of the range could be conservatively supported by the updated drilling data.

The high end of the range (1.0) considers that a brine reservoir beneath the waste panels could be of the type encountered at WIPP-12: it could have a dense, well dispersed, transmissive fracture network consisting of rare large fractures, a larger number of smaller fractures, and many microfractures. Brine yields need not be large to be of potential importance to WIPP performance and such yields could come from smaller as well as larger fractures and be supported long-term by a large array of microfractures. The density of the network could be large enough to support a high probability that a borehole would intersect at least one fracture that would yield sufficient brine to be important to WIPP performance. As a bounding limit that probability would be the physically possible value of *pupper*=1.0.

C.3.4 Panel Area Weights

Panel selection probabilities were developed by computing the total waste area inside each waste panel. The panel area weights w_j are defined as the proportion of the total waste area that is contained in panel j. The weight values are shown in Table C-1.

Table C-1. Waste Panel Areas and Area Probability Weights w_j

Waste Panel Number	Panel Waste Area (m^2)	Percent of Total Area	Panel Probability (w_j)
1	11,728	10.5	0.105
2	11,690	10.5	0.105
3	11,690	10.5	0.105
4	11,690	10.5	0.105
5	11,690	10.5	0.105
6	11,690	10.5	0.105
7	11,690	10.5	0.105
8	11,728	10.5	0.105
9	8,844	7.9	0.079
10	9,064	8.1	0.081
Total	**111,502**	**100**	**1.0**

C.4 Probability Distributions for Uncertain Input Parameters

C.4.1 Random Depth for Base of Castile

Uncertainty in the depth of the base of the Castile is represented by a uniform distribution from $Cupper = 1238\ m$ to $Clower =\ 1268\ m$:

$$C \sim Uniform(Cupper, Clower)$$

C.4.2 Random Depth Sounding within a TDEM Block

Uncertainty in the depth of the uppermost high conductivity zone (HCZ) within a TDEM block is represented by a normal (Gaussian) distribution with mean $T[k]$ (defined above) and standard deviation $S = 75\ m$. The standard deviation represents measurement error in the sounding depth recorded for the block.

$$Z \sim Normal(T[k], S)$$

C.4.3 Conditional Probability of Encountering Brine within a HCZ

A conditional uniform distribution is used in the model for the probability that a borehole encounters brine given that a high conductivity zone (HCZ) above the base of the Castile is penetrated. The upper and lower bounds selected for this uniform distribution are $plower = 0.05$ (5%) and $pupper = 1.0$ (100%).

$$p\{brine|HCZ\} \sim Uniform(plower, pupper)$$

To determine if brine is encountered when a HCZ above the base of the Castile is penetrated by a borehole, a sample value p from this conditional distribution is used as success rate parameter of a Bernoulli random variable:

$$X|p \sim Bernoulli(p)\ and\ p{\sim}Uniform(plower, pupper)$$

The Bernoulli random variable can have a value of 0 or 1:

$$X = 1\ with\ probability\ p; and$$
$$X = 0\ with\ probability\ (1 - p).$$

If the sampled value is $X = 1$, the borehole is counted as encountering brine sufficient to impact repository performance. The expected value of the random variable X is

$$E(X) = E\big(E(X|p)\big) = E(p) = (\ plower +\ pupper)/2 = 0.525$$

C.5 Definitions of Functions, Operators and Commands used in Pseudo-Code

C.5.1 Random Borehole Location inside Panel j*: b=random(P[j])*

The coordinates of a random borehole location $b = (bx, by)$ inside panel j with boundary coordinates $P[j] = (x1, y1, x2, y2)$ are selected from uniform distributions defined by the x and y boundaries of the panel rectangle

$$bx \sim Uniform(x1, x2)$$
$$by \sim Uniform(y1, y2)$$

C.5.2 Search function: $\boldsymbol{m}$=($\boldsymbol{b}$,$\boldsymbol{R}$)

This function is used to find which rectangle contains the borehole location b, given a set of mutually exclusive rectangles $R = (R1, \ldots, Rn)$ to choose from. Here R may be the set of repository layout cells for a panel (1a above), or the set of TDEM blocks (1b above).

C.5.3 Sort function: *v=sort(M)*

This function selects the non-missing elements of an array M, and returns the elements as a 1-dimensional array, sorted from lowest to highest value. The array M may be either 1-dimensional or 2-dimensional. The sort function is included in the R Base package.

C.5.4 If Control Statement: if(Condition,Action A,Action B)

This command controls the flow of the steps in the simulation. If the $Condition$ is true, then $Action\ A$ is performed next, otherwise $Action\ B$ is next.

C.5.5 Increment a Counter by 1 Count: $⟦n[i,j]⟧^{(++)}$

This operator increments the $(i,j)^{th}$ element of the counter array $n[i,j]$ by 1 count. The counter arrays are defined below.

C.5.6 Next: *next*

The "next" command halts the processing of the current borehole and advances to the next borehole in the simulation.

C.5.7 Create Panel Name as Factors: *pfactors(root)*

The *pfactors* function creates panel names to use as factors in *xtabs*. A two-digit character string ("01" to "10") is appended to *root*.

C.5.8 Combine into a Dataframe: *combined(array1,array2)*

The *combined* function combines the two arrays into a dataframe and adds the panel names as factors.

C.5.9 Calculate a Weighted-Average Distribution: *weights(matrix)*

The *weights* function uses matrix multiplication to calculate the weighted average of the 10 panel distributions (contained in *matrix*) using the panel area weights.

C.5.10 Print output: output(table,filename)

The output function prints a table as a text file to the filename provided and to standard output.

C.6 Arrays for Counting Borehole Outcomes

The counter arrays are used to store the output of the simulation. The counter arrays are initialized to the value 0. The underlined letters in the text below indicate the source of the subscripts. The counter arrays are three of the seven output files created by the model. The output files are listed in Attachment B. The file names are *blok7_nw.txt, blok7_nwc.txt,* and *blok7_nwcb.txt*, respectively.

C.6.1 Waste Area Intrusions

The number of boreholes penetrating a Waste area type cell in panel j in iteration i:

$$n_W[i,j]$$

C.6.2 Waste Area Intrusions that Penetrate a HCZ above the Base of the Castile

The number of boreholes which pass through the Waste area of panel j and penetrate a HCZ located above the base of the Castile in iteration i:

$$n_{WC}[i,j] \leq n_W[i,j]$$

C.6.3 Waste Area Intrusions that Penetrate a HCZ above the Base of the Castile and Encounter Brine

The number of boreholes which pass through the Waste area of panel j, penetrate a HCZ located above the base of the Castile, and encounter Brine in iteration i:

$$n_{WCB}[i,j] \leq n_{WC}[i,j]$$

C.7 R Code for Monte Carlo Simulation

This section introduces the algorithm used to implement the Monte Carlo simulation. The algorithm is described in terms of pseudo-code. The pseudo-code has a similar structure to the R computer code used to implement the model. Procedures for summarizing results of the Monte Carlo simulation at the repository level are discussed in Section C.8.

The algorithm for the Monte Carlo simulation is shown in pseudo-code below. Attachment C contains a listing of all variables used in the R code with variable descriptions, file names, and file formats. The most recent version of the R code for the EPA Block Model is in the file *blok6.r*. This text file contains an R script that was run from the DOS command line using the Windows batch file *DoR.bat* using R version 3.0.3. The batch file must be modified to ensure that the location and version number of the *Rterm.exe* executable correspond to the local implementation of R. A complete listing of the code and batch file is included in Attachment D, and a listing of the runfile generated by the R interpreter is included in Attachment E. The code requires only the R Base package. Run time is approximately five minutes, depending on the hardware. The R script was run under the Windows 7 operating system.

The basic algorithm implemented in the code contains three nested loops. In the outer loop a random value *C[i]* is selected for the depth of the base of the Castile. Within the outer loop is another loop over the 10 panels. A random borehole location (b) is selected in the first step of the innermost loop. The repository layout cell (m) for this borehole location is determined using the find function. If the borehole passes through a waste cell, the $n_W[i,j]$ counter is incremented. Otherwise processing of this borehole is completed, and another random borehole location is selected.

For the boreholes that pass through a waste cell, the TDEM block (k) for the borehole location is determined. A random value Z is selected for the depth of the HCZ encountered from the Normal distribution for this TDEM block defined in Section C.4.2. If the depth of the HCZ is less than the depth of the base of the Castile ($Z \leq C[i]$), the borehole is determined to have encountered a HCZ above the base of the Castile, and the $n_{WC}[i,j]$ counter is incremented. Otherwise processing of this borehole is completed, and another random borehole location is selected.

```
for (iteration i in 1:100) {
        C[i] ~ Uniform(Cupper, Clower)
        for (panel j in 1:10) {
                while(n_W[i,j] < 100) {
                        b = random(P[j])
                        m = find(b, R[:, j])
                        if(R[m,j](t) = "Waste Area", n_W[i,j]++, next)

                        k = find(b, B[:])
                        Z ~ Normal(T[k], S)
                        if(Z ≤ C[i], n_WC[i,j]++, next)

                        p ~ Uniform(plower, pupper)
                        X ~ Bernoulli(p)
                        if(X = 1, n_WCB[i,j]++, next)
                }
        }
}
```

If the borehole encounters a HCZ above the base of the Castile, a random value (p) is selected for the probability that brine is encountered in the HCZ using the uniform distribution defined in Section C.4.3. Using the selected value of p, a value of 0 or 1 is selected for the random variable X based on the Bernoulli distribution defined in Section C.4.3. If $X = 1$, the borehole is determined to have encountered brine within the HCZ in sufficient quantity to impact repository performance, and the $n_{WCB}[i, j]$ counter is incremented.

The calculations in the innermost loop are repeated until 100 borehole locations in the waste cells of this panel have been analyzed. Then the next panel is processed in the same fashion until all 10 panels have been analyzed for the value selected for the base of the Castile at the beginning of the outer loop. Then another random value is selected for the base of the Castile and the outer loop is repeated until 100 values for the base of the Castile have been analyzed. The algorithm then terminates. The functions, control statements and commands used in the pseudo-code are defined in Section C.6.

C.8 Summary of Simulation Outcomes for Repository

C.8.1 Introduction

The result for each simulated borehole is one of three outcomes: 1) No HCZ was encountered; 2) an HCZ was encountered but brine was not; or 3) brine was encountered within the HCZ. The frequency of the three possible outcomes is depicted in Figure C-7, which shows results for Panel 2. In this example there are no HCZ or brine encounters in the eastern part of the panel due to the greater depth of the TDEM sounding to the east of the panel. All boreholes within this TDEM block encountered no HCZ. The western part of the panel has many HCZ and brine encounters because this part of the panel is in a TDEM block with a sounding at much higher elevation.

The ensemble of all possible outcomes of the Monte Carlo simulation of the probability of encountering brine are obtained from the counter arrays n_W, n_{WC} and n_{WCB}. The counter array n_W[i, j] contains the number of boreholes intrusions into the waste area of panel j in iteration i. All counts in this array are equal to 100 at the completion of the simulation algorithm. The counter array $n_{WC}[i,j]$ contains the number of these 100 boreholes that also encountered a HCZ above the base of the Castile. The counter array $n_{WCB}[i,j]$ contains the number of the 100 boreholes that encountered a HCZ above the base of the Castile and also produced brine.

C.8.2 Frequency of Encountering a High Conductivity Zone (HCZ)

The fraction of boreholes passing through a waste area and entering a HCZ above the base of the Castile in iteration i for panel j is:

$$f_{HCZ}[i,j] = n_{WC}[i,j]/n_W[i,j]$$

The f_{HCZ} array contains the simulation results for the frequency of encountering a HCZ by panel. This array is one of the seven output files created by the model. This output file is listed in Attachment B. The file name is *blok7_phcz.txt*.

The sorted array of outcomes for the frequency of encountering a HCZ above the base of the Castile for panel j is

$$p_{HCZ}^{(j)} = sort(f_{HCZ}[:,j])$$

The sorted $p_{HCZ}^{(j)}$ arrays contain 100 outcomes for the frequency of encountering a HCZ above the base of the Castile when a borehole penetrates panel j. These arrays are used to create the CDFs of p_{HCZ} for individual panels shown in Figure C-8.

Area probability weights were used to create the CDF of p_{HCZ} for the repository. Panels 9 and 10 currently are planned to have different configurations than the original eight panels, resulting in smaller areas available for waste storage. To account for this difference, smaller area weights were used for Panels 9 and 10 than for the other eight panels when constructing the repository-wide distribution. The probability-weighted CDF for pHCZ for the repository is:

$$p_{HCZ} = \sum_{j=1}^{10} w_j p_{HCZ}^{(j)}$$

Table C-1 of Section C.3.4 shows the waste areas and area probability weights assigned to each panel. The output file *blok7_phczPF.txt* contains the weighted-average frequency distribution of p_{HCZ}. The file contains 81 lines of data, one line for each realized outcome value between 0.12 and 0.93. This frequency table is one of the seven output files created by the model and is listed in Attachment B.

C.8.3 Frequency of Encountering Brine

The fraction of boreholes passing through a waste area, entering a HCZ above the base of the Castile and encountering brine within the HCZ in iteration i for panel j is:

$$f_{brine}[i,j] = n_{WCB}[i,j]/n_W[i,j]$$

The f_{brine} array contains the simulation results for the frequency of encountering brine by panel. This array is one of the seven output files created by the model. This output file is listed in Attachment B. The file name is *blok7_pbrine.txt*.

The sorted array of outcomes for the frequency of encountering brine in a HCZ above the base of the Castile for panel j is

$$p^{j}_{brine} = sort(f_{brine}[:, j]$$

The sorted $p^{(j)}_{brine}$ arrays contain 100 outcomes for the frequency of encountering brine in a HCZ above the base of the Castile when a borehole penetrates panel j. These arrays are used to create CDFs of $p_{brine}$for individual panels shown in Figure C-9. The probability weighted distribution of the parameter $PBRINE$ for the repository by combining the 10 panel CDFs using the weighting procedure described in Section C.3.2. The probability-weighted CDF for *PBRINE* for the repository is:

$$p_{brine} = \sum_{j=1}^{10} w_j p^{(j)}_{brine}$$

The $n_W[i, j]$ elements in the denominator of the expression for $f_{brine}[i, j]$ are all equal to 100, and the elements of $n_{WCB}[i, j]$ in the numerator are integer counts of a subset of these boreholes which encountered brine within a HCZ above the base of the Castile, hence the $1{,}000$ fractions in $f_{brine}[i, j]$ are all integer multiples of 0.01. The outcomes form a discrete distribution, with multiple occurrences of these discrete values among the $1{,}000$ outcomes ranging from 0.04 to 0.57. This discrete distribution is shown in Table C-2 (rounded to 3 decimal places).

A histogram of the frequency distribution of $PBRINE$ is shown in Figure C-10, where it is compared with the currently mandated uniform distribution for $PBRINE$. The output file *blok7_pbrinePF.txt* contains the frequency distribution of the 1,000 values in the p_{brine} array. The file contains 54 lines of data, one line for each possible outcome value between 0.04 and 0.57. This frequency table is one of the seven output files created by the model. This output file is listed in Attachment B.

The cumulative distribution of $PBRINE$ for the repository is shown in Figure C-11. The granularity of the discrete distribution is an artifact of the counting scheme in the model. A continuous CDF with piecewise-linear segments between adjacent discrete values could be constructed for ease of implementation. Other continuous approximations to the discrete distribution also are possible, including spline techniques. The only requirement is that the approximating continuous distribution passes through all points on the empirical CDF of the discrete distribution.

References for Appendix C

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Table C-2. Discrete Probability Function for Sampling PBRINE

Rank	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*	*Rank*	*PBRINE*	*Probability of Sampling PBRINE*	*Cumulative Distribution Function (CDF) Value*
1	0.04	0.002	0.002	28	0.31	0.016	0.609
2	0.05	0.002	0.004	29	0.32	0.024	0.633
3	0.06	0.002	0.006	30	0.33	0.020	0.653
4	0.07	0.008	0.014	31	0.34	0.020	0.673
5	0.08	0.009	0.023	32	0.35	0.016	0.689
6	0.09	0.020	0.043	33	0.36	0.023	0.713
7	0.1	0.037	0.080	34	0.37	0.023	0.735
8	0.11	0.029	0.109	35	0.38	0.024	0.759
9	0.12	0.031	0.139	36	0.39	0.015	0.774
10	0.13	0.046	0.185	37	0.4	0.022	0.796
11	0.14	0.038	0.223	38	0.41	0.029	0.825
12	0.15	0.042	0.264	39	0.42	0.027	0.851
13	0.16	0.030	0.294	40	0.43	0.023	0.875
14	0.17	0.035	0.330	41	0.44	0.015	0.890
15	0.18	0.033	0.363	42	0.45	0.018	0.908
16	0.19	0.023	0.385	43	0.46	0.019	0.927
17	0.2	0.028	0.414	44	0.47	0.012	0.939
18	0.21	0.016	0.429	45	0.48	0.013	0.953
19	0.22	0.025	0.455	46	0.49	0.012	0.964
20	0.23	0.023	0.478	47	0.5	0.012	0.976
21	0.24	0.009	0.487	48	0.51	0.006	0.982
22	0.25	0.024	0.512	49	0.52	0.004	0.986
23	0.26	0.021	0.533	50	0.53	0.006	0.993
24	0.27	0.013	0.546	51	0.54	0.004	0.997
25	0.28	0.017	0.563	52	0.55	0.001	0.998
26	0.29	0.014	0.577	53	0.56	0.001	0.999
27	0.3	0.016	0.593	54	0.57	0.001	1.000

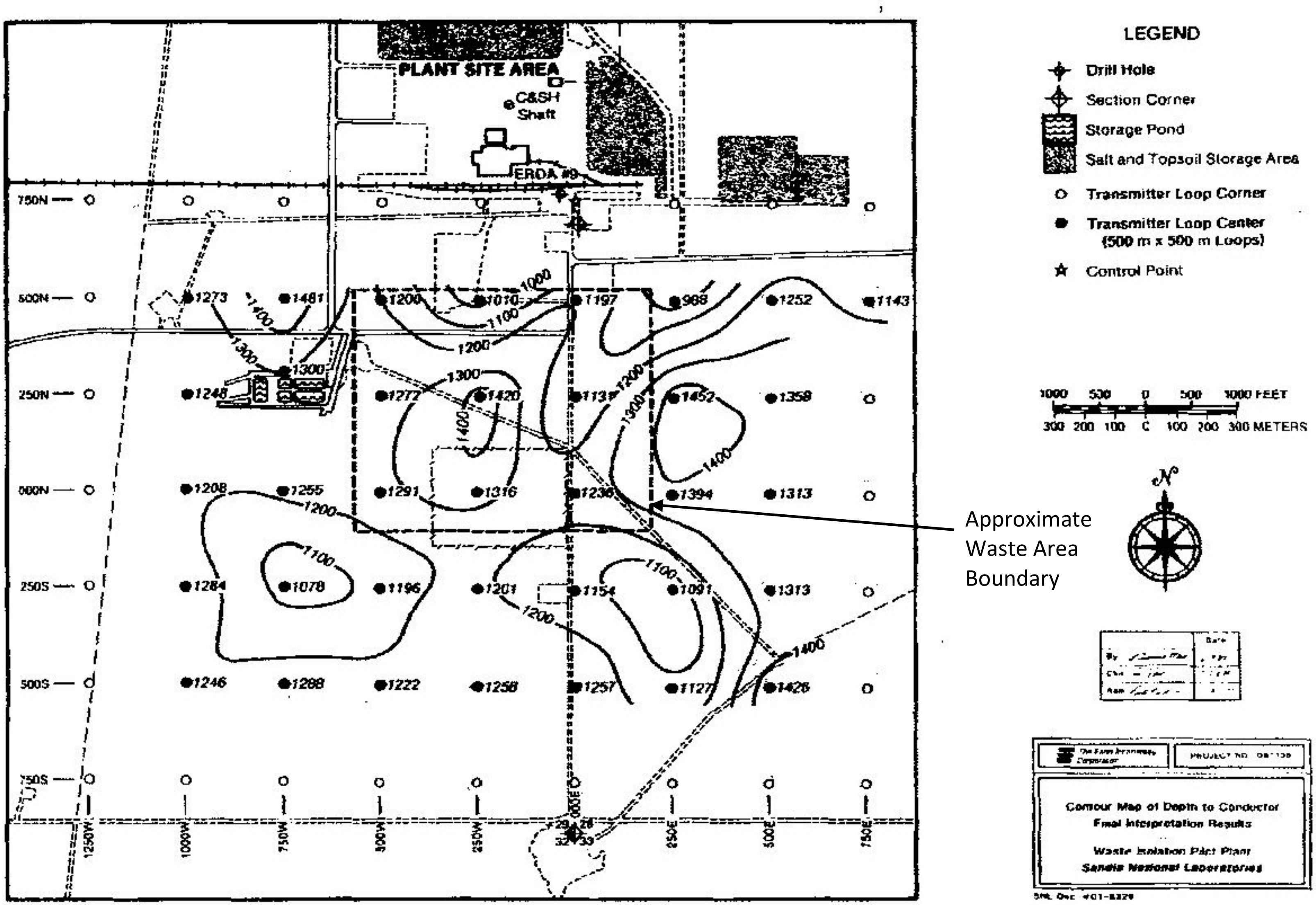

Figure C-1. TDEM Sounding Depth Data and Coordinates (The Earth Technology Corporation 1988, Figure 3-3).

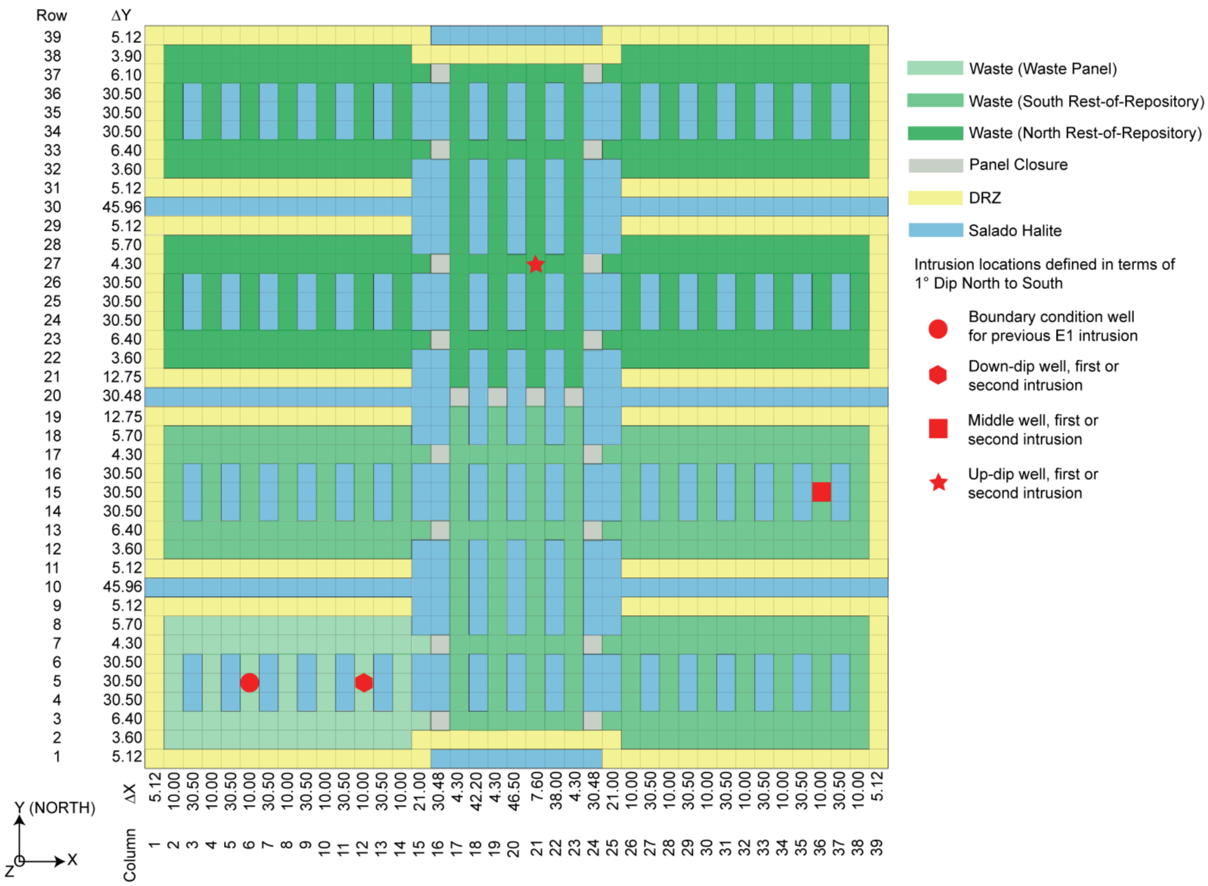

Figure C-2. Waste Panel Cell Dimensions from BRAGFLO-DBR Grid used in WIPP PA (DOE 2014, Appendix PA, Figure PA-24).

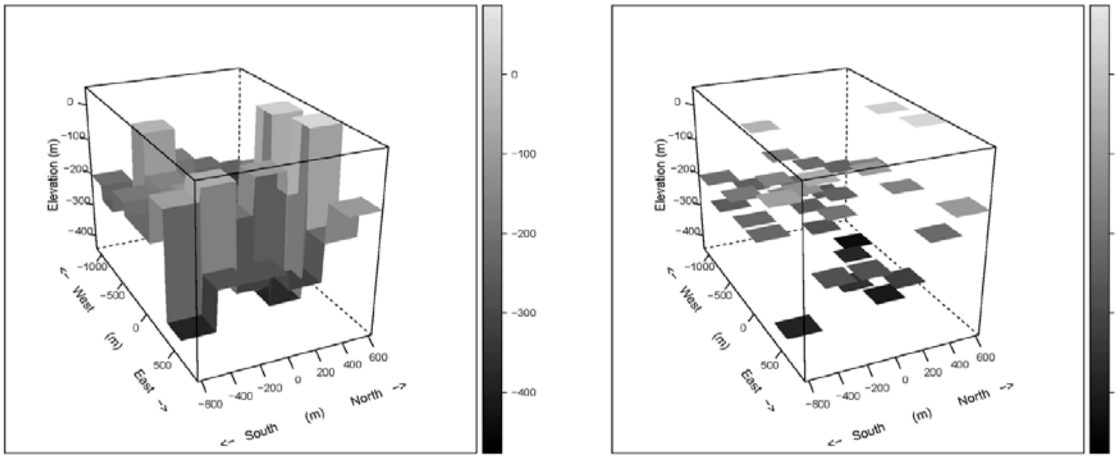

Figure C-3. Schematic illustrations of the block model for TDEM depth data, 3-dimensional (left) and laminar (right) views. All dimensions are in meters and the elevation datum is sea level (adapted from EPA 1998b, Figure 5-1A).

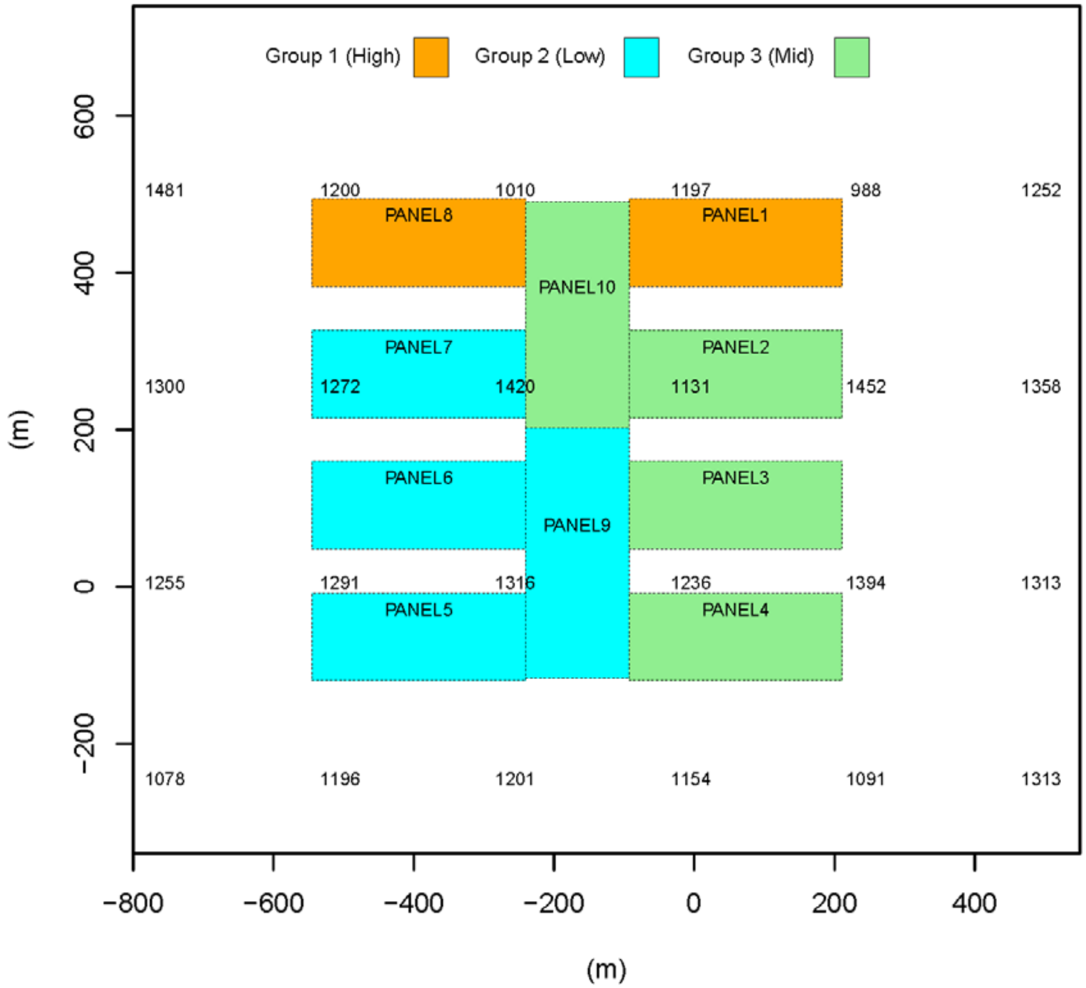

Figure C-4. Waste Panel Layout and TDEM Sounding Depths.

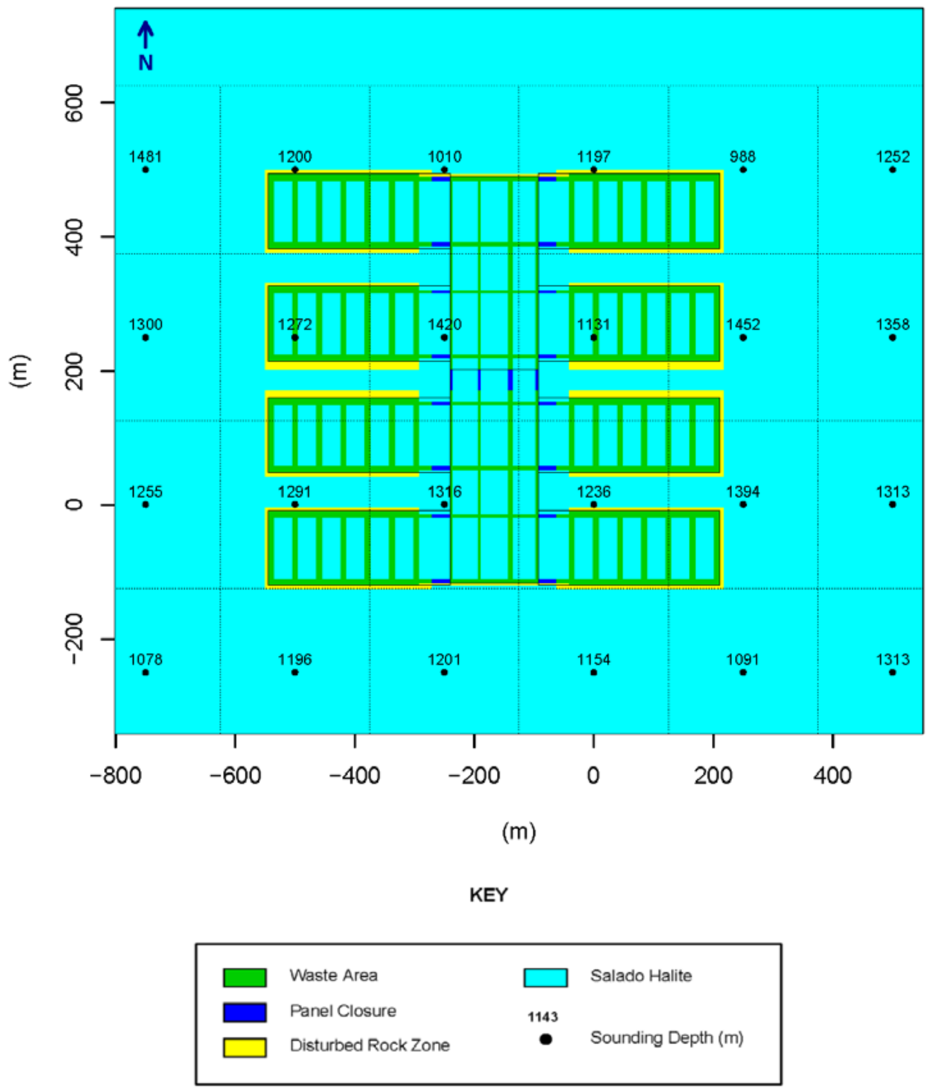

Figure C-5. Repository Cells, TDEM Blocks and Panel Layout.

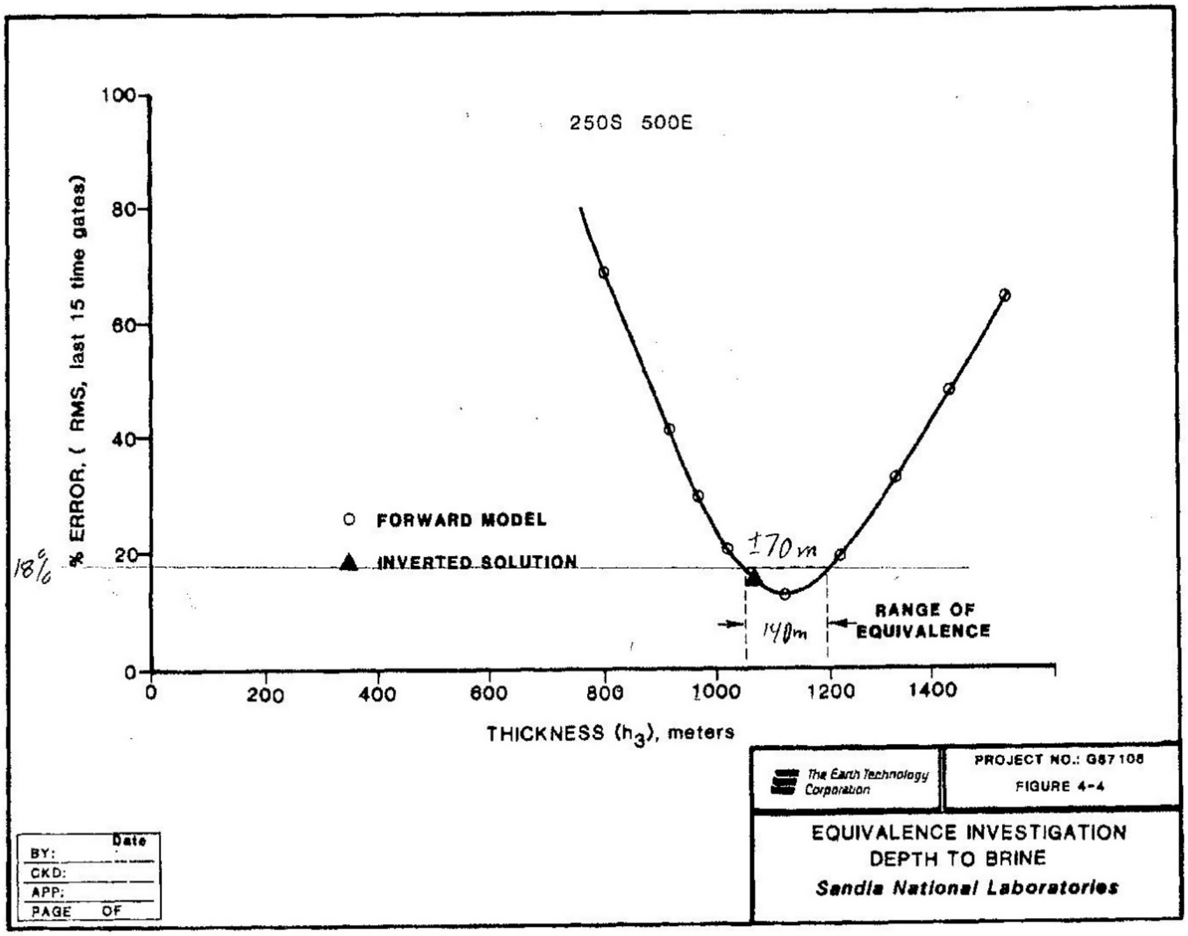

Figure C-6. Illustration of uncertainty in depth to brine (modified from The Earth Technology Corporation 1987, Figure 4-4).

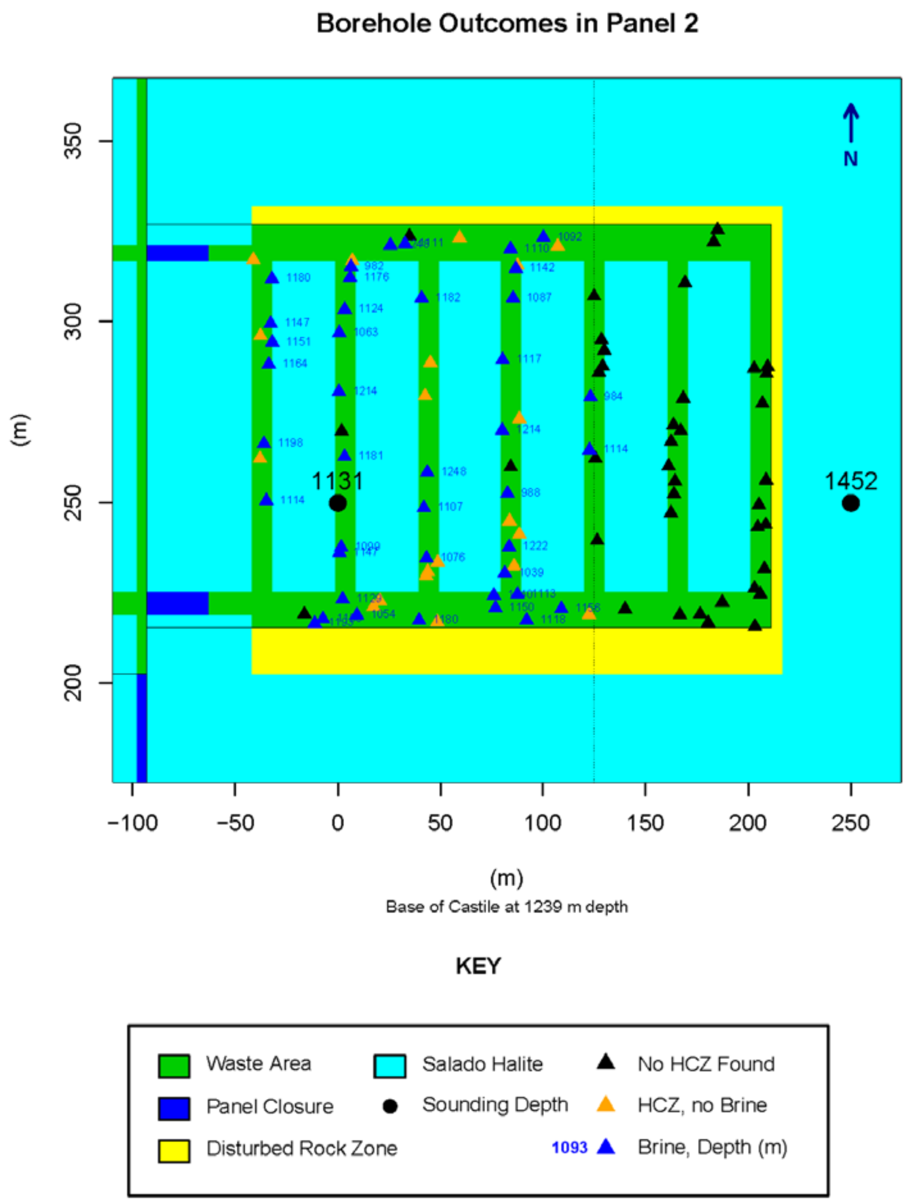

Figure C-7. Simulated borehole outcomes in Panel 2.

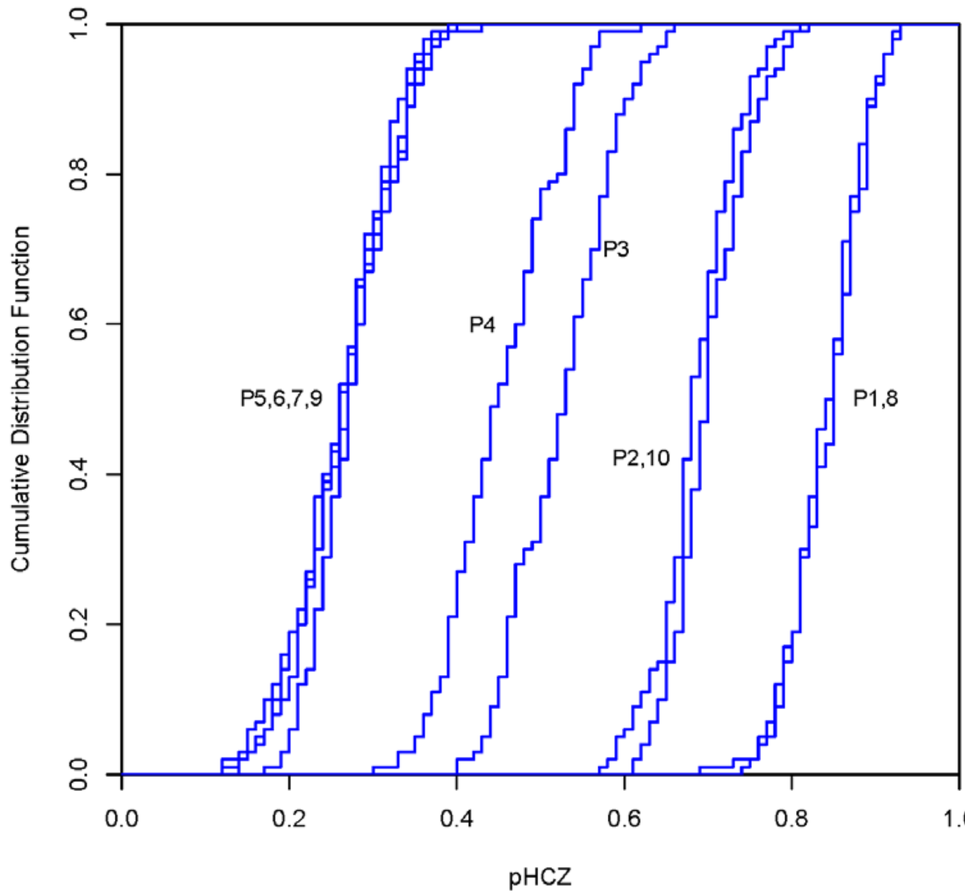

Figure C-8. Cumulative Distribution Functions (CDFs) of pHCZ by Waste Panel.

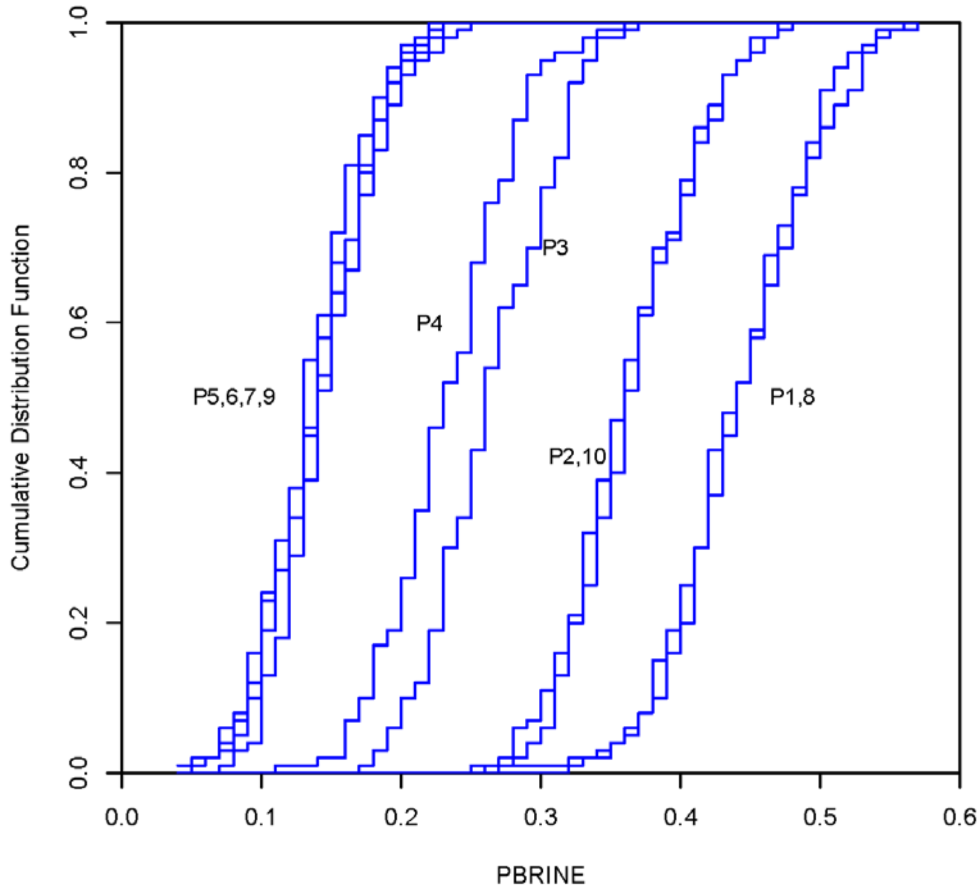

Figure C-9. Cumulative Distribution Functions (CDFs) of PBRINE by Waste Panel.

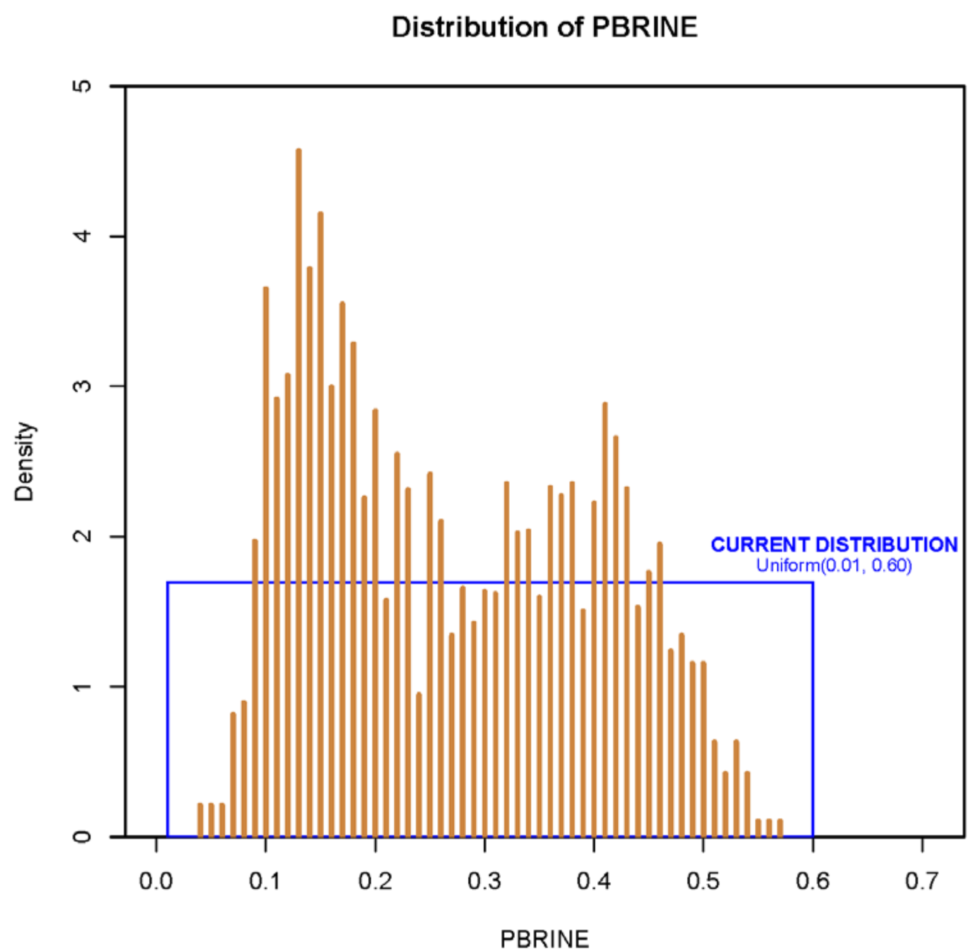

Figure C-10. . Frequency Distribution of PBRINE Compared with Currently Mandated Uniform Distribution.

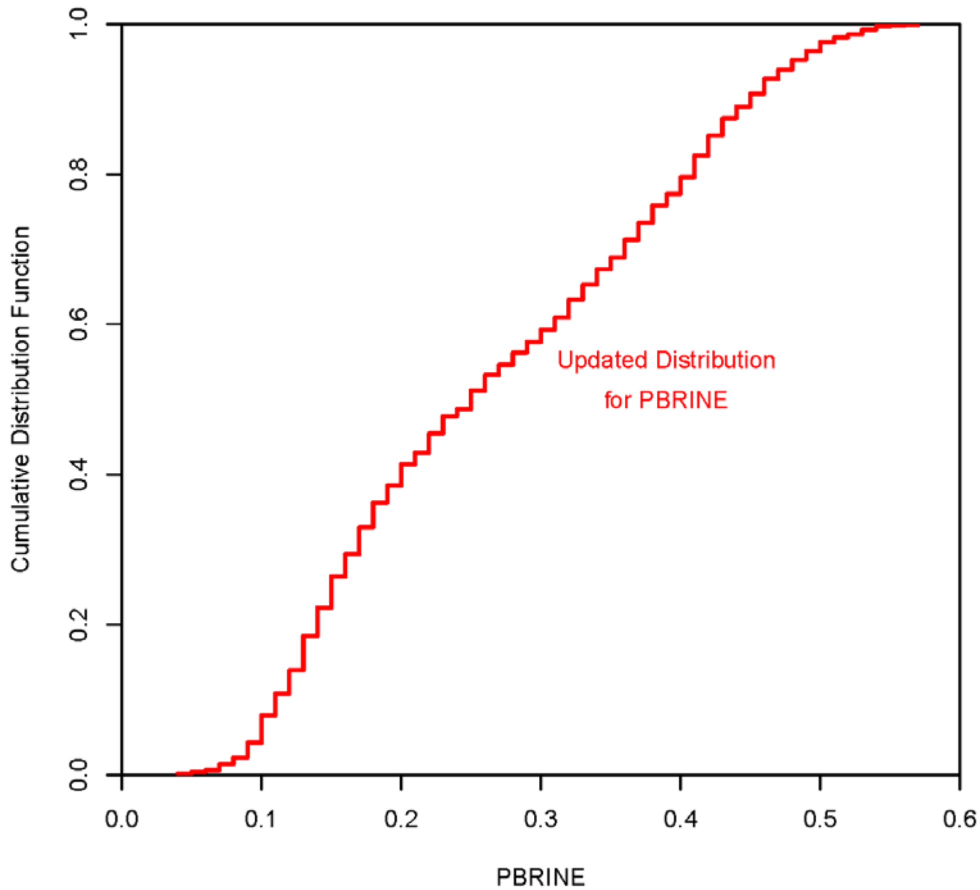

Figure C-11. Cumulative Distribution Function (CDF) of PBRINE.

Attachment A to Appendix C

Listing of EPA Block Model Input Files

1. Panels1-10.prn
   Panel Coordinates. File contains the lower-left and upper-right coordinates of a rectangle describing each panel.
2. Blocks.prn
   TDEM Block Coordinates. File contains the lower-left and upper-right coordinates of a rectangle describing each TDEM block.
3. cells-by-panel.prn
   Panel Cell Coordinates and Cell Type. File contains the lower-left and upper-right coordinates of a rectangle describing the cells within each panel.

1. **Panels1-10.prn**

panel	pxleft	pybottom	pxright	pytop
Panel1	-93.19999999999999	383.0000000000001	211.2800000000000	494.5000000000001
Panel2	-93.19999999999999	215.3000000000001	211.2800000000000	326.8000000000001
Panel3	-93.19999999999999	47.82000000000002	211.2800000000000	159.3200000000000
Panel4	-93.19999999999999	-119.8800000000000	211.2800000000000	-8.379999999999995
Panel5	-544.8800000000000	-119.8800000000000	-240.4000000000000	-8.379999999999995
Panel6	-544.8800000000000	47.82000000000002	-240.4000000000000	159.3200000000000
Panel7	-544.8800000000000	215.3000000000001	-240.4000000000000	326.8000000000001
Panel8	-544.8800000000000	383.0000000000001	-240.4000000000000	494.5000000000001
Panel9	-240.4000000000000	-116.2800000000000	-93.19999999999999	202.5500000000001
Panel10	-240.4000000000000	202.5500000000001	-93.19999999999999	490.6000000000001

2. Blocks.prn

```
      block   centerx           centery           depth            bxleft           bybottom           bxright           bytop
500N-1000W   -1000.000000000000 500.0000000000000 1273.000000000000 -1125.000000000000 375.0000000000000 -875.0000000000000 625.0000000000000
250N-1000W   -1000.000000000000 250.0000000000000 1248.000000000000 -1125.000000000000 125.0000000000000 -875.0000000000000 375.0000000000000
000N-1000W   -1000.000000000000 0.000000000000000E+00 1208.000000000000 -1125.000000000000 -125.0000000000000 -875.0000000000000 125.0000000000000
250S-1000W   -1000.000000000000 -250.0000000000000 1284.000000000000 -1125.000000000000 -375.0000000000000 -875.0000000000000 -125.0000000000000
500S-1000W   -1000.000000000000 -500.0000000000000 1246.000000000000 -1125.000000000000 -625.0000000000000 -875.0000000000000 -375.0000000000000
500N-750W    -750.0000000000000 500.0000000000000 1481.000000000000 -875.0000000000000 375.0000000000000 -625.0000000000000 625.0000000000000
250N-750W    -750.0000000000000 250.0000000000000 1300.000000000000 -875.0000000000000 125.0000000000000 -625.0000000000000 375.0000000000000
000N-750W    -750.0000000000000 0.000000000000000E+00 1255.000000000000 -875.0000000000000 -125.0000000000000 -625.0000000000000 125.0000000000000
250S-750W    -750.0000000000000 -250.0000000000000 1078.000000000000 -875.0000000000000 -375.0000000000000 -625.0000000000000 -125.0000000000000
500S-750W    -750.0000000000000 -500.0000000000000 1288.000000000000 -875.0000000000000 -625.0000000000000 -625.0000000000000 -375.0000000000000
500N-500W    -500.0000000000000 500.0000000000000 1200.000000000000 -625.0000000000000 375.0000000000000 -375.0000000000000 625.0000000000000
250N-500W    -500.0000000000000 250.0000000000000 1272.000000000000 -625.0000000000000 125.0000000000000 -375.0000000000000 375.0000000000000
000N-500W    -500.0000000000000 0.000000000000000E+00 1291.000000000000 -625.0000000000000 -125.0000000000000 -375.0000000000000 125.0000000000000
250S-500W    -500.0000000000000 -250.0000000000000 1196.000000000000 -625.0000000000000 -375.0000000000000 -375.0000000000000 -125.0000000000000
500S-500W    -500.0000000000000 -500.0000000000000 1222.000000000000 -625.0000000000000 -625.0000000000000 -375.0000000000000 -375.0000000000000
500N-250W    -250.0000000000000 500.0000000000000 1010.000000000000 -375.0000000000000 375.0000000000000 -125.0000000000000 625.0000000000000
250N-250W    -250.0000000000000 250.0000000000000 1420.000000000000 -375.0000000000000 125.0000000000000 -125.0000000000000 375.0000000000000
000N-250W    -250.0000000000000 0.000000000000000E+00 1316.000000000000 -375.0000000000000 -125.0000000000000 -125.0000000000000 125.0000000000000
250S-250W    -250.0000000000000 -250.0000000000000 1201.000000000000 -375.0000000000000 -375.0000000000000 -125.0000000000000 -125.0000000000000
500S-250W    -250.0000000000000 -500.0000000000000 1258.000000000000 -375.0000000000000 -625.0000000000000 -125.0000000000000 -375.0000000000000
500N-000E    0.000000000000000E+00 500.0000000000000 1197.000000000000 -125.0000000000000 375.0000000000000 125.0000000000000 625.0000000000000
250N-000E    0.000000000000000E+00 250.0000000000000 1131.000000000000 -125.0000000000000 125.0000000000000 125.0000000000000 375.0000000000000
000N-000E    0.000000000000000E+00 1236.000000000000 -125.0000000000000 -125.0000000000000 125.0000000000000 125.0000000000000
250S-000E    0.000000000000000E+00 -250.0000000000000 1154.000000000000 -125.0000000000000 -375.0000000000000 125.0000000000000 -125.0000000000000
500S-000E    0.000000000000000E+00 -500.0000000000000 1257.000000000000 -125.0000000000000 -625.0000000000000 125.0000000000000 -375.0000000000000
500N-250E    250.0000000000000 500.0000000000000 988.0000000000000 125.0000000000000 375.0000000000000 375.0000000000000 625.0000000000000
250N-250E    250.0000000000000 250.0000000000000 1452.000000000000 125.0000000000000 125.0000000000000 375.0000000000000 375.0000000000000
000N-250E    250.0000000000000 0.000000000000000E+00 1394.000000000000 125.0000000000000 -125.0000000000000 375.0000000000000 125.0000000000000
250S-250E    250.0000000000000 -250.0000000000000 1091.000000000000 125.0000000000000 -375.0000000000000 375.0000000000000 -125.0000000000000
500S-250E    250.0000000000000 -500.0000000000000 1127.000000000000 125.0000000000000 -625.0000000000000 375.0000000000000 -375.0000000000000
500N-500E    500.0000000000000 500.0000000000000 1252.000000000000 375.0000000000000 375.0000000000000 625.0000000000000 625.0000000000000
250N-500E    500.0000000000000 250.0000000000000 1358.000000000000 375.0000000000000 125.0000000000000 625.0000000000000 375.0000000000000
000N-500E    500.0000000000000 0.000000000000000E+00 1313.000000000000 375.0000000000000 -125.0000000000000 625.0000000000000 125.0000000000000
250S-500E    500.0000000000000 -250.0000000000000 1313.000000000000 375.0000000000000 -375.0000000000000 625.0000000000000 -125.0000000000000
500S-500E    500.0000000000000 -500.0000000000000 1426.000000000000 375.0000000000000 -625.0000000000000 625.0000000000000 -375.0000000000000
500N-750E    750.0000000000000 500.0000000000000 1143.000000000000 625.0000000000000 375.0000000000000 875.0000000000000 625.0000000000000
```

3. cells-by-panel.prn (1st 20 lines of 1522)

cpanel	cell	ccolor	cxleft	cybottom	cxright	cytop
5	D5	7	-550	-125	-544.88	-119.88
5	D5	7	-544.88	-125	-534.88	-119.88
5	D5	7	-534.88	-125	-504.38	-119.88
5	D5	7	-504.38	-125	-494.38	-119.88
5	D5	7	-494.38	-125	-463.88	-119.88
5	D5	7	-463.88	-125	-453.88	-119.88
5	D5	7	-453.88	-125	-423.38	-119.88
5	D5	7	-423.38	-125	-413.38	-119.88
5	D5	7	-413.38	-125	-382.88	-119.88
5	D5	7	-382.88	-125	-372.88	-119.88
5	D5	7	-372.88	-125	-342.38	-119.88
5	D5	7	-342.38	-125	-332.38	-119.88
5	D5	7	-332.38	-125	-301.88	-119.88
5	D5	7	-301.88	-125	-291.88	-119.88
5	D5	7	-291.88	-125	-270.88	-119.88
0	S0	5	-270.88	-125	-240.4	-119.88
0	S0	5	-240.4	-125	-235.83	-119.88
0	S0	5	-235.83	-125	-193.9	-119.88
0	S0	5	-193.9	-125	-189.32	-119.88

Attachment B to Appendix C

Listing of EPA Block Model Output Files

1. blok7_nw.txt
   Waste Area Intrusions. The number of boreholes penetrating a waste area type cell in panel j in iteration i: $n_W[i,j]$. All values are equal to 100 at end of simulation.

2. blok7_nwc.txt
   Waste Area Intrusions that Penetrate a HCZ above the Base of the Castile. The number of boreholes which pass through the waste area of panel j and penetrate a HCZ located above the base of the Castile in iteration i: $n_{WC}[i,j]$

3. blok7_nwcb.txt
   Waste Area Intrusions that Penetrate a HCZ above the Base of the Castile and Encounter Brine. The number of boreholes which pass through the waste area of panel j, penetrate a HCZ located above the base of the Castile, and encounter brine in iteration i: $n_{WCB}[i,j]$

4. blok7_phcz.txt
   Frequency of Encountering a High Conductivity Zone. The fraction of boreholes passing through a waste area and entering a HCZ above the base of the Castile in iteration i for panel j: $f_{HCZ}[i,j] = n_{WC}[i,j]/n_W[i,j]$.

5. blok7_pbrine.txt
   Frequency of Encountering Brine. The fraction of boreholes passing through a waste area, entering a HCZ above the base of the Castile and encountering brine within the HCZ in iteration i for panel j: $f_{brine}[i,j] = n_{WCB}[i,j]/n_W[i,j]$.

6. blok7_phczPF.txt
   Weighted-average Frequency Distribution of p_{HCZ}. The file contains 81 lines of data, one line for each realized discrete outcome of p_{HCZ} between 0.12 and 0.93. See Section C.8.2 for details.
7. blok7_pbrinePF.txt
   Weighted-average Frequency Distribution of p_{brine}. The file contains 54 lines of data, one line for each realized discrete outcome of p_{brine} between 0.04 and 0.57. See Section C.8.3 for details.

1. blok7_nw.txt

	Panel1	Panel2	Panel3	Panel4	Panel5	Panel6	Panel7	Panel8	Panel9	Panel10
1	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	100	100	100	100	100
9	100	100	100	100	100	100	100	100	100	100
10	100	100	100	100	100	100	100	100	100	100
11	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100
13	100	100	100	100	100	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100
15	100	100	100	100	100	100	100	100	100	100
16	100	100	100	100	100	100	100	100	100	100
17	100	100	100	100	100	100	100	100	100	100
18	100	100	100	100	100	100	100	100	100	100
19	100	100	100	100	100	100	100	100	100	100
20	100	100	100	100	100	100	100	100	100	100
21	100	100	100	100	100	100	100	100	100	100
22	100	100	100	100	100	100	100	100	100	100
23	100	100	100	100	100	100	100	100	100	100
24	100	100	100	100	100	100	100	100	100	100
25	100	100	100	100	100	100	100	100	100	100
26	100	100	100	100	100	100	100	100	100	100
27	100	100	100	100	100	100	100	100	100	100
28	100	100	100	100	100	100	100	100	100	100
29	100	100	100	100	100	100	100	100	100	100
30	100	100	100	100	100	100	100	100	100	100
31	100	100	100	100	100	100	100	100	100	100
32	100	100	100	100	100	100	100	100	100	100
33	100	100	100	100	100	100	100	100	100	100
34	100	100	100	100	100	100	100	100	100	100
35	100	100	100	100	100	100	100	100	100	100
36	100	100	100	100	100	100	100	100	100	100
37	100	100	100	100	100	100	100	100	100	100
38	100	100	100	100	100	100	100	100	100	100
39	100	100	100	100	100	100	100	100	100	100
40	100	100	100	100	100	100	100	100	100	100
41	100	100	100	100	100	100	100	100	100	100
42	100	100	100	100	100	100	100	100	100	100
43	100	100	100	100	100	100	100	100	100	100
44	100	100	100	100	100	100	100	100	100	100
45	100	100	100	100	100	100	100	100	100	100
46	100	100	100	100	100	100	100	100	100	100
47	100	100	100	100	100	100	100	100	100	100
48	100	100	100	100	100	100	100	100	100	100
49	100	100	100	100	100	100	100	100	100	100
50	100	100	100	100	100	100	100	100	100	100
51	100	100	100	100	100	100	100	100	100	100
52	100	100	100	100	100	100	100	100	100	100
53	100	100	100	100	100	100	100	100	100	100
54	100	100	100	100	100	100	100	100	100	100
55	100	100	100	100	100	100	100	100	100	100
56	100	100	100	100	100	100	100	100	100	100
57	100	100	100	100	100	100	100	100	100	100
58	100	100	100	100	100	100	100	100	100	100
59	100	100	100	100	100	100	100	100	100	100
60	100	100	100	100	100	100	100	100	100	100

61	100	100	100	100	100	100	100	100	100	100
62	100	100	100	100	100	100	100	100	100	100
63	100	100	100	100	100	100	100	100	100	100
64	100	100	100	100	100	100	100	100	100	100
65	100	100	100	100	100	100	100	100	100	100
66	100	100	100	100	100	100	100	100	100	100
67	100	100	100	100	100	100	100	100	100	100
68	100	100	100	100	100	100	100	100	100	100
69	100	100	100	100	100	100	100	100	100	100
70	100	100	100	100	100	100	100	100	100	100
71	100	100	100	100	100	100	100	100	100	100
72	100	100	100	100	100	100	100	100	100	100
73	100	100	100	100	100	100	100	100	100	100
74	100	100	100	100	100	100	100	100	100	100
75	100	100	100	100	100	100	100	100	100	100
76	100	100	100	100	100	100	100	100	100	100
77	100	100	100	100	100	100	100	100	100	100
78	100	100	100	100	100	100	100	100	100	100
79	100	100	100	100	100	100	100	100	100	100
80	100	100	100	100	100	100	100	100	100	100
81	100	100	100	100	100	100	100	100	100	100
82	100	100	100	100	100	100	100	100	100	100
83	100	100	100	100	100	100	100	100	100	100
84	100	100	100	100	100	100	100	100	100	100
85	100	100	100	100	100	100	100	100	100	100
86	100	100	100	100	100	100	100	100	100	100
87	100	100	100	100	100	100	100	100	100	100
88	100	100	100	100	100	100	100	100	100	100
89	100	100	100	100	100	100	100	100	100	100
90	100	100	100	100	100	100	100	100	100	100
91	100	100	100	100	100	100	100	100	100	100
92	100	100	100	100	100	100	100	100	100	100
93	100	100	100	100	100	100	100	100	100	100
94	100	100	100	100	100	100	100	100	100	100
95	100	100	100	100	100	100	100	100	100	100
96	100	100	100	100	100	100	100	100	100	100
97	100	100	100	100	100	100	100	100	100	100
98	100	100	100	100	100	100	100	100	100	100
99	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100

2. blok7_nwc.txt

	Panel1	Panel2	Panel3	Panel4	Panel5	Panel6	Panel7	Panel8	Panel9	Panel10
1	81	73	62	43	28	37	28	85	32	79
2	81	70	54	46	23	17	28	83	26	68
3	88	71	55	55	35	20	29	90	29	69
4	83	66	44	40	25	26	26	80	21	63
5	79	61	50	33	21	23	21	82	31	70
6	81	67	66	49	28	33	30	91	29	68
7	89	65	52	55	33	23	37	85	36	70
8	82	71	45	39	14	14	27	85	21	67
9	76	65	46	44	27	20	14	78	21	73
10	79	59	54	41	28	18	21	85	23	68
11	81	70	51	43	36	15	26	81	24	67
12	84	66	47	46	34	28	27	92	27	73
13	87	65	47	48	21	25	26	79	27	69
14	77	70	48	43	24	26	23	85	25	68
15	86	69	62	53	25	35	26	87	34	79
16	83	66	58	46	28	37	22	86	27	68
17	86	68	50	36	18	24	19	86	29	69
18	82	71	47	40	21	21	24	80	25	73
19	78	61	53	40	24	16	25	79	17	70
20	81	67	47	39	22	12	18	86	20	63
21	81	71	48	36	22	22	21	87	27	79
22	90	75	65	54	37	28	25	89	31	67
23	86	67	57	37	22	24	20	76	24	71
24	80	67	45	44	24	19	18	76	24	69
25	78	63	44	39	22	24	28	83	32	65
26	88	57	63	36	24	26	28	93	28	69
27	92	71	52	57	30	28	26	85	34	67
28	92	81	60	54	33	39	28	93	38	72
29	89	73	55	57	26	30	33	85	30	73
30	93	72	56	44	35	31	23	83	27	69
31	85	68	46	44	24	24	20	81	23	68
32	81	67	44	49	25	31	24	81	39	73
33	85	68	53	30	30	21	30	83	19	73
34	78	70	51	43	28	27	20	87	29	62
35	89	75	56	49	34	27	36	87	23	64
36	86	68	57	53	28	15	26	85	33	72
37	86	69	58	35	24	24	20	78	24	77
38	81	67	47	44	16	17	23	81	23	70
39	86	74	64	39	14	27	23	81	25	65
40	85	68	59	39	33	26	31	89	28	82
41	87	72	54	49	28	34	37	85	28	68
42	69	68	50	45	19	23	23	87	29	70
43	81	69	44	48	23	28	17	78	21	64
44	79	68	47	39	17	25	23	75	25	61
45	82	75	49	37	29	32	19	89	34	70
46	88	70	50	47	25	29	34	91	26	65
47	88	67	59	49	27	22	32	91	29	61
48	85	77	54	42	24	28	28	88	35	74
49	85	70	53	56	35	27	31	85	32	80
50	91	58	59	54	37	40	28	91	34	66
51	79	66	56	33	24	22	18	77	26	62
52	87	67	46	54	31	34	34	79	24	74
53	83	71	52	48	27	29	34	88	30	70
54	86	77	54	46	15	24	22	80	27	67
55	90	59	61	42	28	27	27	81	19	69
56	86	68	46	45	26	28	23	87	28	71
57	89	74	47	49	36	38	32	85	35	65
58	77	65	43	39	31	15	15	74	20	74
59	88	66	53	50	34	35	29	83	35	71
60	90	75	57	39	33	34	29	79	23	70

61	86	73	57	53	34	24	31	89	34	66
62	76	67	58	50	29	23	22	82	34	66
63	80	68	46	53	21	20	12	86	32	68
64	83	70	57	38	19	27	20	78	23	75
65	82	67	57	49	35	33	34	87	34	78
66	82	73	58	42	26	30	37	90	34	70
67	78	70	59	41	29	27	25	89	25	72
68	83	70	55	47	33	30	31	89	34	67
69	91	62	59	53	26	34	30	89	28	65
70	82	79	54	54	29	27	32	86	31	67
71	81	64	45	42	21	19	25	85	27	64
72	86	77	52	54	24	31	28	87	27	70
73	83	69	53	52	35	35	30	92	35	74
74	83	65	45	41	21	17	17	83	28	68
75	84	73	60	44	27	31	30	87	36	75
76	73	63	40	41	16	19	19	81	23	70
77	83	69	57	47	39	31	27	82	21	74
78	91	67	58	50	31	34	35	90	25	75
79	78	72	43	43	27	18	22	81	24	70
80	87	72	55	38	31	26	22	83	23	77
81	85	63	51	48	21	36	27	87	30	75
82	88	60	52	56	20	27	33	79	32	70
83	86	66	46	56	31	37	39	86	25	76
84	84	76	46	46	22	33	19	84	25	66
85	85	71	46	48	26	33	29	89	28	71
86	82	73	56	48	33	28	33	89	22	71
87	81	61	52	40	18	23	31	83	26	69
88	92	65	40	40	20	19	23	82	24	70
89	76	59	50	44	23	21	23	86	27	76
90	84	67	42	42	26	12	23	80	20	76
91	79	68	51	37	29	29	18	79	26	74
92	89	68	51	51	27	28	26	84	31	73
93	87	71	55	62	29	34	32	87	29	77
94	83	73	65	53	24	28	32	86	32	72
95	89	65	61	35	23	25	16	89	21	67
96	86	75	58	50	26	24	31	88	31	67
97	86	67	50	40	28	27	29	89	27	67
98	87	62	62	45	43	31	32	81	34	80
99	85	78	53	48	22	30	26	81	28	69
100	88	65	54	42	20	36	26	84	22	63

3. blok7_nwcb.txt

	Panel1	Panel2	Panel3	Panel4	Panel5	Panel6	Panel7	Panel8	Panel9	Panel10
1	41	41	34	21	14	19	13	47	12	48
2	42	38	25	27	14	9	11	38	15	33
3	53	36	30	25	23	10	17	50	11	33
4	40	37	19	21	11	10	16	44	14	34
5	44	28	25	14	9	15	15	40	14	37
6	52	45	37	26	13	19	15	48	15	33
7	49	33	26	29	17	13	19	54	22	35
8	40	35	24	16	7	8	12	48	12	34
9	33	40	18	25	12	13	8	41	12	36
10	43	30	28	19	15	9	10	46	12	38
11	46	38	32	22	20	9	15	42	12	36
12	40	37	22	20	19	16	16	46	17	41
13	48	26	23	26	9	14	15	40	15	28
14	43	38	23	16	14	15	13	40	10	36
15	49	43	34	33	18	21	12	50	20	40
16	52	37	29	21	15	20	10	44	10	33
17	43	42	31	19	12	11	8	43	16	35
18	39	43	25	22	9	12	12	48	11	39
19	54	36	26	16	8	9	13	32	7	33
20	46	42	24	17	10	4	11	50	12	33
21	39	33	22	22	13	13	13	49	14	46
22	57	34	32	25	24	14	18	49	18	41
23	47	32	26	16	11	15	12	45	18	34
24	35	31	19	18	9	9	11	36	10	35
25	37	34	24	20	14	8	14	39	16	41
26	42	31	30	22	10	15	15	44	18	37
27	42	35	30	29	12	11	14	51	15	37
28	49	43	22	29	17	15	11	56	22	36
29	50	42	31	22	18	16	16	38	15	44
30	48	34	27	24	19	15	13	41	10	32
31	45	34	23	18	15	18	10	39	16	34
32	46	34	25	28	12	19	10	50	15	34
33	44	36	26	11	17	10	17	51	12	39
34	41	41	27	20	14	14	9	42	17	30
35	38	40	32	28	14	13	23	43	14	37
36	46	28	26	29	17	9	11	37	21	32
37	48	45	32	17	13	13	13	43	14	42
38	44	32	32	22	8	9	13	42	10	33
39	49	41	32	18	7	17	9	49	10	30
40	48	38	32	23	18	15	18	42	14	43
41	55	39	28	21	16	18	23	49	18	32
42	36	37	23	29	12	13	12	49	18	40
43	39	41	20	23	11	16	6	46	12	31
44	42	32	25	21	9	10	10	25	16	29
45	42	37	25	18	17	17	10	47	19	41
46	47	45	25	26	13	20	15	42	9	38
47	47	27	36	23	17	10	18	52	14	29
48	51	41	23	16	11	14	18	46	17	38
49	51	36	24	33	14	15	15	47	15	40
50	43	35	22	34	18	20	13	45	21	31
51	41	40	23	18	7	12	11	41	13	27
52	42	34	18	30	17	19	22	38	10	33
53	48	40	25	23	14	18	13	45	17	36
54	43	43	27	24	5	13	16	38	17	32
55	43	31	30	22	10	15	11	40	13	31
56	41	31	21	30	9	12	11	46	17	35
57	45	47	22	25	19	23	13	47	13	40
58	36	36	19	20	17	10	4	39	10	36
59	35	29	29	28	16	19	12	45	20	41
60	46	44	23	25	18	17	19	42	11	41

61	41	36	28	26	20	14	20	44	18	44
62	44	32	34	24	15	10	14	41	13	31
63	48	38	27	26	10	13	7	42	14	37
64	41	35	30	18	6	14	11	46	13	45
65	43	38	33	23	14	18	10	40	17	40
66	41	37	33	26	17	15	15	50	22	36
67	51	34	31	25	14	11	13	50	13	35
68	44	33	27	23	19	20	15	45	17	32
69	45	30	32	27	15	17	16	46	16	33
70	46	44	27	28	11	15	13	43	14	33
71	37	31	23	21	13	12	15	53	17	32
72	44	38	23	31	15	16	14	40	14	42
73	45	30	26	36	23	18	11	48	21	38
74	41	28	22	17	11	10	7	45	15	31
75	39	37	29	26	18	16	14	52	19	40
76	32	37	22	25	9	10	11	46	8	35
77	44	41	30	25	25	16	10	42	8	31
78	47	28	32	27	12	20	22	49	13	47
79	45	43	21	28	17	7	13	38	11	33
80	53	36	27	18	15	11	9	46	13	43
81	50	38	30	21	10	19	15	42	15	39
82	43	36	29	29	10	13	17	42	21	43
83	53	32	20	28	14	20	17	42	13	42
84	45	35	23	25	15	22	12	35	12	40
85	54	40	23	25	13	17	13	45	16	43
86	50	39	26	22	20	17	19	42	17	35
87	47	30	26	20	7	13	19	41	17	31
88	39	36	17	21	12	12	10	38	14	32
89	42	34	20	22	13	10	13	43	12	34
90	38	35	20	20	14	5	11	38	10	46
91	46	47	26	20	10	13	13	46	17	41
92	48	34	31	25	19	10	16	42	13	38
93	39	43	32	28	16	12	18	39	15	38
94	41	41	33	25	15	20	22	48	20	40
95	50	36	30	22	15	12	8	51	11	34
96	49	37	26	22	13	14	16	37	20	35
97	40	36	26	21	11	16	14	54	14	38
98	41	37	29	26	20	20	16	50	18	37
99	53	37	27	28	9	14	16	34	17	33
100	53	33	25	24	10	18	13	37	12	36

4. blok7_phcz.txt

	Panel1	Panel2	Panel3	Panel4	Panel5	Panel6	Panel7	Panel8	Panel9	Panel10
1	0.81	0.73	0.62	0.43	0.28	0.37	0.28	0.85	0.32	0.79
2	0.81	0.70	0.54	0.46	0.23	0.17	0.28	0.83	0.26	0.68
3	0.88	0.71	0.55	0.55	0.35	0.20	0.29	0.90	0.29	0.69
4	0.83	0.66	0.44	0.40	0.25	0.26	0.26	0.80	0.21	0.63
5	0.79	0.61	0.50	0.33	0.21	0.23	0.21	0.82	0.31	0.70
6	0.81	0.67	0.66	0.49	0.28	0.33	0.30	0.91	0.29	0.68
7	0.89	0.65	0.52	0.55	0.33	0.23	0.37	0.85	0.36	0.70
8	0.82	0.71	0.45	0.39	0.14	0.14	0.27	0.85	0.21	0.67
9	0.76	0.65	0.46	0.44	0.27	0.20	0.14	0.78	0.21	0.73
10	0.79	0.59	0.54	0.41	0.28	0.18	0.21	0.85	0.23	0.68
11	0.81	0.70	0.51	0.43	0.36	0.15	0.26	0.81	0.24	0.67
12	0.84	0.66	0.47	0.46	0.34	0.28	0.27	0.92	0.27	0.73
13	0.87	0.65	0.47	0.48	0.21	0.25	0.26	0.79	0.27	0.69
14	0.77	0.70	0.48	0.43	0.24	0.26	0.23	0.85	0.25	0.68
15	0.86	0.69	0.62	0.53	0.25	0.35	0.26	0.87	0.34	0.79
16	0.83	0.66	0.58	0.46	0.28	0.37	0.22	0.86	0.27	0.68
17	0.86	0.68	0.50	0.36	0.18	0.24	0.19	0.86	0.29	0.69
18	0.82	0.71	0.47	0.40	0.21	0.21	0.24	0.80	0.25	0.73
19	0.78	0.61	0.53	0.40	0.24	0.16	0.25	0.79	0.17	0.70
20	0.81	0.67	0.47	0.39	0.22	0.12	0.18	0.86	0.20	0.63
21	0.81	0.71	0.48	0.36	0.22	0.22	0.21	0.87	0.27	0.79
22	0.90	0.75	0.65	0.54	0.37	0.28	0.25	0.89	0.31	0.67
23	0.86	0.67	0.57	0.37	0.22	0.24	0.20	0.76	0.24	0.71
24	0.80	0.67	0.45	0.44	0.24	0.19	0.18	0.76	0.24	0.69
25	0.78	0.63	0.44	0.39	0.22	0.24	0.28	0.83	0.32	0.65
26	0.88	0.57	0.63	0.36	0.24	0.26	0.28	0.93	0.28	0.69
27	0.92	0.71	0.52	0.57	0.30	0.28	0.26	0.85	0.34	0.67
28	0.92	0.81	0.60	0.54	0.33	0.39	0.28	0.93	0.38	0.72
29	0.89	0.73	0.55	0.57	0.26	0.30	0.33	0.85	0.30	0.73
30	0.93	0.72	0.56	0.44	0.35	0.31	0.23	0.83	0.27	0.69
31	0.85	0.68	0.46	0.44	0.24	0.24	0.20	0.81	0.23	0.68
32	0.81	0.67	0.44	0.49	0.25	0.31	0.24	0.81	0.39	0.73
33	0.85	0.68	0.53	0.30	0.30	0.21	0.30	0.83	0.19	0.73
34	0.78	0.70	0.51	0.43	0.28	0.27	0.20	0.87	0.29	0.62
35	0.89	0.75	0.56	0.49	0.34	0.27	0.36	0.87	0.23	0.64
36	0.86	0.68	0.57	0.53	0.28	0.15	0.26	0.85	0.33	0.72
37	0.86	0.69	0.58	0.35	0.24	0.24	0.20	0.78	0.24	0.77
38	0.81	0.67	0.47	0.44	0.16	0.17	0.23	0.81	0.23	0.70
39	0.86	0.74	0.64	0.39	0.14	0.27	0.23	0.81	0.25	0.65
40	0.85	0.68	0.59	0.39	0.33	0.26	0.31	0.89	0.28	0.82
41	0.87	0.72	0.54	0.49	0.28	0.34	0.37	0.85	0.28	0.68
42	0.69	0.68	0.50	0.45	0.19	0.23	0.23	0.87	0.29	0.70
43	0.81	0.69	0.44	0.48	0.23	0.28	0.17	0.78	0.21	0.64
44	0.79	0.68	0.47	0.39	0.17	0.25	0.23	0.75	0.25	0.61
45	0.82	0.75	0.49	0.37	0.29	0.32	0.19	0.89	0.34	0.70
46	0.88	0.70	0.50	0.47	0.25	0.29	0.34	0.91	0.26	0.65
47	0.88	0.67	0.59	0.49	0.27	0.22	0.32	0.91	0.29	0.61
48	0.85	0.77	0.54	0.42	0.24	0.28	0.28	0.88	0.35	0.74
49	0.85	0.70	0.53	0.56	0.35	0.27	0.31	0.85	0.32	0.80
50	0.91	0.58	0.59	0.54	0.37	0.40	0.28	0.91	0.34	0.66
51	0.79	0.66	0.56	0.33	0.24	0.22	0.18	0.77	0.26	0.62
52	0.87	0.67	0.46	0.54	0.31	0.34	0.34	0.79	0.24	0.74
53	0.83	0.71	0.52	0.48	0.27	0.29	0.34	0.88	0.30	0.70
54	0.86	0.77	0.54	0.46	0.15	0.24	0.22	0.80	0.27	0.67
55	0.90	0.59	0.61	0.42	0.28	0.27	0.27	0.81	0.19	0.69
56	0.86	0.68	0.46	0.45	0.26	0.28	0.23	0.87	0.28	0.71
57	0.89	0.74	0.47	0.49	0.36	0.38	0.32	0.85	0.35	0.65
58	0.77	0.65	0.43	0.39	0.31	0.15	0.15	0.74	0.20	0.74
59	0.88	0.66	0.53	0.50	0.34	0.35	0.29	0.83	0.35	0.71
60	0.90	0.75	0.57	0.39	0.33	0.34	0.29	0.79	0.23	0.70

61	0.86	0.73	0.57	0.53	0.34	0.24	0.31	0.89	0.34	0.66
62	0.76	0.67	0.58	0.50	0.29	0.23	0.22	0.82	0.34	0.66
63	0.80	0.68	0.46	0.53	0.21	0.20	0.12	0.86	0.32	0.68
64	0.83	0.70	0.57	0.38	0.19	0.27	0.20	0.78	0.23	0.75
65	0.82	0.67	0.57	0.49	0.35	0.33	0.34	0.87	0.34	0.78
66	0.82	0.73	0.58	0.42	0.26	0.30	0.37	0.90	0.34	0.70
67	0.78	0.70	0.59	0.41	0.29	0.27	0.25	0.89	0.25	0.72
68	0.83	0.70	0.55	0.47	0.33	0.30	0.31	0.89	0.34	0.67
69	0.91	0.62	0.59	0.53	0.26	0.34	0.30	0.89	0.28	0.65
70	0.82	0.79	0.54	0.54	0.29	0.27	0.32	0.86	0.31	0.67
71	0.81	0.64	0.45	0.42	0.21	0.19	0.25	0.85	0.27	0.64
72	0.86	0.77	0.52	0.54	0.24	0.31	0.28	0.87	0.27	0.70
73	0.83	0.69	0.53	0.52	0.35	0.35	0.30	0.92	0.35	0.74
74	0.83	0.65	0.45	0.41	0.21	0.17	0.17	0.83	0.28	0.68
75	0.84	0.73	0.60	0.44	0.27	0.31	0.30	0.87	0.36	0.75
76	0.73	0.63	0.40	0.41	0.16	0.19	0.19	0.81	0.23	0.70
77	0.83	0.69	0.57	0.47	0.39	0.31	0.27	0.82	0.21	0.74
78	0.91	0.67	0.58	0.50	0.31	0.34	0.35	0.90	0.25	0.75
79	0.78	0.72	0.43	0.43	0.27	0.18	0.22	0.81	0.24	0.70
80	0.87	0.72	0.55	0.38	0.31	0.26	0.22	0.83	0.23	0.77
81	0.85	0.63	0.51	0.48	0.21	0.36	0.27	0.87	0.30	0.75
82	0.88	0.60	0.52	0.56	0.20	0.27	0.33	0.79	0.32	0.70
83	0.86	0.66	0.46	0.56	0.31	0.37	0.39	0.86	0.25	0.76
84	0.84	0.76	0.46	0.46	0.22	0.33	0.19	0.84	0.25	0.66
85	0.85	0.71	0.46	0.48	0.26	0.33	0.29	0.89	0.28	0.71
86	0.82	0.73	0.56	0.48	0.33	0.28	0.33	0.89	0.22	0.71
87	0.81	0.61	0.52	0.40	0.18	0.23	0.31	0.83	0.26	0.69
88	0.92	0.65	0.40	0.40	0.20	0.19	0.23	0.82	0.24	0.70
89	0.76	0.59	0.50	0.44	0.23	0.21	0.23	0.86	0.27	0.76
90	0.84	0.67	0.42	0.42	0.26	0.12	0.23	0.80	0.20	0.76
91	0.79	0.68	0.51	0.37	0.29	0.29	0.18	0.79	0.26	0.74
92	0.89	0.68	0.51	0.51	0.27	0.28	0.26	0.84	0.31	0.73
93	0.87	0.71	0.55	0.62	0.29	0.34	0.32	0.87	0.29	0.77
94	0.83	0.73	0.65	0.53	0.24	0.28	0.32	0.86	0.32	0.72
95	0.89	0.65	0.61	0.35	0.23	0.25	0.16	0.89	0.21	0.67
96	0.86	0.75	0.58	0.50	0.26	0.24	0.31	0.88	0.31	0.67
97	0.86	0.67	0.50	0.40	0.28	0.27	0.29	0.89	0.27	0.67
98	0.87	0.62	0.62	0.45	0.43	0.31	0.32	0.81	0.34	0.80
99	0.85	0.78	0.53	0.48	0.22	0.30	0.26	0.81	0.28	0.69
100	0.88	0.65	0.54	0.42	0.20	0.36	0.26	0.84	0.22	0.63

5. blok7_pbrine.txt

	Panel1	Panel2	Panel3	Panel4	Panel5	Panel6	Panel7	Panel8	Panel9	Panel10
1	0.41	0.41	0.34	0.21	0.14	0.19	0.13	0.47	0.12	0.48
2	0.42	0.38	0.25	0.27	0.14	0.09	0.11	0.38	0.15	0.33
3	0.53	0.36	0.30	0.25	0.23	0.10	0.17	0.50	0.11	0.33
4	0.40	0.37	0.19	0.21	0.11	0.10	0.16	0.44	0.14	0.34
5	0.44	0.28	0.25	0.14	0.09	0.15	0.15	0.40	0.14	0.37
6	0.52	0.45	0.37	0.26	0.13	0.19	0.15	0.48	0.15	0.33
7	0.49	0.33	0.26	0.29	0.17	0.13	0.19	0.54	0.22	0.35
8	0.40	0.35	0.24	0.16	0.07	0.08	0.12	0.48	0.12	0.34
9	0.33	0.40	0.18	0.25	0.12	0.13	0.08	0.41	0.12	0.36
10	0.43	0.30	0.28	0.19	0.15	0.09	0.10	0.46	0.12	0.38
11	0.46	0.38	0.32	0.22	0.20	0.09	0.15	0.42	0.12	0.36
12	0.40	0.37	0.22	0.20	0.19	0.16	0.16	0.46	0.17	0.41
13	0.48	0.26	0.23	0.26	0.09	0.14	0.15	0.40	0.15	0.28
14	0.43	0.38	0.23	0.16	0.14	0.15	0.13	0.40	0.10	0.36
15	0.49	0.43	0.34	0.33	0.18	0.21	0.12	0.50	0.20	0.40
16	0.52	0.37	0.29	0.21	0.15	0.20	0.10	0.44	0.10	0.33
17	0.43	0.42	0.31	0.19	0.12	0.11	0.08	0.43	0.16	0.35
18	0.39	0.43	0.25	0.22	0.09	0.12	0.12	0.48	0.11	0.39
19	0.54	0.36	0.26	0.16	0.08	0.09	0.13	0.32	0.07	0.33
20	0.46	0.42	0.24	0.17	0.10	0.04	0.11	0.50	0.12	0.33
21	0.39	0.33	0.22	0.22	0.13	0.13	0.13	0.49	0.14	0.46
22	0.57	0.34	0.32	0.25	0.24	0.14	0.18	0.49	0.18	0.41
23	0.47	0.32	0.26	0.16	0.11	0.15	0.12	0.45	0.18	0.34
24	0.35	0.31	0.19	0.18	0.09	0.09	0.11	0.36	0.10	0.35
25	0.37	0.34	0.24	0.20	0.14	0.08	0.14	0.39	0.16	0.41
26	0.42	0.31	0.30	0.22	0.10	0.15	0.15	0.44	0.18	0.37
27	0.42	0.35	0.30	0.29	0.12	0.11	0.14	0.51	0.15	0.37
28	0.49	0.43	0.22	0.29	0.17	0.15	0.11	0.56	0.22	0.36
29	0.50	0.42	0.31	0.22	0.18	0.16	0.16	0.38	0.15	0.44
30	0.48	0.34	0.27	0.24	0.19	0.15	0.13	0.41	0.10	0.32
31	0.45	0.34	0.23	0.18	0.15	0.18	0.10	0.39	0.16	0.34
32	0.46	0.34	0.25	0.28	0.12	0.19	0.10	0.50	0.15	0.34
33	0.44	0.36	0.26	0.11	0.17	0.10	0.17	0.51	0.12	0.39
34	0.41	0.41	0.27	0.20	0.14	0.14	0.09	0.42	0.17	0.30
35	0.38	0.40	0.32	0.28	0.14	0.13	0.23	0.43	0.14	0.37
36	0.46	0.28	0.26	0.29	0.17	0.09	0.11	0.37	0.21	0.32
37	0.48	0.45	0.32	0.17	0.13	0.13	0.13	0.43	0.14	0.42
38	0.44	0.32	0.32	0.22	0.08	0.09	0.13	0.42	0.10	0.33
39	0.49	0.41	0.32	0.18	0.07	0.17	0.09	0.49	0.10	0.30
40	0.48	0.38	0.32	0.23	0.18	0.15	0.18	0.42	0.14	0.43
41	0.55	0.39	0.28	0.21	0.16	0.18	0.23	0.49	0.18	0.32
42	0.36	0.37	0.23	0.29	0.12	0.13	0.12	0.49	0.18	0.40
43	0.39	0.41	0.20	0.23	0.11	0.16	0.06	0.46	0.12	0.31
44	0.42	0.32	0.25	0.21	0.09	0.10	0.10	0.25	0.16	0.29
45	0.42	0.37	0.25	0.18	0.17	0.17	0.10	0.47	0.19	0.41
46	0.47	0.45	0.25	0.26	0.13	0.20	0.15	0.42	0.09	0.38
47	0.47	0.27	0.36	0.23	0.17	0.10	0.18	0.52	0.14	0.29
48	0.51	0.41	0.23	0.16	0.11	0.14	0.18	0.46	0.17	0.38
49	0.51	0.36	0.24	0.33	0.14	0.15	0.15	0.47	0.15	0.40
50	0.43	0.35	0.22	0.34	0.18	0.20	0.13	0.45	0.21	0.31
51	0.41	0.40	0.23	0.18	0.07	0.12	0.11	0.41	0.13	0.27
52	0.42	0.34	0.18	0.30	0.17	0.19	0.22	0.38	0.10	0.33
53	0.48	0.40	0.25	0.23	0.14	0.18	0.13	0.45	0.17	0.36
54	0.43	0.43	0.27	0.24	0.05	0.13	0.16	0.38	0.17	0.32
55	0.43	0.31	0.30	0.22	0.10	0.15	0.11	0.40	0.13	0.31
56	0.41	0.31	0.21	0.30	0.09	0.12	0.11	0.46	0.17	0.35
57	0.45	0.47	0.22	0.25	0.19	0.23	0.13	0.47	0.13	0.40
58	0.36	0.36	0.19	0.20	0.17	0.10	0.04	0.39	0.10	0.36
59	0.35	0.29	0.29	0.28	0.16	0.19	0.12	0.45	0.20	0.41
60	0.46	0.44	0.23	0.25	0.18	0.17	0.19	0.42	0.11	0.41

61	0.41	0.36	0.28	0.26	0.20	0.14	0.20	0.44	0.18	0.44
62	0.44	0.32	0.34	0.24	0.15	0.10	0.14	0.41	0.13	0.31
63	0.48	0.38	0.27	0.26	0.10	0.13	0.07	0.42	0.14	0.37
64	0.41	0.35	0.30	0.18	0.06	0.14	0.11	0.46	0.13	0.45
65	0.43	0.38	0.33	0.23	0.14	0.18	0.10	0.40	0.17	0.40
66	0.41	0.37	0.33	0.26	0.17	0.15	0.15	0.50	0.22	0.36
67	0.51	0.34	0.31	0.25	0.14	0.11	0.13	0.50	0.13	0.35
68	0.44	0.33	0.27	0.23	0.19	0.20	0.15	0.45	0.17	0.32
69	0.45	0.30	0.32	0.27	0.15	0.17	0.16	0.46	0.16	0.33
70	0.46	0.44	0.27	0.28	0.11	0.15	0.13	0.43	0.14	0.33
71	0.37	0.31	0.23	0.21	0.13	0.12	0.15	0.53	0.17	0.32
72	0.44	0.38	0.23	0.31	0.15	0.16	0.14	0.40	0.14	0.42
73	0.45	0.30	0.26	0.36	0.23	0.18	0.11	0.48	0.21	0.38
74	0.41	0.28	0.22	0.17	0.11	0.10	0.07	0.45	0.15	0.31
75	0.39	0.37	0.29	0.26	0.18	0.16	0.14	0.52	0.19	0.40
76	0.32	0.37	0.22	0.25	0.09	0.10	0.11	0.46	0.08	0.35
77	0.44	0.41	0.30	0.25	0.25	0.16	0.10	0.42	0.08	0.31
78	0.47	0.28	0.32	0.27	0.12	0.20	0.22	0.49	0.13	0.47
79	0.45	0.43	0.21	0.28	0.17	0.07	0.13	0.38	0.11	0.33
80	0.53	0.36	0.27	0.18	0.15	0.11	0.09	0.46	0.13	0.43
81	0.50	0.38	0.30	0.21	0.10	0.19	0.15	0.42	0.15	0.39
82	0.43	0.36	0.29	0.29	0.10	0.13	0.17	0.42	0.21	0.43
83	0.53	0.32	0.20	0.28	0.14	0.20	0.17	0.42	0.13	0.42
84	0.45	0.35	0.23	0.25	0.15	0.22	0.12	0.35	0.12	0.40
85	0.54	0.40	0.23	0.25	0.13	0.17	0.13	0.45	0.16	0.43
86	0.50	0.39	0.26	0.22	0.20	0.17	0.19	0.42	0.17	0.35
87	0.47	0.30	0.26	0.20	0.07	0.13	0.19	0.41	0.17	0.31
88	0.39	0.36	0.17	0.21	0.12	0.12	0.10	0.38	0.14	0.32
89	0.42	0.34	0.20	0.22	0.13	0.10	0.13	0.43	0.12	0.34
90	0.38	0.35	0.20	0.20	0.14	0.05	0.11	0.38	0.10	0.46
91	0.46	0.47	0.26	0.20	0.10	0.13	0.13	0.46	0.17	0.41
92	0.48	0.34	0.31	0.25	0.19	0.10	0.16	0.42	0.13	0.38
93	0.39	0.43	0.32	0.28	0.16	0.12	0.18	0.39	0.15	0.38
94	0.41	0.41	0.33	0.25	0.15	0.20	0.22	0.48	0.20	0.40
95	0.50	0.36	0.30	0.22	0.15	0.12	0.08	0.51	0.11	0.34
96	0.49	0.37	0.26	0.22	0.13	0.14	0.16	0.37	0.20	0.35
97	0.40	0.36	0.26	0.21	0.11	0.16	0.14	0.54	0.14	0.38
98	0.41	0.37	0.29	0.26	0.20	0.20	0.16	0.50	0.18	0.37
99	0.53	0.37	0.27	0.28	0.09	0.14	0.16	0.34	0.17	0.33
100	0.53	0.33	0.25	0.24	0.10	0.18	0.13	0.37	0.12	0.36

6. blok7_phczPF.txt

Distribution of pHCZ

Rank	pHCZ	Probability	CDF
1	0.12	0.00315	0.00315
2	0.14	0.00420	0.00735
3	0.15	0.00525	0.01260
4	0.16	0.00420	0.01680
5	0.17	0.00709	0.02389
6	0.18	0.00840	0.03229
7	0.19	0.01208	0.04437
8	0.20	0.01392	0.05829
9	0.21	0.01839	0.07668
10	0.22	0.01628	0.09296
11	0.23	0.02627	0.11923
12	0.24	0.02653	0.14576
13	0.25	0.01787	0.16363
14	0.26	0.02600	0.18963
15	0.27	0.02995	0.21958
16	0.28	0.03362	0.25320
17	0.29	0.02023	0.27343
18	0.30	0.01497	0.28840
19	0.31	0.02180	0.31020
20	0.32	0.01209	0.32229
21	0.33	0.01654	0.33883
22	0.34	0.02260	0.36143
23	0.35	0.01471	0.37614
24	0.36	0.00998	0.38612
25	0.37	0.01155	0.39767
26	0.38	0.00394	0.40161
27	0.39	0.01234	0.41395
28	0.40	0.00945	0.42340
29	0.41	0.00420	0.42760
30	0.42	0.00735	0.43495
31	0.43	0.00840	0.44335
32	0.44	0.01155	0.45490
33	0.45	0.00735	0.46225
34	0.46	0.01365	0.47590
35	0.47	0.01050	0.48640
36	0.48	0.00945	0.49585
37	0.49	0.00840	0.50425
38	0.50	0.01050	0.51475
39	0.51	0.00630	0.52105
40	0.52	0.00735	0.52840
41	0.53	0.01260	0.54100
42	0.54	0.01365	0.55465
43	0.55	0.00735	0.56200
44	0.56	0.00735	0.56935
45	0.57	0.01050	0.57985
46	0.58	0.00735	0.58720
47	0.59	0.00840	0.59560
48	0.60	0.00315	0.59875
49	0.61	0.00687	0.60562
50	0.62	0.00792	0.61354
51	0.63	0.00663	0.62017
52	0.64	0.00453	0.62470
53	0.65	0.01455	0.63925
54	0.66	0.01059	0.64984
55	0.67	0.02175	0.67159
56	0.68	0.01884	0.69043
57	0.69	0.01359	0.70402
58	0.70	0.02079	0.72481
59	0.71	0.01245	0.73726

60	0.72	0.00744	0.74470
61	0.73	0.01407	0.75877
62	0.74	0.00801	0.76678
63	0.75	0.00954	0.77632
64	0.76	0.00873	0.78505
65	0.77	0.00873	0.79378
66	0.78	0.01131	0.80509
67	0.79	0.01503	0.82012
68	0.80	0.00792	0.82804
69	0.81	0.02310	0.85114
70	0.82	0.01236	0.86350
71	0.83	0.01785	0.88135
72	0.84	0.00735	0.88870
73	0.85	0.02100	0.90970
74	0.86	0.02205	0.93175
75	0.87	0.01785	0.94960
76	0.88	0.01050	0.96010
77	0.89	0.01785	0.97795
78	0.90	0.00630	0.98425
79	0.91	0.00735	0.99160
80	0.92	0.00525	0.99685
81	0.93	0.00315	1.00000

7. blok7_pbrinePF.txt

Distribution of pBRINE

Rank	pBRINE	Probability	CDF
1	0.04	0.00210	0.00210
2	0.05	0.00210	0.00420
3	0.06	0.00210	0.00630
4	0.07	0.00814	0.01444
5	0.08	0.00893	0.02337
6	0.09	0.01969	0.04306
7	0.10	0.03651	0.07957
8	0.11	0.02915	0.10872
9	0.12	0.03074	0.13946
10	0.13	0.04570	0.18516
11	0.14	0.03783	0.22299
12	0.15	0.04150	0.26449
13	0.16	0.02994	0.29443
14	0.17	0.03547	0.32990
15	0.18	0.03283	0.36273
16	0.19	0.02258	0.38531
17	0.20	0.02836	0.41367
18	0.21	0.01576	0.42943
19	0.22	0.02547	0.45490
20	0.23	0.02310	0.47800
21	0.24	0.00945	0.48745
22	0.25	0.02415	0.51160
23	0.26	0.02100	0.53260
24	0.27	0.01341	0.54601
25	0.28	0.01656	0.56257
26	0.29	0.01422	0.57679
27	0.30	0.01632	0.59311
28	0.31	0.01617	0.60928
29	0.32	0.02352	0.63280
30	0.33	0.02022	0.65302
31	0.34	0.02037	0.67339
32	0.35	0.01593	0.68932
33	0.36	0.02328	0.71260
34	0.37	0.02271	0.73531
35	0.38	0.02352	0.75883
36	0.39	0.01503	0.77386
37	0.40	0.02223	0.79609
38	0.41	0.02877	0.82486
39	0.42	0.02658	0.85144
40	0.43	0.02319	0.87463
41	0.44	0.01527	0.88990
42	0.45	0.01761	0.90751
43	0.46	0.01947	0.92698
44	0.47	0.01236	0.93934
45	0.48	0.01341	0.95275
46	0.49	0.01155	0.96430
47	0.50	0.01155	0.97585
48	0.51	0.00630	0.98215
49	0.52	0.00420	0.98635
50	0.53	0.00630	0.99265
51	0.54	0.00420	0.99685
52	0.55	0.00105	0.99790
53	0.56	0.00105	0.99895
54	0.57	0.00105	1.00000

Attachment C to Appendix C

Variable Definitions, File Names and Formats			
Clas Name	**Description**	**File Name (if Used)**	**File Format**
Parameters			
Clower	Depth to bottom of range for base of Castile		
Cupper	Depth to top of range for base of Castile		
S	Measurement error standard deviation		
plower	Lowest value for P{brine|HCZ}		
pupper	Highest value for P{brine|HCZ}		
Nhole	Number of boreholes per panel		
Niter	Number of iterations of outer loop		
Npanel	Number of panels		
panelweight	Area weights for panels		
Functions			
find	Find which rectangle a point is in		
inside	Determine if a point is in an interval		
nplus	Increment an array element by 1 unit		
random	Pick random location inside a rectangle		
pfactors	Create panel names as factors		
combined	Combine phcz & pbrine into dataframe		
output	Print object to file named and print to log		
weights	Apply area weights to panel distributions		
Random Variables			
C	Random depth for base of Castile		
b	Random borehole location		
Z	Random TDEM depth measurement		
p	Random value for P{brine|HCZ}		
X	Binary indicator there was brine (1) or not (0)		
Input Data			
block.data	Block coordinates and TDEM depths	Blocks.prn	
cell.data	Site layout cell coordinates and type	cells-by-panel.prn	
panel.data	Panel coordinates	Panels1-10.prn	
Output Data			
Counter Arrays			
nw	Number of boreholes penetrating waste	blok7_nw.txt	Columns for 10 panels
nwc	Number of boreholes penetrating HCZ	blok7_nwc.txt	Columns for 10 panels
nwcb	Number of boreholes encountering brine	blok7_nwcb.txt	Columns for 10 panels
Sample for pHCZ			
phcz	Fraction of boreholes penetrating HCZ	blok7_phcz.txt	Columns for 10 panels
Frequency Distribution for pHCZ			
phczdist	Frequency distribution of phcz	blok7_phczPF.txt	phcz, probability,CDF

Variable Definitions, File Names and Formats				
Clas	Name	Description	File Name (if Used)	File Format
Sample for PBRINE				
	pbrine	Fraction of boreholes encountering brine	blok7_pbrine.txt	Columns for 10 panels
Frequency Distribution for PBRINE				
	pbrinedist	Frequency distribution of pbrine	blok7_pbrinePF.txt	pbrine, probability,CDF
Internal Objects				
	blocks	Matrix form of block.data rectangles		
	NB	Number of block.data rectangles		
	cells	Matrix form of layout cell rectangles		
	NC	Number of layout cell rectangles		
	cellspj	Subset of cells in in panel j		
	dimcel	Dimensions of cellspj		
	numcel	Number of cells in in panel j		
	type	Type of cell encountered (3=waste)		
	panelnames	Panel name factors		
	pbrinedata	phcz & pbrine as dataframe with panel factors		
	phczpanel	Frequency distribution of phcz by panel		
	pbrinepanel	Frequency distribution of pbrine by panel		
	iseed	Initial seed for random number generator		
	i	Index of outer loop		
	j	Index for panel loop		
	k	Index of block found in blocks matrix		
	m	Index of cell found in cells matrix		

Attachment D to Appendix C

EPA Block Model R Code Listing

1. DoR.bat
2. blok7.r

1. DoR.bat

“C:\Program Files\R\R-3.0.3\bin\i386\Rterm.exe" --vanilla --no-Rconsole -q <%1.r >%1.txt

Usage: DoR blok7

2. blok7.r

```
#........................   Parameters   ................................
Niter <- 100
Npanel <- 10
Nhole <- 100

S <- 75
Cupper <- 1238
Clower <- 1268
plower <- 0.05
pupper <- 1.0

iseed <- 17981
set.seed(iseed)

#........................    Arrays      ...............................
C <- 1:Niter
panelnames <- paste("Panel",1:Npanel,sep="")
nw <- array(0,dim=c(Niter,Npanel),dimnames=list(C,panelnames))
nwc <- nw
nwcb <- nw

panelweight <- as.matrix(c(105,105,105,105,105,105,105,105,79,81)/1000)
print(panelweight)

#........................   Functions    ................................
nplus=function(n,i,j) {
  n[i,j] <- n[i,j]+1
  return(n)
}
inside=function(x,a,b) {
  !(x<a | x>b)
}
find=function(b,Rect,NR) {
  numr <- 0
  for (j in 1:NR) {
    if( inside(b[1],Rect[j,1],Rect[j,3]) & inside(b[2],Rect[j,2],Rect[j,4]) ) {
      numr <- j
    next
    }
  }
  if(numr==0)
    cat("\nNot found:",b,"\n")
  return(numr)
}
random=function(x1,y1,x2,y2) {
  bx <- runif(1,x1,x2)
  by <- runif(1,y1,y2)
  b <- array(c(bx,by),dim=2)
}
pfactors=function(root) {
  factor <- array("0",dim=Niter*Npanel)
  for (j in 1:Npanel) {
    i2 <- Niter*j
    i1 <- i2-(Niter-1)
    factor[i1:i2] <- paste(root,sprintf("%02i",j),sep="")
  }
```

```
  return(factor)
}
combined=function(pbrine,phcz) {
  pBRINE <- array(pbrine,dim=Niter*Npanel)
  pHCZ <- array(phcz,dim=Niter*Npanel)
  PANEL <- pfactors("Panl")
  pbrinedata <- as.data.frame(cbind(pBRINE,pHCZ,PANEL))
}
weights=function(panelpfs) {
  Probability <- panelpfs%*%panelweight
  xvalue <- as.data.frame(dimnames(Probability)[1],stringsAsFactors=FALSE)
  row.names(xvalue) <- seq(length(Probability))
  CDF <- cumsum(Probability)
  weighted <- data.matrix(cbind(xvalue,Probability,CDF))
  names(dimnames(weighted))=c("Rank",paste("Distribution of",names(xvalue)))
  return(weighted)
}
output=function(table,filename) {
  sink(file=paste(filename,".txt",sep=""))
  print(table)
  sink()
  print(table)
}

#........................      Main      ...............................
panel.data <- read.table("Panels1-10.prn",header=TRUE)
print(panel.data)
attach(panel.data)

block.data <- read.table("Blocks.prn",header=TRUE)
print(block.data)
attach(block.data)
blocks <- as.matrix(cbind(bxleft,bybottom,bxright,bytop))
NB <- length(bxleft)

cell.data <- read.table("cells-by-panel.prn",header=TRUE)
print(cell.data)
attach(cell.data)
cells <- as.matrix(cbind(cxleft,cybottom,cxright,cytop))
NC <- length(cxleft)

## drill test hole in panel 3; find cell type & TDEM block
b <- random(pxleft[3],pybottom[3],pxright[3],pytop[3])
b
m <- find(b,cells,NC)
m
ccolor[m]
k <- find(b,blocks,NB)
k

## begin simulation
for (i in 1:Niter) {
    C[i] <- runif(1,Cupper,Clower)
    for (j in 1:Npanel) {
      cellspj <- subset(cells,cpanel==j)
      dimcel <- dim(cellspj)
      numcel <- dimcel[1]
      while(nw[i,j]<Nhole) {
           b <- random(pxleft[j],pybottom[j],pxright[j],pytop[j])
           m <- find(b,cellspj,numcel)
           type <- ccolor[m]
           if(type==3) {
                  nw <- nplus(nw,i,j)
```

```
                 k <- find(b,blocks,NB)
                 Z <- rnorm(1,depth[k],S)
                 if(Z<=C[i]) {
                        nwc <- nplus(nwc,i,j)
                        p <- runif(1,plower,pupper)
                        X <- rbinom(1,1,p)
                        if(X==1) {
                                 nwcb <- nplus(nwcb,i,j)
                        }
                 }
          }
      }# End borehole
    } # End panel
} # End iteration

# End simulation
# print counts
output(nw,"blok7_nw")
output(nwc,"blok7_nwc")
output(nwcb,"blok7_nwcb")

# percentage estimates for phcz & pbrine
phcz <- nwc/nw
pbrine <- nwcb/nw
output(phcz,"blok7_phcz")
output(pbrine,"blok7_pbrine")

# convert to dataframe with PANEL as factor
pbrinedata <- combined(pbrine,phcz)
print(pbrinedata)

# calculate frequency distributions by panel
phczpanel <- xtabs(~pHCZ+PANEL,data=pbrinedata)/Niter
pbrinepanel <- xtabs(~pBRINE+PANEL,data=pbrinedata)/Niter
print(phczpanel)
print(pbrinepanel)

# get weighted distributions for repository & output
phczdist <- weights(phczpanel)
output(phczdist,"blok7_phczPF")

pbrinedist <- weights(pbrinepanel)
output(pbrinedist,"blok7_pbrinePF")

ls()
q("no")
```

Attachment E to Appendix C

EPA Block Model Runfile Output

1. blok7.txt

1. blok7.txt

```
> #........................   Parameters   ...............................
> Niter <- 100
> Npanel <- 10
> Nhole <- 100
>
> S <- 75
> Cupper <- 1238
> Clower <- 1268
> plower <- 0.05
> pupper <- 1.0
>
> iseed <- 17981
> set.seed(iseed)
>
> #........................    Arrays      ..............................
> C <- 1:Niter
> panelnames <- paste("Panel",1:Npanel,sep="")
> nw <- array(0,dim=c(Niter,Npanel),dimnames=list(C,panelnames))
> nwc <- nw
> nwcb <- nw
>
> panelweight <- as.matrix(c(105,105,105,105,105,105,105,105,79,81)/1000)
> print(panelweight)
       [,1]
 [1,] 0.105
 [2,] 0.105
 [3,] 0.105
 [4,] 0.105
 [5,] 0.105
 [6,] 0.105
 [7,] 0.105
 [8,] 0.105
 [9,] 0.079
[10,] 0.081
>
> #........................   Functions    ...............................
> nplus=function(n,i,j) {
+   n[i,j] <- n[i,j]+1
+   return(n)
+ }
> inside=function(x,a,b) {
+   !(x<a | x>b)
+ }
> find=function(b,Rect,NR) {
+   numr <- 0
+   for (j in 1:NR) {
+     if( inside(b[1],Rect[j,1],Rect[j,3]) & inside(b[2],Rect[j,2],Rect[j,4]) ) {
+       numr <- j
+        next
+      }
+   }
+   if(numr==0)
+     cat("\nNot found:",b,"\n")
+   return(numr)
+ }
> random=function(x1,y1,x2,y2) {
+   bx <- runif(1,x1,x2)
+   by <- runif(1,y1,y2)
+   b <- array(c(bx,by),dim=2)
+ }
```

```
> pfactors=function(root) {
+   factor <- array("0",dim=Niter*Npanel)
+   for (j in 1:Npanel) {
+     i2 <- Niter*j
+      i1 <- i2-(Niter-1)
+      factor[i1:i2] <- paste(root,sprintf("%02i",j),sep="")
+   }
+   return(factor)
+ }
> combined=function(pbrine,phcz) {
+   pBRINE <- array(pbrine,dim=Niter*Npanel)
+   pHCZ <- array(phcz,dim=Niter*Npanel)
+   PANEL <- pfactors("Panl")
+   pbrinedata <- as.data.frame(cbind(pBRINE,pHCZ,PANEL))
+ }
> weights=function(panelpfs) {
+   Probability <- panelpfs%*%panelweight
+   xvalue <- as.data.frame(dimnames(Probability)[1],stringsAsFactors=FALSE)
+   row.names(xvalue) <- seq(length(Probability))
+   CDF <- cumsum(Probability)
+   weighted <- data.matrix(cbind(xvalue,Probability,CDF))
+   names(dimnames(weighted))=c("Rank",paste("Distribution of",names(xvalue)))
+   return(weighted)
+ }
> output=function(table,filename) {
+   sink(file=paste(filename,".txt",sep=""))
+   print(table)
+   sink()
+   print(table)
+ }
>
> #.........................      Main      ...............................
> panel.data <- read.table("Panels1-10.prn",header=TRUE)
> print(panel.data)
     panel  pxleft pybottom pxright  pytop
1   Panel1  -93.20   383.00  211.28 494.50
2   Panel2  -93.20   215.30  211.28 326.80
3   Panel3  -93.20    47.82  211.28 159.32
4   Panel4  -93.20  -119.88  211.28  -8.38
5   Panel5 -544.88  -119.88 -240.40  -8.38
6   Panel6 -544.88    47.82 -240.40 159.32
7   Panel7 -544.88   215.30 -240.40 326.80
8   Panel8 -544.88   383.00 -240.40 494.50
9   Panel9 -240.40  -116.28  -93.20 202.55
10 Panel10 -240.40   202.55  -93.20 490.60
> attach(panel.data)
>
> block.data <- read.table("Blocks.prn",header=TRUE)
> print(block.data)
        block centerx centery depth bxleft bybottom bxright bytop
1  500N-1000W   -1000     500  1273  -1125      375    -875   625
2  250N-1000W   -1000     250  1248  -1125      125    -875   375
3  000N-1000W   -1000       0  1208  -1125     -125    -875   125
4  250S-1000W   -1000    -250  1284  -1125     -375    -875  -125
5  500S-1000W   -1000    -500  1246  -1125     -625    -875  -375
6   500N-750W    -750     500  1481   -875      375    -625   625
7   250N-750W    -750     250  1300   -875      125    -625   375
8   000N-750W    -750       0  1255   -875     -125    -625   125
9   250S-750W    -750    -250  1078   -875     -375    -625  -125
10  500S-750W    -750    -500  1288   -875     -625    -625  -375
11  500N-500W    -500     500  1200   -625      375    -375   625
12  250N-500W    -500     250  1272   -625      125    -375   375
13  000N-500W    -500       0  1291   -625     -125    -375   125
```

```
14  250S-500W    -500    -250  1196   -625     -375    -375  -125
15  500S-500W    -500    -500  1222   -625     -625    -375  -375
16  500N-250W    -250     500  1010   -375      375    -125   625
17  250N-250W    -250     250  1420   -375      125    -125   375
18  000N-250W    -250       0  1316   -375     -125    -125   125
19  250S-250W    -250    -250  1201   -375     -375    -125  -125
20  500S-250W    -250    -500  1258   -375     -625    -125  -375
21  500N-000E       0     500  1197   -125      375     125   625
22  250N-000E       0     250  1131   -125      125     125   375
23  000N-000E       0       0  1236   -125     -125     125   125
24  250S-000E       0    -250  1154   -125     -375     125  -125
25  500S-000E       0    -500  1257   -125     -625     125  -375
26  500N-250E     250     500   988    125      375     375   625
27  250N-250E     250     250  1452    125      125     375   375
28  000N-250E     250       0  1394    125     -125     375   125
29  250S-250E     250    -250  1091    125     -375     375  -125
30  500S-250E     250    -500  1127    125     -625     375  -375
31  500N-500E     500     500  1252    375      375     625   625
32  250N-500E     500     250  1358    375      125     625   375
33  000N-500E     500       0  1313    375     -125     625   125
34  250S-500E     500    -250  1313    375     -375     625  -125
35  500S-500E     500    -500  1426    375     -625     625  -375
36  500N-750E     750     500  1143    625      375     875   625
> attach(block.data)
> blocks <- as.matrix(cbind(bxleft,bybottom,bxright,bytop))
> NB <- length(bxleft)
>
> cell.data <- read.table("cells-by-panel.prn",header=TRUE)
> print(cell.data)
     cpanel cell ccolor  cxleft cybottom cxright   cytop
1         5   D5      7 -550.00  -125.00 -544.88 -119.88
2         5   D5      7 -544.88  -125.00 -534.88 -119.88
3         5   D5      7 -534.88  -125.00 -504.38 -119.88
4         5   D5      7 -504.38  -125.00 -494.38 -119.88
5         5   D5      7 -494.38  -125.00 -463.88 -119.88
6         5   D5      7 -463.88  -125.00 -453.88 -119.88
7         5   D5      7 -453.88  -125.00 -423.38 -119.88
8         5   D5      7 -423.38  -125.00 -413.38 -119.88
9         5   D5      7 -413.38  -125.00 -382.88 -119.88

                    […]

1512      1   D1      7   39.28   494.50   49.28  499.62
1513      1   D1      7   49.28   494.50   79.78  499.62
1514      1   D1      7   79.78   494.50   89.78  499.62
1515      1   D1      7   89.78   494.50  120.28  499.62
1516      1   D1      7  120.28   494.50  130.28  499.62
1517      1   D1      7  130.28   494.50  160.78  499.62
1518      1   D1      7  160.78   494.50  170.78  499.62
1519      1   D1      7  170.78   494.50  201.28  499.62
1520      1   D1      7  201.28   494.50  211.28  499.62
1521      1   D1      7  211.28   494.50  216.40  499.62
> attach(cell.data)
> cells <- as.matrix(cbind(cxleft,cybottom,cxright,cytop))
> NC <- length(cxleft)
>
> ## drill test hole in panel 3; find cell type & TDEM block
> b <- random(pxleft[3],pybottom[3],pxright[3],pytop[3])
> b
[1] -36.98239  59.66386
> m <- find(b,cells,NC)
> m
[1] 533
```

```
> ccolor[m]
[1] 3
> k <- find(b,blocks,NB)
> k
[1] 23
>
> ## begin simulation
> for (i in 1:Niter) {
+      C[i] <- runif(1,Cupper,Clower)
+      for (j in 1:Npanel) {
+          cellspj <- subset(cells,cpanel==j)
+             dimcel <- dim(cellspj)
+             numcel <- dimcel[1]
+             while(nw[i,j]<Nhole) {
+              b <- random(pxleft[j],pybottom[j],pxright[j],pytop[j])
+                    m <- find(b,cellspj,numcel)
+                    type <- ccolor[m]
+                    if(type==3) {
+                           nw <- nplus(nw,i,j)
+                           k <- find(b,blocks,NB)
+                           Z <- rnorm(1,depth[k],S)
+                           if(Z<=C[i]) {
+                                  nwc <- nplus(nwc,i,j)
+                                  p <- runif(1,plower,pupper)
+                                  X <- rbinom(1,1,p)
+                                  if(X==1) {
+                                    nwcb <- nplus(nwcb,i,j)
+                                  }
+                           }
+                    }
+             } # End borehole
+      } # End panel
+ } # End iteration
>
> # End simulation
> # print counts
> output(nw,"blok7_nw")
    Panel1 Panel2 Panel3 Panel4 Panel5 Panel6 Panel7 Panel8 Panel9 Panel10
1      100    100    100    100    100    100    100    100    100     100
2      100    100    100    100    100    100    100    100    100     100
3      100    100    100    100    100    100    100    100    100     100
4      100    100    100    100    100    100    100    100    100     100
5      100    100    100    100    100    100    100    100    100     100
6      100    100    100    100    100    100    100    100    100     100
7      100    100    100    100    100    100    100    100    100     100
8      100    100    100    100    100    100    100    100    100     100
9      100    100    100    100    100    100    100    100    100     100
10     100    100    100    100    100    100    100    100    100     100
11     100    100    100    100    100    100    100    100    100     100
12     100    100    100    100    100    100    100    100    100     100
13     100    100    100    100    100    100    100    100    100     100
14     100    100    100    100    100    100    100    100    100     100
15     100    100    100    100    100    100    100    100    100     100
16     100    100    100    100    100    100    100    100    100     100
17     100    100    100    100    100    100    100    100    100     100
18     100    100    100    100    100    100    100    100    100     100
19     100    100    100    100    100    100    100    100    100     100
20     100    100    100    100    100    100    100    100    100     100
21     100    100    100    100    100    100    100    100    100     100
22     100    100    100    100    100    100    100    100    100     100
23     100    100    100    100    100    100    100    100    100     100
24     100    100    100    100    100    100    100    100    100     100
25     100    100    100    100    100    100    100    100    100     100
```

26	100	100	100	100	100	100	100	100	100	100
27	100	100	100	100	100	100	100	100	100	100
28	100	100	100	100	100	100	100	100	100	100
29	100	100	100	100	100	100	100	100	100	100
30	100	100	100	100	100	100	100	100	100	100
31	100	100	100	100	100	100	100	100	100	100
32	100	100	100	100	100	100	100	100	100	100
33	100	100	100	100	100	100	100	100	100	100
34	100	100	100	100	100	100	100	100	100	100
35	100	100	100	100	100	100	100	100	100	100
36	100	100	100	100	100	100	100	100	100	100
37	100	100	100	100	100	100	100	100	100	100
38	100	100	100	100	100	100	100	100	100	100
39	100	100	100	100	100	100	100	100	100	100
40	100	100	100	100	100	100	100	100	100	100
41	100	100	100	100	100	100	100	100	100	100
42	100	100	100	100	100	100	100	100	100	100
43	100	100	100	100	100	100	100	100	100	100
44	100	100	100	100	100	100	100	100	100	100
45	100	100	100	100	100	100	100	100	100	100
46	100	100	100	100	100	100	100	100	100	100
47	100	100	100	100	100	100	100	100	100	100
48	100	100	100	100	100	100	100	100	100	100
49	100	100	100	100	100	100	100	100	100	100
50	100	100	100	100	100	100	100	100	100	100
51	100	100	100	100	100	100	100	100	100	100
52	100	100	100	100	100	100	100	100	100	100
53	100	100	100	100	100	100	100	100	100	100
54	100	100	100	100	100	100	100	100	100	100
55	100	100	100	100	100	100	100	100	100	100
56	100	100	100	100	100	100	100	100	100	100
57	100	100	100	100	100	100	100	100	100	100
58	100	100	100	100	100	100	100	100	100	100
59	100	100	100	100	100	100	100	100	100	100
60	100	100	100	100	100	100	100	100	100	100
61	100	100	100	100	100	100	100	100	100	100
62	100	100	100	100	100	100	100	100	100	100
63	100	100	100	100	100	100	100	100	100	100
64	100	100	100	100	100	100	100	100	100	100
65	100	100	100	100	100	100	100	100	100	100
66	100	100	100	100	100	100	100	100	100	100
67	100	100	100	100	100	100	100	100	100	100
68	100	100	100	100	100	100	100	100	100	100
69	100	100	100	100	100	100	100	100	100	100
70	100	100	100	100	100	100	100	100	100	100
71	100	100	100	100	100	100	100	100	100	100
72	100	100	100	100	100	100	100	100	100	100
73	100	100	100	100	100	100	100	100	100	100
74	100	100	100	100	100	100	100	100	100	100
75	100	100	100	100	100	100	100	100	100	100
76	100	100	100	100	100	100	100	100	100	100
77	100	100	100	100	100	100	100	100	100	100
78	100	100	100	100	100	100	100	100	100	100
79	100	100	100	100	100	100	100	100	100	100
80	100	100	100	100	100	100	100	100	100	100
81	100	100	100	100	100	100	100	100	100	100
82	100	100	100	100	100	100	100	100	100	100
83	100	100	100	100	100	100	100	100	100	100
84	100	100	100	100	100	100	100	100	100	100
85	100	100	100	100	100	100	100	100	100	100
86	100	100	100	100	100	100	100	100	100	100
87	100	100	100	100	100	100	100	100	100	100
88	100	100	100	100	100	100	100	100	100	100

```
89      100    100    100    100    100    100    100    100    100     100
90      100    100    100    100    100    100    100    100    100     100
91      100    100    100    100    100    100    100    100    100     100
92      100    100    100    100    100    100    100    100    100     100
93      100    100    100    100    100    100    100    100    100     100
94      100    100    100    100    100    100    100    100    100     100
95      100    100    100    100    100    100    100    100    100     100
96      100    100    100    100    100    100    100    100    100     100
97      100    100    100    100    100    100    100    100    100     100
98      100    100    100    100    100    100    100    100    100     100
99      100    100    100    100    100    100    100    100    100     100
100     100    100    100    100    100    100    100    100    100     100
> output(nwc,"blok7_nwc")
    Panel1 Panel2 Panel3 Panel4 Panel5 Panel6 Panel7 Panel8 Panel9 Panel10
1       81     73     62     43     28     37     28     85     32      79
2       81     70     54     46     23     17     28     83     26      68
3       88     71     55     55     35     20     29     90     29      69
4       83     66     44     40     25     26     26     80     21      63
5       79     61     50     33     21     23     21     82     31      70
6       81     67     66     49     28     33     30     91     29      68
7       89     65     52     55     33     23     37     85     36      70
8       82     71     45     39     14     14     27     85     21      67
9       76     65     46     44     27     20     14     78     21      73
10      79     59     54     41     28     18     21     85     23      68
11      81     70     51     43     36     15     26     81     24      67
12      84     66     47     46     34     28     27     92     27      73
13      87     65     47     48     21     25     26     79     27      69
14      77     70     48     43     24     26     23     85     25      68
15      86     69     62     53     25     35     26     87     34      79
16      83     66     58     46     28     37     22     86     27      68
17      86     68     50     36     18     24     19     86     29      69
18      82     71     47     40     21     21     24     80     25      73
19      78     61     53     40     24     16     25     79     17      70
20      81     67     47     39     22     12     18     86     20      63
21      81     71     48     36     22     22     21     87     27      79
22      90     75     65     54     37     28     25     89     31      67
23      86     67     57     37     22     24     20     76     24      71
24      80     67     45     44     24     19     18     76     24      69
25      78     63     44     39     22     24     28     83     32      65
26      88     57     63     36     24     26     28     93     28      69
27      92     71     52     57     30     28     26     85     34      67
28      92     81     60     54     33     39     28     93     38      72
29      89     73     55     57     26     30     33     85     30      73
30      93     72     56     44     35     31     23     83     27      69
31      85     68     46     44     24     24     20     81     23      68
32      81     67     44     49     25     31     24     81     39      73
33      85     68     53     30     30     21     30     83     19      73
34      78     70     51     43     28     27     20     87     29      62
35      89     75     56     49     34     27     36     87     23      64
36      86     68     57     53     28     15     26     85     33      72
37      86     69     58     35     24     24     20     78     24      77
38      81     67     47     44     16     17     23     81     23      70
39      86     74     64     39     14     27     23     81     25      65
40      85     68     59     39     33     26     31     89     28      82
41      87     72     54     49     28     34     37     85     28      68
42      69     68     50     45     19     23     23     87     29      70
43      81     69     44     48     23     28     17     78     21      64
44      79     68     47     39     17     25     23     75     25      61
45      82     75     49     37     29     32     19     89     34      70
46      88     70     50     47     25     29     34     91     26      65
47      88     67     59     49     27     22     32     91     29      61
48      85     77     54     42     24     28     28     88     35      74
49      85     70     53     56     35     27     31     85     32      80
```

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50      91     58     59     54     37     40     28     91     34     66
51      79     66     56     33     24     22     18     77     26     62
52      87     67     46     54     31     34     34     79     24     74
53      83     71     52     48     27     29     34     88     30     70
54      86     77     54     46     15     24     22     80     27     67
55      90     59     61     42     28     27     27     81     19     69
56      86     68     46     45     26     28     23     87     28     71
57      89     74     47     49     36     38     32     85     35     65
58      77     65     43     39     31     15     15     74     20     74
59      88     66     53     50     34     35     29     83     35     71
60      90     75     57     39     33     34     29     79     23     70
61      86     73     57     53     34     24     31     89     34     66
62      76     67     58     50     29     23     22     82     34     66
63      80     68     46     53     21     20     12     86     32     68
64      83     70     57     38     19     27     20     78     23     75
65      82     67     57     49     35     33     34     87     34     78
66      82     73     58     42     26     30     37     90     34     70
67      78     70     59     41     29     27     25     89     25     72
68      83     70     55     47     33     30     31     89     34     67
69      91     62     59     53     26     34     30     89     28     65
70      82     79     54     54     29     27     32     86     31     67
71      81     64     45     42     21     19     25     85     27     64
72      86     77     52     54     24     31     28     87     27     70
73      83     69     53     52     35     35     30     92     35     74
74      83     65     45     41     21     17     17     83     28     68
75      84     73     60     44     27     31     30     87     36     75
76      73     63     40     41     16     19     19     81     23     70
77      83     69     57     47     39     31     27     82     21     74
78      91     67     58     50     31     34     35     90     25     75
79      78     72     43     43     27     18     22     81     24     70
80      87     72     55     38     31     26     22     83     23     77
81      85     63     51     48     21     36     27     87     30     75
82      88     60     52     56     20     27     33     79     32     70
83      86     66     46     56     31     37     39     86     25     76
84      84     76     46     46     22     33     19     84     25     66
85      85     71     46     48     26     33     29     89     28     71
86      82     73     56     48     33     28     33     89     22     71
87      81     61     52     40     18     23     31     83     26     69
88      92     65     40     40     20     19     23     82     24     70
89      76     59     50     44     23     21     23     86     27     76
90      84     67     42     42     26     12     23     80     20     76
91      79     68     51     37     29     29     18     79     26     74
92      89     68     51     51     27     28     26     84     31     73
93      87     71     55     62     29     34     32     87     29     77
94      83     73     65     53     24     28     32     86     32     72
95      89     65     61     35     23     25     16     89     21     67
96      86     75     58     50     26     24     31     88     31     67
97      86     67     50     40     28     27     29     89     27     67
98      87     62     62     45     43     31     32     81     34     80
99      85     78     53     48     22     30     26     81     28     69
100     88     65     54     42     20     36     26     84     22     63
> output(nwcb,"blok7_nwcb")
    Panel1 Panel2 Panel3 Panel4 Panel5 Panel6 Panel7 Panel8 Panel9 Panel10
1       41     41     34     21     14     19     13     47     12     48
2       42     38     25     27     14      9     11     38     15     33
3       53     36     30     25     23     10     17     50     11     33
4       40     37     19     21     11     10     16     44     14     34
5       44     28     25     14      9     15     15     40     14     37
6       52     45     37     26     13     19     15     48     15     33
7       49     33     26     29     17     13     19     54     22     35
8       40     35     24     16      7      8     12     48     12     34
9       33     40     18     25     12     13      8     41     12     36
10      43     30     28     19     15      9     10     46     12     38
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11	46	38	32	22	20	9	15	42	12	36
12	40	37	22	20	19	16	16	46	17	41
13	48	26	23	26	9	14	15	40	15	28
14	43	38	23	16	14	15	13	40	10	36
15	49	43	34	33	18	21	12	50	20	40
16	52	37	29	21	15	20	10	44	10	33
17	43	42	31	19	12	11	8	43	16	35
18	39	43	25	22	9	12	12	48	11	39
19	54	36	26	16	8	9	13	32	7	33
20	46	42	24	17	10	4	11	50	12	33
21	39	33	22	22	13	13	13	49	14	46
22	57	34	32	25	24	14	18	49	18	41
23	47	32	26	16	11	15	12	45	18	34
24	35	31	19	18	9	9	11	36	10	35
25	37	34	24	20	14	8	14	39	16	41
26	42	31	30	22	10	15	15	44	18	37
27	42	35	30	29	12	11	14	51	15	37
28	49	43	22	29	17	15	11	56	22	36
29	50	42	31	22	18	16	16	38	15	44
30	48	34	27	24	19	15	13	41	10	32
31	45	34	23	18	15	18	10	39	16	34
32	46	34	25	28	12	19	10	50	15	34
33	44	36	26	11	17	10	17	51	12	39
34	41	41	27	20	14	14	9	42	17	30
35	38	40	32	28	14	13	23	43	14	37
36	46	28	26	29	17	9	11	37	21	32
37	48	45	32	17	13	13	13	43	14	42
38	44	32	32	22	8	9	13	42	10	33
39	49	41	32	18	7	17	9	49	10	30
40	48	38	32	23	18	15	18	42	14	43
41	55	39	28	21	16	18	23	49	18	32
42	36	37	23	29	12	13	12	49	18	40
43	39	41	20	23	11	16	6	46	12	31
44	42	32	25	21	9	10	10	25	16	29
45	42	37	25	18	17	17	10	47	19	41
46	47	45	25	26	13	20	15	42	9	38
47	47	27	36	23	17	10	18	52	14	29
48	51	41	23	16	11	14	18	46	17	38
49	51	36	24	33	14	15	15	47	15	40
50	43	35	22	34	18	20	13	45	21	31
51	41	40	23	18	7	12	11	41	13	27
52	42	34	18	30	17	19	22	38	10	33
53	48	40	25	23	14	18	13	45	17	36
54	43	43	27	24	5	13	16	38	17	32
55	43	31	30	22	10	15	11	40	13	31
56	41	31	21	30	9	12	11	46	17	35
57	45	47	22	25	19	23	13	47	13	40
58	36	36	19	20	17	10	4	39	10	36
59	35	29	29	28	16	19	12	45	20	41
60	46	44	23	25	18	17	19	42	11	41
61	41	36	28	26	20	14	20	44	18	44
62	44	32	34	24	15	10	14	41	13	31
63	48	38	27	26	10	13	7	42	14	37
64	41	35	30	18	6	14	11	46	13	45
65	43	38	33	23	14	18	10	40	17	40
66	41	37	33	26	17	15	15	50	22	36
67	51	34	31	25	14	11	13	50	13	35
68	44	33	27	23	19	20	15	45	17	32
69	45	30	32	27	15	17	16	46	16	33
70	46	44	27	28	11	15	13	43	14	33
71	37	31	23	21	13	12	15	53	17	32
72	44	38	23	31	15	16	14	40	14	42
73	45	30	26	36	23	18	11	48	21	38

```
74      41     28     22     17     11     10      7     45     15      31
75      39     37     29     26     18     16     14     52     19      40
76      32     37     22     25      9     10     11     46      8      35
77      44     41     30     25     25     16     10     42      8      31
78      47     28     32     27     12     20     22     49     13      47
79      45     43     21     28     17      7     13     38     11      33
80      53     36     27     18     15     11      9     46     13      43
81      50     38     30     21     10     19     15     42     15      39
82      43     36     29     29     10     13     17     42     21      43
83      53     32     20     28     14     20     17     42     13      42
84      45     35     23     25     15     22     12     35     12      40
85      54     40     23     25     13     17     13     45     16      43
86      50     39     26     22     20     17     19     42     17      35
87      47     30     26     20      7     13     19     41     17      31
88      39     36     17     21     12     12     10     38     14      32
89      42     34     20     22     13     10     13     43     12      34
90      38     35     20     20     14      5     11     38     10      46
91      46     47     26     20     10     13     13     46     17      41
92      48     34     31     25     19     10     16     42     13      38
93      39     43     32     28     16     12     18     39     15      38
94      41     41     33     25     15     20     22     48     20      40
95      50     36     30     22     15     12      8     51     11      34
96      49     37     26     22     13     14     16     37     20      35
97      40     36     26     21     11     16     14     54     14      38
98      41     37     29     26     20     20     16     50     18      37
99      53     37     27     28      9     14     16     34     17      33
100     53     33     25     24     10     18     13     37     12      36
>
> # percentage estimates for phcz & pbrine
> phcz <- nwc/nw
> pbrine <- nwcb/nw
> output(phcz,"blok7_phcz")
    Panel1 Panel2 Panel3 Panel4 Panel5 Panel6 Panel7 Panel8 Panel9 Panel10
1     0.81   0.73   0.62   0.43   0.28   0.37   0.28   0.85   0.32    0.79
2     0.81   0.70   0.54   0.46   0.23   0.17   0.28   0.83   0.26    0.68
3     0.88   0.71   0.55   0.55   0.35   0.20   0.29   0.90   0.29    0.69
4     0.83   0.66   0.44   0.40   0.25   0.26   0.26   0.80   0.21    0.63
5     0.79   0.61   0.50   0.33   0.21   0.23   0.21   0.82   0.31    0.70
6     0.81   0.67   0.66   0.49   0.28   0.33   0.30   0.91   0.29    0.68
7     0.89   0.65   0.52   0.55   0.33   0.23   0.37   0.85   0.36    0.70
8     0.82   0.71   0.45   0.39   0.14   0.14   0.27   0.85   0.21    0.67
9     0.76   0.65   0.46   0.44   0.27   0.20   0.14   0.78   0.21    0.73
10    0.79   0.59   0.54   0.41   0.28   0.18   0.21   0.85   0.23    0.68
11    0.81   0.70   0.51   0.43   0.36   0.15   0.26   0.81   0.24    0.67
12    0.84   0.66   0.47   0.46   0.34   0.28   0.27   0.92   0.27    0.73
13    0.87   0.65   0.47   0.48   0.21   0.25   0.26   0.79   0.27    0.69
14    0.77   0.70   0.48   0.43   0.24   0.26   0.23   0.85   0.25    0.68
15    0.86   0.69   0.62   0.53   0.25   0.35   0.26   0.87   0.34    0.79
16    0.83   0.66   0.58   0.46   0.28   0.37   0.22   0.86   0.27    0.68
17    0.86   0.68   0.50   0.36   0.18   0.24   0.19   0.86   0.29    0.69
18    0.82   0.71   0.47   0.40   0.21   0.21   0.24   0.80   0.25    0.73
19    0.78   0.61   0.53   0.40   0.24   0.16   0.25   0.79   0.17    0.70
20    0.81   0.67   0.47   0.39   0.22   0.12   0.18   0.86   0.20    0.63
21    0.81   0.71   0.48   0.36   0.22   0.22   0.21   0.87   0.27    0.79
22    0.90   0.75   0.65   0.54   0.37   0.28   0.25   0.89   0.31    0.67
23    0.86   0.67   0.57   0.37   0.22   0.24   0.20   0.76   0.24    0.71
24    0.80   0.67   0.45   0.44   0.24   0.19   0.18   0.76   0.24    0.69
25    0.78   0.63   0.44   0.39   0.22   0.24   0.28   0.83   0.32    0.65
26    0.88   0.57   0.63   0.36   0.24   0.26   0.28   0.93   0.28    0.69
27    0.92   0.71   0.52   0.57   0.30   0.28   0.26   0.85   0.34    0.67
28    0.92   0.81   0.60   0.54   0.33   0.39   0.28   0.93   0.38    0.72
29    0.89   0.73   0.55   0.57   0.26   0.30   0.33   0.85   0.30    0.73
30    0.93   0.72   0.56   0.44   0.35   0.31   0.23   0.83   0.27    0.69
```

31	0.85	0.68	0.46	0.44	0.24	0.24	0.20	0.81	0.23	0.68
32	0.81	0.67	0.44	0.49	0.25	0.31	0.24	0.81	0.39	0.73
33	0.85	0.68	0.53	0.30	0.30	0.21	0.30	0.83	0.19	0.73
34	0.78	0.70	0.51	0.43	0.28	0.27	0.20	0.87	0.29	0.62
35	0.89	0.75	0.56	0.49	0.34	0.27	0.36	0.87	0.23	0.64
36	0.86	0.68	0.57	0.53	0.28	0.15	0.26	0.85	0.33	0.72
37	0.86	0.69	0.58	0.35	0.24	0.24	0.20	0.78	0.24	0.77
38	0.81	0.67	0.47	0.44	0.16	0.17	0.23	0.81	0.23	0.70
39	0.86	0.74	0.64	0.39	0.14	0.27	0.23	0.81	0.25	0.65
40	0.85	0.68	0.59	0.39	0.33	0.26	0.31	0.89	0.28	0.82
41	0.87	0.72	0.54	0.49	0.28	0.34	0.37	0.85	0.28	0.68
42	0.69	0.68	0.50	0.45	0.19	0.23	0.23	0.87	0.29	0.70
43	0.81	0.69	0.44	0.48	0.23	0.28	0.17	0.78	0.21	0.64
44	0.79	0.68	0.47	0.39	0.17	0.25	0.23	0.75	0.25	0.61
45	0.82	0.75	0.49	0.37	0.29	0.32	0.19	0.89	0.34	0.70
46	0.88	0.70	0.50	0.47	0.25	0.29	0.34	0.91	0.26	0.65
47	0.88	0.67	0.59	0.49	0.27	0.22	0.32	0.91	0.29	0.61
48	0.85	0.77	0.54	0.42	0.24	0.28	0.28	0.88	0.35	0.74
49	0.85	0.70	0.53	0.56	0.35	0.27	0.31	0.85	0.32	0.80
50	0.91	0.58	0.59	0.54	0.37	0.40	0.28	0.91	0.34	0.66
51	0.79	0.66	0.56	0.33	0.24	0.22	0.18	0.77	0.26	0.62
52	0.87	0.67	0.46	0.54	0.31	0.34	0.34	0.79	0.24	0.74
53	0.83	0.71	0.52	0.48	0.27	0.29	0.34	0.88	0.30	0.70
54	0.86	0.77	0.54	0.46	0.15	0.24	0.22	0.80	0.27	0.67
55	0.90	0.59	0.61	0.42	0.28	0.27	0.27	0.81	0.19	0.69
56	0.86	0.68	0.46	0.45	0.26	0.28	0.23	0.87	0.28	0.71
57	0.89	0.74	0.47	0.49	0.36	0.38	0.32	0.85	0.35	0.65
58	0.77	0.65	0.43	0.39	0.31	0.15	0.15	0.74	0.20	0.74
59	0.88	0.66	0.53	0.50	0.34	0.35	0.29	0.83	0.35	0.71
60	0.90	0.75	0.57	0.39	0.33	0.34	0.29	0.79	0.23	0.70
61	0.86	0.73	0.57	0.53	0.34	0.24	0.31	0.89	0.34	0.66
62	0.76	0.67	0.58	0.50	0.29	0.23	0.22	0.82	0.34	0.66
63	0.80	0.68	0.46	0.53	0.21	0.20	0.12	0.86	0.32	0.68
64	0.83	0.70	0.57	0.38	0.19	0.27	0.20	0.78	0.23	0.75
65	0.82	0.67	0.57	0.49	0.35	0.33	0.34	0.87	0.34	0.78
66	0.82	0.73	0.58	0.42	0.26	0.30	0.37	0.90	0.34	0.70
67	0.78	0.70	0.59	0.41	0.29	0.27	0.25	0.89	0.25	0.72
68	0.83	0.70	0.55	0.47	0.33	0.30	0.31	0.89	0.34	0.67
69	0.91	0.62	0.59	0.53	0.26	0.34	0.30	0.89	0.28	0.65
70	0.82	0.79	0.54	0.54	0.29	0.27	0.32	0.86	0.31	0.67
71	0.81	0.64	0.45	0.42	0.21	0.19	0.25	0.85	0.27	0.64
72	0.86	0.77	0.52	0.54	0.24	0.31	0.28	0.87	0.27	0.70
73	0.83	0.69	0.53	0.52	0.35	0.35	0.30	0.92	0.35	0.74
74	0.83	0.65	0.45	0.41	0.21	0.17	0.17	0.83	0.28	0.68
75	0.84	0.73	0.60	0.44	0.27	0.31	0.30	0.87	0.36	0.75
76	0.73	0.63	0.40	0.41	0.16	0.19	0.19	0.81	0.23	0.70
77	0.83	0.69	0.57	0.47	0.39	0.31	0.27	0.82	0.21	0.74
78	0.91	0.67	0.58	0.50	0.31	0.34	0.35	0.90	0.25	0.75
79	0.78	0.72	0.43	0.43	0.27	0.18	0.22	0.81	0.24	0.70
80	0.87	0.72	0.55	0.38	0.31	0.26	0.22	0.83	0.23	0.77
81	0.85	0.63	0.51	0.48	0.21	0.36	0.27	0.87	0.30	0.75
82	0.88	0.60	0.52	0.56	0.20	0.27	0.33	0.79	0.32	0.70
83	0.86	0.66	0.46	0.56	0.31	0.37	0.39	0.86	0.25	0.76
84	0.84	0.76	0.46	0.46	0.22	0.33	0.19	0.84	0.25	0.66
85	0.85	0.71	0.46	0.48	0.26	0.33	0.29	0.89	0.28	0.71
86	0.82	0.73	0.56	0.48	0.33	0.28	0.33	0.89	0.22	0.71
87	0.81	0.61	0.52	0.40	0.18	0.23	0.31	0.83	0.26	0.69
88	0.92	0.65	0.40	0.40	0.20	0.19	0.23	0.82	0.24	0.70
89	0.76	0.59	0.50	0.44	0.23	0.21	0.23	0.86	0.27	0.76
90	0.84	0.67	0.42	0.42	0.26	0.12	0.23	0.80	0.20	0.76
91	0.79	0.68	0.51	0.37	0.29	0.29	0.18	0.79	0.26	0.74
92	0.89	0.68	0.51	0.51	0.27	0.28	0.26	0.84	0.31	0.73
93	0.87	0.71	0.55	0.62	0.29	0.34	0.32	0.87	0.29	0.77

```
94     0.83   0.73   0.65   0.53   0.24   0.28   0.32   0.86   0.32    0.72
95     0.89   0.65   0.61   0.35   0.23   0.25   0.16   0.89   0.21    0.67
96     0.86   0.75   0.58   0.50   0.26   0.24   0.31   0.88   0.31    0.67
97     0.86   0.67   0.50   0.40   0.28   0.27   0.29   0.89   0.27    0.67
98     0.87   0.62   0.62   0.45   0.43   0.31   0.32   0.81   0.34    0.80
99     0.85   0.78   0.53   0.48   0.22   0.30   0.26   0.81   0.28    0.69
100    0.88   0.65   0.54   0.42   0.20   0.36   0.26   0.84   0.22    0.63
> output(pbrine,"blok7_pbrine")
    Panel1 Panel2 Panel3 Panel4 Panel5 Panel6 Panel7 Panel8 Panel9 Panel10
1      0.41   0.41   0.34   0.21   0.14   0.19   0.13   0.47   0.12    0.48
2      0.42   0.38   0.25   0.27   0.14   0.09   0.11   0.38   0.15    0.33
3      0.53   0.36   0.30   0.25   0.23   0.10   0.17   0.50   0.11    0.33
4      0.40   0.37   0.19   0.21   0.11   0.10   0.16   0.44   0.14    0.34
5      0.44   0.28   0.25   0.14   0.09   0.15   0.15   0.40   0.14    0.37
6      0.52   0.45   0.37   0.26   0.13   0.19   0.15   0.48   0.15    0.33
7      0.49   0.33   0.26   0.29   0.17   0.13   0.19   0.54   0.22    0.35
8      0.40   0.35   0.24   0.16   0.07   0.08   0.12   0.48   0.12    0.34
9      0.33   0.40   0.18   0.25   0.12   0.13   0.08   0.41   0.12    0.36
10     0.43   0.30   0.28   0.19   0.15   0.09   0.10   0.46   0.12    0.38
11     0.46   0.38   0.32   0.22   0.20   0.09   0.15   0.42   0.12    0.36
12     0.40   0.37   0.22   0.20   0.19   0.16   0.16   0.46   0.17    0.41
13     0.48   0.26   0.23   0.26   0.09   0.14   0.15   0.40   0.15    0.28
14     0.43   0.38   0.23   0.16   0.14   0.15   0.13   0.40   0.10    0.36
15     0.49   0.43   0.34   0.33   0.18   0.21   0.12   0.50   0.20    0.40
16     0.52   0.37   0.29   0.21   0.15   0.20   0.10   0.44   0.10    0.33
17     0.43   0.42   0.31   0.19   0.12   0.11   0.08   0.43   0.16    0.35
18     0.39   0.43   0.25   0.22   0.09   0.12   0.12   0.48   0.11    0.39
19     0.54   0.36   0.26   0.16   0.08   0.09   0.13   0.32   0.07    0.33
20     0.46   0.42   0.24   0.17   0.10   0.04   0.11   0.50   0.12    0.33
21     0.39   0.33   0.22   0.22   0.13   0.13   0.13   0.49   0.14    0.46
22     0.57   0.34   0.32   0.25   0.24   0.14   0.18   0.49   0.18    0.41
23     0.47   0.32   0.26   0.16   0.11   0.15   0.12   0.45   0.18    0.34
24     0.35   0.31   0.19   0.18   0.09   0.09   0.11   0.36   0.10    0.35
25     0.37   0.34   0.24   0.20   0.14   0.08   0.14   0.39   0.16    0.41
26     0.42   0.31   0.30   0.22   0.10   0.15   0.15   0.44   0.18    0.37
27     0.42   0.35   0.30   0.29   0.12   0.11   0.14   0.51   0.15    0.37
28     0.49   0.43   0.22   0.29   0.17   0.15   0.11   0.56   0.22    0.36
29     0.50   0.42   0.31   0.22   0.18   0.16   0.16   0.38   0.15    0.44
30     0.48   0.34   0.27   0.24   0.19   0.15   0.13   0.41   0.10    0.32
31     0.45   0.34   0.23   0.18   0.15   0.18   0.10   0.39   0.16    0.34
32     0.46   0.34   0.25   0.28   0.12   0.19   0.10   0.50   0.15    0.34
33     0.44   0.36   0.26   0.11   0.17   0.10   0.17   0.51   0.12    0.39
34     0.41   0.41   0.27   0.20   0.14   0.14   0.09   0.42   0.17    0.30
35     0.38   0.40   0.32   0.28   0.14   0.13   0.23   0.43   0.14    0.37
36     0.46   0.28   0.26   0.29   0.17   0.09   0.11   0.37   0.21    0.32
37     0.48   0.45   0.32   0.17   0.13   0.13   0.13   0.43   0.14    0.42
38     0.44   0.32   0.32   0.22   0.08   0.09   0.13   0.42   0.10    0.33
39     0.49   0.41   0.32   0.18   0.07   0.17   0.09   0.49   0.10    0.30
40     0.48   0.38   0.32   0.23   0.18   0.15   0.18   0.42   0.14    0.43
41     0.55   0.39   0.28   0.21   0.16   0.18   0.23   0.49   0.18    0.32
42     0.36   0.37   0.23   0.29   0.12   0.13   0.12   0.49   0.18    0.40
43     0.39   0.41   0.20   0.23   0.11   0.16   0.06   0.46   0.12    0.31
44     0.42   0.32   0.25   0.21   0.09   0.10   0.10   0.25   0.16    0.29
45     0.42   0.37   0.25   0.18   0.17   0.17   0.10   0.47   0.19    0.41
46     0.47   0.45   0.25   0.26   0.13   0.20   0.15   0.42   0.09    0.38
47     0.47   0.27   0.36   0.23   0.17   0.10   0.18   0.52   0.14    0.29
48     0.51   0.41   0.23   0.16   0.11   0.14   0.18   0.46   0.17    0.38
49     0.51   0.36   0.24   0.33   0.14   0.15   0.15   0.47   0.15    0.40
50     0.43   0.35   0.22   0.34   0.18   0.20   0.13   0.45   0.21    0.31
51     0.41   0.40   0.23   0.18   0.07   0.12   0.11   0.41   0.13    0.27
52     0.42   0.34   0.18   0.30   0.17   0.19   0.22   0.38   0.10    0.33
53     0.48   0.40   0.25   0.23   0.14   0.18   0.13   0.45   0.17    0.36
54     0.43   0.43   0.27   0.24   0.05   0.13   0.16   0.38   0.17    0.32
```

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55    0.43   0.31   0.30   0.22   0.10   0.15   0.11   0.40   0.13    0.31
56    0.41   0.31   0.21   0.30   0.09   0.12   0.11   0.46   0.17    0.35
57    0.45   0.47   0.22   0.25   0.19   0.23   0.13   0.47   0.13    0.40
58    0.36   0.36   0.19   0.20   0.17   0.10   0.04   0.39   0.10    0.36
59    0.35   0.29   0.29   0.28   0.16   0.19   0.12   0.45   0.20    0.41
60    0.46   0.44   0.23   0.25   0.18   0.17   0.19   0.42   0.11    0.41
61    0.41   0.36   0.28   0.26   0.20   0.14   0.20   0.44   0.18    0.44
62    0.44   0.32   0.34   0.24   0.15   0.10   0.14   0.41   0.13    0.31
63    0.48   0.38   0.27   0.26   0.10   0.13   0.07   0.42   0.14    0.37
64    0.41   0.35   0.30   0.18   0.06   0.14   0.11   0.46   0.13    0.45
65    0.43   0.38   0.33   0.23   0.14   0.18   0.10   0.40   0.17    0.40
66    0.41   0.37   0.33   0.26   0.17   0.15   0.15   0.50   0.22    0.36
67    0.51   0.34   0.31   0.25   0.14   0.11   0.13   0.50   0.13    0.35
68    0.44   0.33   0.27   0.23   0.19   0.20   0.15   0.45   0.17    0.32
69    0.45   0.30   0.32   0.27   0.15   0.17   0.16   0.46   0.16    0.33
70    0.46   0.44   0.27   0.28   0.11   0.15   0.13   0.43   0.14    0.33
71    0.37   0.31   0.23   0.21   0.13   0.12   0.15   0.53   0.17    0.32
72    0.44   0.38   0.23   0.31   0.15   0.16   0.14   0.40   0.14    0.42
73    0.45   0.30   0.26   0.36   0.23   0.18   0.11   0.48   0.21    0.38
74    0.41   0.28   0.22   0.17   0.11   0.10   0.07   0.45   0.15    0.31
75    0.39   0.37   0.29   0.26   0.18   0.16   0.14   0.52   0.19    0.40
76    0.32   0.37   0.22   0.25   0.09   0.10   0.11   0.46   0.08    0.35
77    0.44   0.41   0.30   0.25   0.25   0.16   0.10   0.42   0.08    0.31
78    0.47   0.28   0.32   0.27   0.12   0.20   0.22   0.49   0.13    0.47
79    0.45   0.43   0.21   0.28   0.17   0.07   0.13   0.38   0.11    0.33
80    0.53   0.36   0.27   0.18   0.15   0.11   0.09   0.46   0.13    0.43
81    0.50   0.38   0.30   0.21   0.10   0.19   0.15   0.42   0.15    0.39
82    0.43   0.36   0.29   0.29   0.10   0.13   0.17   0.42   0.21    0.43
83    0.53   0.32   0.20   0.28   0.14   0.20   0.17   0.42   0.13    0.42
84    0.45   0.35   0.23   0.25   0.15   0.22   0.12   0.35   0.12    0.40
85    0.54   0.40   0.23   0.25   0.13   0.17   0.13   0.45   0.16    0.43
86    0.50   0.39   0.26   0.22   0.20   0.17   0.19   0.42   0.17    0.35
87    0.47   0.30   0.26   0.20   0.07   0.13   0.19   0.41   0.17    0.31
88    0.39   0.36   0.17   0.21   0.12   0.12   0.10   0.38   0.14    0.32
89    0.42   0.34   0.20   0.22   0.13   0.10   0.13   0.43   0.12    0.34
90    0.38   0.35   0.20   0.20   0.14   0.05   0.11   0.38   0.10    0.46
91    0.46   0.47   0.26   0.20   0.10   0.13   0.13   0.46   0.17    0.41
92    0.48   0.34   0.31   0.25   0.19   0.10   0.16   0.42   0.13    0.38
93    0.39   0.43   0.32   0.28   0.16   0.12   0.18   0.39   0.15    0.38
94    0.41   0.41   0.33   0.25   0.15   0.20   0.22   0.48   0.20    0.40
95    0.50   0.36   0.30   0.22   0.15   0.12   0.08   0.51   0.11    0.34
96    0.49   0.37   0.26   0.22   0.13   0.14   0.16   0.37   0.20    0.35
97    0.40   0.36   0.26   0.21   0.11   0.16   0.14   0.54   0.14    0.38
98    0.41   0.37   0.29   0.26   0.20   0.20   0.16   0.50   0.18    0.37
99    0.53   0.37   0.27   0.28   0.09   0.14   0.16   0.34   0.17    0.33
100   0.53   0.33   0.25   0.24   0.10   0.18   0.13   0.37   0.12    0.36
>
> # convert to dataframe with PANEL as factor
> pbrinedata <- combined(pbrine,phcz)
> print(pbrinedata)
     pBRINE pHCZ  PANEL
1      0.41 0.81 Panl01
2      0.42 0.81 Panl01
3      0.53 0.88 Panl01
4       0.4 0.83 Panl01
5      0.44 0.79 Panl01
6      0.52 0.81 Panl01
7      0.49 0.89 Panl01

             […]

990    0.46 0.76 Panl10
991    0.41 0.74 Panl10
```

```
992    0.38 0.73 Panl10
993    0.38 0.77 Panl10
994     0.4 0.72 Panl10
995    0.34 0.67 Panl10
996    0.35 0.67 Panl10
997    0.38 0.67 Panl10
998    0.37  0.8 Panl10
999    0.33 0.69 Panl10
1000   0.36 0.63 Panl10
>
> # calculate frequency distributions by panel
> phczpanel <- xtabs(~pHCZ+PANEL,data=pbrinedata)/Niter
> pbrinepanel <- xtabs(~pBRINE+PANEL,data=pbrinedata)/Niter
> print(phczpanel)
      PANEL
pHCZ   Panl01 Panl02 Panl03 Panl04 Panl05 Panl06 Panl07 Panl08 Panl09 Panl10
  0.12   0.00   0.00   0.00   0.00   0.00   0.02   0.01   0.00   0.00   0.00
  0.14   0.00   0.00   0.00   0.00   0.02   0.01   0.01   0.00   0.00   0.00
  0.15   0.00   0.00   0.00   0.00   0.01   0.03   0.01   0.00   0.00   0.00
  0.16   0.00   0.00   0.00   0.00   0.02   0.01   0.01   0.00   0.00   0.00
  0.17   0.00   0.00   0.00   0.00   0.01   0.03   0.02   0.00   0.01   0.00
  0.18   0.00   0.00   0.00   0.00   0.02   0.02   0.04   0.00   0.00   0.00
  0.19   0.00   0.00   0.00   0.00   0.02   0.04   0.04   0.00   0.02   0.00
  0.2    0.00   0.00   0.00   0.00   0.03   0.03   0.05   0.00   0.03   0.00
  0.21   0.00   0.00   0.00   0.00   0.07   0.03   0.03   0.00   0.06   0.00
  0.22   0.00   0.00   0.00   0.00   0.06   0.03   0.05   0.00   0.02   0.00
  0.23   0.00   0.00   0.00   0.00   0.04   0.05   0.10   0.00   0.08   0.00
  0.24   0.00   0.00   0.00   0.00   0.10   0.08   0.02   0.00   0.07   0.00
  0.25   0.00   0.00   0.00   0.00   0.04   0.03   0.04   0.00   0.08   0.00
  0.26   0.00   0.00   0.00   0.00   0.07   0.05   0.09   0.00   0.05   0.00
  0.27   0.00   0.00   0.00   0.00   0.06   0.10   0.05   0.00   0.10   0.00
  0.28   0.00   0.00   0.00   0.00   0.09   0.09   0.08   0.00   0.08   0.00
  0.29   0.00   0.00   0.00   0.00   0.06   0.03   0.05   0.00   0.07   0.00
  0.3    0.00   0.00   0.00   0.01   0.02   0.04   0.05   0.00   0.03   0.00
  0.31   0.00   0.00   0.00   0.00   0.05   0.06   0.06   0.00   0.05   0.00
  0.32   0.00   0.00   0.00   0.00   0.00   0.01   0.06   0.00   0.06   0.00
  0.33   0.00   0.00   0.00   0.02   0.06   0.04   0.03   0.00   0.01   0.00
  0.34   0.00   0.00   0.00   0.00   0.04   0.06   0.04   0.00   0.10   0.00
  0.35   0.00   0.00   0.00   0.02   0.05   0.03   0.01   0.00   0.04   0.00
  0.36   0.00   0.00   0.00   0.03   0.02   0.02   0.01   0.00   0.02   0.00
  0.37   0.00   0.00   0.00   0.03   0.02   0.03   0.03   0.00   0.00   0.00
  0.38   0.00   0.00   0.00   0.02   0.00   0.01   0.00   0.00   0.01   0.00
  0.39   0.00   0.00   0.00   0.08   0.01   0.01   0.01   0.00   0.01   0.00
  0.4    0.00   0.00   0.02   0.06   0.00   0.01   0.00   0.00   0.00   0.00
  0.41   0.00   0.00   0.00   0.04   0.00   0.00   0.00   0.00   0.00   0.00
  0.42   0.00   0.00   0.01   0.06   0.00   0.00   0.00   0.00   0.00   0.00
  0.43   0.00   0.00   0.02   0.05   0.01   0.00   0.00   0.00   0.00   0.00
  0.44   0.00   0.00   0.04   0.07   0.00   0.00   0.00   0.00   0.00   0.00
  0.45   0.00   0.00   0.04   0.03   0.00   0.00   0.00   0.00   0.00   0.00
  0.46   0.00   0.00   0.08   0.05   0.00   0.00   0.00   0.00   0.00   0.00
  0.47   0.00   0.00   0.07   0.03   0.00   0.00   0.00   0.00   0.00   0.00
  0.48   0.00   0.00   0.02   0.07   0.00   0.00   0.00   0.00   0.00   0.00
  0.49   0.00   0.00   0.01   0.07   0.00   0.00   0.00   0.00   0.00   0.00
  0.5    0.00   0.00   0.06   0.04   0.00   0.00   0.00   0.00   0.00   0.00
  0.51   0.00   0.00   0.05   0.01   0.00   0.00   0.00   0.00   0.00   0.00
  0.52   0.00   0.00   0.06   0.01   0.00   0.00   0.00   0.00   0.00   0.00
  0.53   0.00   0.00   0.06   0.06   0.00   0.00   0.00   0.00   0.00   0.00
  0.54   0.00   0.00   0.07   0.06   0.00   0.00   0.00   0.00   0.00   0.00
  0.55   0.00   0.00   0.05   0.02   0.00   0.00   0.00   0.00   0.00   0.00
  0.56   0.00   0.00   0.04   0.03   0.00   0.00   0.00   0.00   0.00   0.00
  0.57   0.00   0.01   0.07   0.02   0.00   0.00   0.00   0.00   0.00   0.00
  0.58   0.00   0.01   0.06   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  0.59   0.00   0.03   0.05   0.00   0.00   0.00   0.00   0.00   0.00   0.00
```

```
  0.6    0.00   0.01   0.02   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  0.61   0.00   0.03   0.02   0.00   0.00   0.00   0.00   0.00   0.00   0.02
  0.62   0.00   0.02   0.03   0.01   0.00   0.00   0.00   0.00   0.00   0.02
  0.63   0.00   0.03   0.01   0.00   0.00   0.00   0.00   0.00   0.00   0.03
  0.64   0.00   0.01   0.01   0.00   0.00   0.00   0.00   0.00   0.00   0.03
  0.65   0.00   0.08   0.02   0.00   0.00   0.00   0.00   0.00   0.00   0.05
  0.66   0.00   0.06   0.01   0.00   0.00   0.00   0.00   0.00   0.00   0.04
  0.67   0.00   0.13   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.10
  0.68   0.00   0.11   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.09
  0.69   0.01   0.05   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.09
  0.7    0.00   0.09   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.14
  0.71   0.00   0.08   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.05
  0.72   0.00   0.04   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.04
  0.73   0.01   0.07   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.07
  0.74   0.00   0.02   0.00   0.00   0.00   0.00   0.00   0.01   0.00   0.06
  0.75   0.00   0.05   0.00   0.00   0.00   0.00   0.00   0.01   0.00   0.04
  0.76   0.03   0.01   0.00   0.00   0.00   0.00   0.00   0.02   0.00   0.03
  0.77   0.02   0.03   0.00   0.00   0.00   0.00   0.00   0.01   0.00   0.03
  0.78   0.05   0.01   0.00   0.00   0.00   0.00   0.00   0.04   0.00   0.01
  0.79   0.05   0.01   0.00   0.00   0.00   0.00   0.00   0.06   0.00   0.03
  0.8    0.02   0.00   0.00   0.00   0.00   0.00   0.00   0.04   0.00   0.02
  0.81   0.11   0.01   0.00   0.00   0.00   0.00   0.00   0.10   0.00   0.00
  0.82   0.07   0.00   0.00   0.00   0.00   0.00   0.00   0.04   0.00   0.01
  0.83   0.09   0.00   0.00   0.00   0.00   0.00   0.00   0.08   0.00   0.00
  0.84   0.04   0.00   0.00   0.00   0.00   0.00   0.00   0.03   0.00   0.00
  0.85   0.08   0.00   0.00   0.00   0.00   0.00   0.00   0.12   0.00   0.00
  0.86   0.13   0.00   0.00   0.00   0.00   0.00   0.00   0.08   0.00   0.00
  0.87   0.06   0.00   0.00   0.00   0.00   0.00   0.00   0.11   0.00   0.00
  0.88   0.07   0.00   0.00   0.00   0.00   0.00   0.00   0.03   0.00   0.00
  0.89   0.06   0.00   0.00   0.00   0.00   0.00   0.00   0.11   0.00   0.00
  0.9    0.03   0.00   0.00   0.00   0.00   0.00   0.00   0.03   0.00   0.00
  0.91   0.03   0.00   0.00   0.00   0.00   0.00   0.00   0.04   0.00   0.00
  0.92   0.03   0.00   0.00   0.00   0.00   0.00   0.00   0.02   0.00   0.00
  0.93   0.01   0.00   0.00   0.00   0.00   0.00   0.00   0.02   0.00   0.00
> print(pbrinepanel)
      PANEL
pBRINE Panl01 Panl02 Panl03 Panl04 Panl05 Panl06 Panl07 Panl08 Panl09 Panl10
  0.04   0.00   0.00   0.00   0.00   0.00   0.01   0.01   0.00   0.00   0.00
  0.05   0.00   0.00   0.00   0.00   0.01   0.01   0.00   0.00   0.00   0.00
  0.06   0.00   0.00   0.00   0.00   0.01   0.00   0.01   0.00   0.00   0.00
  0.07   0.00   0.00   0.00   0.00   0.04   0.01   0.02   0.00   0.01   0.00
  0.08   0.00   0.00   0.00   0.00   0.02   0.02   0.03   0.00   0.02   0.00
  0.09   0.00   0.00   0.00   0.00   0.08   0.07   0.03   0.00   0.01   0.00
  0.1    0.00   0.00   0.00   0.00   0.08   0.11   0.09   0.00   0.09   0.00
  0.11   0.00   0.00   0.00   0.01   0.07   0.04   0.12   0.00   0.05   0.00
  0.12   0.00   0.00   0.00   0.00   0.07   0.07   0.07   0.00   0.11   0.00
  0.13   0.00   0.00   0.00   0.00   0.08   0.11   0.17   0.00   0.10   0.00
  0.14   0.00   0.00   0.00   0.01   0.12   0.08   0.06   0.00   0.12   0.00
  0.15   0.00   0.00   0.00   0.00   0.10   0.11   0.11   0.00   0.10   0.00
  0.16   0.00   0.00   0.00   0.05   0.03   0.07   0.09   0.00   0.06   0.00
  0.17   0.00   0.00   0.01   0.03   0.10   0.06   0.04   0.00   0.13   0.00
  0.18   0.00   0.00   0.02   0.07   0.06   0.06   0.05   0.00   0.07   0.00
  0.19   0.00   0.00   0.03   0.02   0.05   0.06   0.04   0.00   0.02   0.00
  0.2    0.00   0.00   0.04   0.07   0.04   0.08   0.01   0.00   0.04   0.00
  0.21   0.00   0.00   0.02   0.09   0.00   0.01   0.00   0.00   0.04   0.00
  0.22   0.00   0.00   0.07   0.11   0.00   0.01   0.03   0.00   0.03   0.00
  0.23   0.00   0.00   0.11   0.06   0.02   0.01   0.02   0.00   0.00   0.00
  0.24   0.00   0.00   0.04   0.04   0.01   0.00   0.00   0.00   0.00   0.00
  0.25   0.00   0.00   0.09   0.12   0.01   0.00   0.00   0.01   0.00   0.00
  0.26   0.00   0.01   0.11   0.08   0.00   0.00   0.00   0.00   0.00   0.00
  0.27   0.00   0.01   0.08   0.03   0.00   0.00   0.00   0.00   0.00   0.01
  0.28   0.00   0.04   0.03   0.08   0.00   0.00   0.00   0.00   0.00   0.01
  0.29   0.00   0.01   0.05   0.06   0.00   0.00   0.00   0.00   0.00   0.02
```

```
  0.3    0.00   0.04   0.08   0.02   0.00   0.00   0.00   0.00   0.00   0.02
  0.31   0.00   0.05   0.04   0.01   0.00   0.00   0.00   0.00   0.00   0.07
  0.32   0.01   0.05   0.10   0.00   0.00   0.00   0.00   0.01   0.00   0.07
  0.33   0.01   0.04   0.03   0.02   0.00   0.00   0.00   0.00   0.00   0.12
  0.34   0.00   0.09   0.03   0.01   0.00   0.00   0.00   0.01   0.00   0.07
  0.35   0.02   0.06   0.00   0.00   0.00   0.00   0.00   0.01   0.00   0.08
  0.36   0.02   0.11   0.01   0.01   0.00   0.00   0.00   0.01   0.00   0.08
  0.37   0.02   0.11   0.01   0.00   0.00   0.00   0.00   0.03   0.00   0.06
  0.38   0.02   0.08   0.00   0.00   0.00   0.00   0.00   0.07   0.00   0.07
  0.39   0.06   0.02   0.00   0.00   0.00   0.00   0.00   0.04   0.00   0.03
  0.4    0.04   0.05   0.00   0.00   0.00   0.00   0.00   0.06   0.00   0.08
  0.41   0.10   0.07   0.00   0.00   0.00   0.00   0.00   0.05   0.00   0.07
  0.42   0.07   0.03   0.00   0.00   0.00   0.00   0.00   0.13   0.00   0.03
  0.43   0.08   0.06   0.00   0.00   0.00   0.00   0.00   0.05   0.00   0.04
  0.44   0.07   0.02   0.00   0.00   0.00   0.00   0.00   0.04   0.00   0.02
  0.45   0.06   0.03   0.00   0.00   0.00   0.00   0.00   0.07   0.00   0.01
  0.46   0.07   0.00   0.00   0.00   0.00   0.00   0.00   0.10   0.00   0.02
  0.47   0.05   0.02   0.00   0.00   0.00   0.00   0.00   0.04   0.00   0.01
  0.48   0.07   0.00   0.00   0.00   0.00   0.00   0.00   0.05   0.00   0.01
  0.49   0.05   0.00   0.00   0.00   0.00   0.00   0.00   0.06   0.00   0.00
  0.5    0.04   0.00   0.00   0.00   0.00   0.00   0.00   0.07   0.00   0.00
  0.51   0.03   0.00   0.00   0.00   0.00   0.00   0.00   0.03   0.00   0.00
  0.52   0.02   0.00   0.00   0.00   0.00   0.00   0.00   0.02   0.00   0.00
  0.53   0.05   0.00   0.00   0.00   0.00   0.00   0.00   0.01   0.00   0.00
  0.54   0.02   0.00   0.00   0.00   0.00   0.00   0.00   0.02   0.00   0.00
  0.55   0.01   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  0.56   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.01   0.00   0.00
  0.57   0.01   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
>
> # get weighted distributions for repository & output
> phczdist <- weights(phczpanel)
> output(phczdist,"blok7_phczPF")
    Distribution of pHCZ
Rank pHCZ Probability     CDF
  1  0.12     0.00315 0.00315
  2  0.14     0.00420 0.00735
  3  0.15     0.00525 0.01260
  4  0.16     0.00420 0.01680
  5  0.17     0.00709 0.02389
  6  0.18     0.00840 0.03229
  7  0.19     0.01208 0.04437
  8  0.20     0.01392 0.05829
  9  0.21     0.01839 0.07668
  10 0.22     0.01628 0.09296
  11 0.23     0.02627 0.11923
  12 0.24     0.02653 0.14576
  13 0.25     0.01787 0.16363
  14 0.26     0.02600 0.18963
  15 0.27     0.02995 0.21958
  16 0.28     0.03362 0.25320
  17 0.29     0.02023 0.27343
  18 0.30     0.01497 0.28840
  19 0.31     0.02180 0.31020
  20 0.32     0.01209 0.32229
  21 0.33     0.01654 0.33883
  22 0.34     0.02260 0.36143
  23 0.35     0.01471 0.37614
  24 0.36     0.00998 0.38612
  25 0.37     0.01155 0.39767
  26 0.38     0.00394 0.40161
  27 0.39     0.01234 0.41395
  28 0.40     0.00945 0.42340
  29 0.41     0.00420 0.42760
```

```
   30 0.42     0.00735 0.43495
   31 0.43     0.00840 0.44335
   32 0.44     0.01155 0.45490
   33 0.45     0.00735 0.46225
   34 0.46     0.01365 0.47590
   35 0.47     0.01050 0.48640
   36 0.48     0.00945 0.49585
   37 0.49     0.00840 0.50425
   38 0.50     0.01050 0.51475
   39 0.51     0.00630 0.52105
   40 0.52     0.00735 0.52840
   41 0.53     0.01260 0.54100
   42 0.54     0.01365 0.55465
   43 0.55     0.00735 0.56200
   44 0.56     0.00735 0.56935
   45 0.57     0.01050 0.57985
   46 0.58     0.00735 0.58720
   47 0.59     0.00840 0.59560
   48 0.60     0.00315 0.59875
   49 0.61     0.00687 0.60562
   50 0.62     0.00792 0.61354
   51 0.63     0.00663 0.62017
   52 0.64     0.00453 0.62470
   53 0.65     0.01455 0.63925
   54 0.66     0.01059 0.64984
   55 0.67     0.02175 0.67159
   56 0.68     0.01884 0.69043
   57 0.69     0.01359 0.70402
   58 0.70     0.02079 0.72481
   59 0.71     0.01245 0.73726
   60 0.72     0.00744 0.74470
   61 0.73     0.01407 0.75877
   62 0.74     0.00801 0.76678
   63 0.75     0.00954 0.77632
   64 0.76     0.00873 0.78505
   65 0.77     0.00873 0.79378
   66 0.78     0.01131 0.80509
   67 0.79     0.01503 0.82012
   68 0.80     0.00792 0.82804
   69 0.81     0.02310 0.85114
   70 0.82     0.01236 0.86350
   71 0.83     0.01785 0.88135
   72 0.84     0.00735 0.88870
   73 0.85     0.02100 0.90970
   74 0.86     0.02205 0.93175
   75 0.87     0.01785 0.94960
   76 0.88     0.01050 0.96010
   77 0.89     0.01785 0.97795
   78 0.90     0.00630 0.98425
   79 0.91     0.00735 0.99160
   80 0.92     0.00525 0.99685
   81 0.93     0.00315 1.00000
>
> pbrinedist <- weights(pbrinepanel)
> output(pbrinedist,"blok7_pbrinePF")
    Distribution of pBRINE
Rank pBRINE Probability     CDF
  1    0.04     0.00210 0.00210
  2    0.05     0.00210 0.00420
  3    0.06     0.00210 0.00630
  4    0.07     0.00814 0.01444
  5    0.08     0.00893 0.02337
  6    0.09     0.01969 0.04306
```

```
  7    0.10     0.03651 0.07957
  8    0.11     0.02915 0.10872
  9    0.12     0.03074 0.13946
  10   0.13     0.04570 0.18516
  11   0.14     0.03783 0.22299
  12   0.15     0.04150 0.26449
  13   0.16     0.02994 0.29443
  14   0.17     0.03547 0.32990
  15   0.18     0.03283 0.36273
  16   0.19     0.02258 0.38531
  17   0.20     0.02836 0.41367
  18   0.21     0.01576 0.42943
  19   0.22     0.02547 0.45490
  20   0.23     0.02310 0.47800
  21   0.24     0.00945 0.48745
  22   0.25     0.02415 0.51160
  23   0.26     0.02100 0.53260
  24   0.27     0.01341 0.54601
  25   0.28     0.01656 0.56257
  26   0.29     0.01422 0.57679
  27   0.30     0.01632 0.59311
  28   0.31     0.01617 0.60928
  29   0.32     0.02352 0.63280
  30   0.33     0.02022 0.65302
  31   0.34     0.02037 0.67339
  32   0.35     0.01593 0.68932
  33   0.36     0.02328 0.71260
  34   0.37     0.02271 0.73531
  35   0.38     0.02352 0.75883
  36   0.39     0.01503 0.77386
  37   0.40     0.02223 0.79609
  38   0.41     0.02877 0.82486
  39   0.42     0.02658 0.85144
  40   0.43     0.02319 0.87463
  41   0.44     0.01527 0.88990
  42   0.45     0.01761 0.90751
  43   0.46     0.01947 0.92698
  44   0.47     0.01236 0.93934
  45   0.48     0.01341 0.95275
  46   0.49     0.01155 0.96430
  47   0.50     0.01155 0.97585
  48   0.51     0.00630 0.98215
  49   0.52     0.00420 0.98635
  50   0.53     0.00630 0.99265
  51   0.54     0.00420 0.99685
  52   0.55     0.00105 0.99790
  53   0.56     0.00105 0.99895
  54   0.57     0.00105 1.00000
>
> ls()
 [1] "b"           "block.data"  "blocks"      "C"           "cell.data"
 [6] "cells"       "cellspj"     "Clower"      "combined"    "Cupper"
[11] "dimcel"      "find"        "i"           "inside"      "iseed"
[16] "j"           "k"           "m"           "NB"          "NC"
[21] "Nhole"       "Niter"       "Npanel"      "nplus"       "numcel"
[26] "nw"          "nwc"         "nwcb"        "output"      "p"
[31] "panel.data"  "panelnames"  "panelweight" "pbrine"      "pbrinedata"
[36] "pbrinedist"  "pbrinepanel" "pfactors"    "phcz"        "phczdist"
[41] "phczpanel"   "plower"      "pupper"      "random"      "S"
[46] "type"        "weights"     "X"           "Z"
> q("no")
```

Appendix D. Percent of Waste Panel Area Overlying each TDEM Block

TDEM Block	Waste Panel									
	1	2	3	4	5	6	7	8	9	10
500N-500W	0	0	0	0	0	0	0	64.2	0	0
250N-500W	0	0	0	0	0	22.7	64.1	0	0	0
000N-500W	0	0	0	0	65.2	42.5	0	0	0	0
500N-250W	0	0	0	0	0	0	0	35.8	0	48.4
250N-250W	0	0	0	0	0	15.4	35.9	0	23.7	26.2
000N-250W	0	0	0	0	34.8	19.4	0	0	53.5	0
500N-000E	72.1	0	0	0	0	0	0	0	0	14.8
250N-000E	0	72.4	27.1	0	0	0	0	0	7.1	10.6
000N-000E	0	0	45.6	76.4	0	0	0	0	15.7	0
500N-250E	27.9	0	0	0	0	0	0	0	0	0
250N-250E	0	27.6	11.4	0	0	0	0	0	0	0
000N-250E	0	0	15.9	23.6	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100

Note: Percent hits of TDEM blocks (read as percent areas) are based on 10,000 borehole locations per waste panel.

Key: Blue-shaded cells represent values over 40%, and beige-shaded cells are over 50%.

Appendix E. Quality Assurance Review Documentation

This appendix documents the implementation of the quality assurance requirements identified in the project's Quality Assurance Project Plan (QAPP; SC&A 2016), provides documentation of the results of the project's Data Quality Objective (DQO) assessments (Economy 2016), and provides documentation of the project's independent external technical review.

E.1 Data Quality Objective Assessment Results

Literature and data identified for possible inclusion in the study's data analysis were evaluated using the five assessment factors described by EPA's Science and Technology Policy Council in *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (EPA 2003). These factors and the criteria for assessing them are summarized in Table E-1.

Table E-1. Data Quality Assessment Factors and Summary Assessment Criteria

Assessment Factor	Summary Assessment Criteria
Applicability and Utility	The document provides relevant information of the type described above for helping prepare an updated approach for estimating the probability of encountering Castile brine beneath the WIPP waste panels in deep exploratory boreholes.
Evaluation and Review	The document has been independently technically reviewed, peer reviewed, or cited and used by a project that has been so reviewed.
Soundness	The document relies on sound scientific theory and approaches, and its conclusions are consistent with the data presented.
Clarity and Completeness	The document provides underlying data, assumptions, procedures, and model parameters, as applicable, as well as information about sponsorship and author affiliations.
Uncertainty and Variability	The document identifies uncertainties, variability, sources of error and/or bias, and properly reflects them in any conclusions drawn.

The quality of existing data was also determined by evaluating the data with respect to a set of data quality indicators. In implementing the graded approach, each of the following six data quality indicators were considered as potentially applicable to the type of data being assessed.

Precision: For purposes of this project, data precision and accuracy were considered together with an emphasis on accuracy. Geologic and hydrologic information on the Castile Formation and its brine reservoirs were of greatest importance and most such information was obtained by indirect methods such as geophysical techniques and extrapolations of existing data. Such data were not expected to be precise and sensitive data of questionable accuracy were treated as stochastic parameters with assigned ranges of uncertainty.

Bias: Supporting data were carefully reviewed for possible bias. However, potentially biased information was appropriately used in the bounding analysis for the conditional probability of encountering brine given that a borehole intersects a high electrical conductivity zone in the Castile beneath a WIPP waste panel.

Representativeness: Representativeness was very important in identifying data appropriate to the project's objective. Acceptable data that were not directly applicable to geologic and hydrologic conditions in the northern Delaware Basin and at the WIPP site were either not used or used with explanations.

Completeness: The completeness of a study described in the literature was used as an indicator of the quality of the information presented. For each such study, the review team looked for indications that information sources, analyses, and conclusions were well documented, that alternative processes or conclusions were considered, and that the study was independently reviewed and approved.

Comparability: The degree to which the results of a study reported in the literature could be compared with the results of other, similar studies and with the reviewer's general knowledge of physical processes was used as an indicator of the quality of the information presented.

Sensitivity: The sensitivity of project results to specific data was an important consideration in the use of those data in the study. As previously mentioned, the precision and accuracy of data were carefully evaluated in a graded QA approach and uncertainty bounds were established in the analysis for sensitive data of questionable accuracy.

The project team's objective was to cite literature that conforms in full to the criteria for the five assessment factors and to the six data quality indicators. However, sources of information on some topics did not fully conform to all aspects of the criteria. For example, there were some reports and memoranda that did not state that an independent review had been conducted. Although such reviews have long been standard practice in science and engineering, it was not standard practice in older reports to document those reviews. In the few cases where such reports were the only sources of specific information that could be identified, it was found that they were also cited and provided significant inputs to studies that were independently reviewed and those data were therefore considered acceptable for use in this project. In addition, some data sources only marginally met certain acceptance criteria for this study but were retained for use consistent with a graded QA approach because they provided only general background information, corroborative information, or other information where fully meeting the acceptance criterion in question was not key to the project's analysis and conclusions. The graded approach therefore allowed the level of quality assurance applied to the information to be commensurate with the intended use of the information, the degree of confidence necessary in that information, and the importance of the information to the project.

The results of the project's data quality assessments are presented in Table E-2. As explained in the footnote to the table, each of the external sources of information used to support the project's analysis and conclusions were evaluated and scored according to the degree to which the assessment factors and data quality indicators were met. The scores indicate whether the information provided by the source document and used in the project was fully acceptable (A), marginally acceptable (M), or not applicable (N). An additional category, unacceptable (U), was not needed because no unacceptable data were used in the project. It is important to note that the scores apply only to the data in the source document that were used in the project. The source document may have contained other data that were not used in the project and the document may have been scored differently if those data had been used.

The explanations in Table E-2 identify the limited uses of data that were taken from each source. Limiting the use of data enabled the project to use only those data from each source that were needed and found to be of sufficient quality rather than requiring the project to accept all data from a given source, some of which may have been of questionable quality. One such source, for example, is Powers et al. (1996), where the geologic data were needed and found to be acceptable while the conclusions drawn from those data were not acceptable and not needed. The full data source citations for Table E-2 can be found in the reference list for this report.

This project had three key information sources: Popielak et al. (1983), The Earth Technology Corporation (1987), and Kirchner et al. (2012).

Popielak et al. (1983) provided the only comprehensive scientific analyses of Castile brine reservoirs. That analysis was performed on behalf of the DOE pursuant to a stipulated agreement entered into by the DOE and the U.S. Department of the Interior to help resolve a lawsuit by the State of New Mexico by addressing the State's concerns relative to the safety of the WIPP site (Popielak et al. 1983, p. 2). Popielak et al.'s analysis was used to help resolve the State's concerns.

The Earth Technology Corporation (1987) states that the TDEM survey was conducted at the WIPP site "… to determine the occurrence and depth of brine in the geologic formations above and below the waste panels." (The Earth Technology Corporation 1987, p. 1).

Kirchner et al. (2012) provided the only available source of the updated frequency of brine encounters during drilling in the region around the WIPP site. These data were used to establish the lower bound of the conditional distribution *p[brine|HCZ]*.

As part of this project, supplemental quality evaluations were conducted for these three key information sources following a format provided in the QAPP template *Elements of a Quality Assurance Project Plan (QAPP) For Collecting, Identifying and Evaluating Existing Scientific Data/Information* (EPA 2012). The supplemental quality evaluations are presented below in Tables E-3 through E-5. Each of these key sources were found to provide information that is entirely appropriate for the purposes of this project.

Table E-2 Data Quality Assessment Results

Data Source Citation	Data Quality Assessment Factors					Data Quality Indicators						Explanations
	Applicability and Utility	Evaluation and Review	Soundness	Clarity and Completeness	Uncertainty and Variability	Precision	Bias	Representativeness	Completeness	Comparability	Sensitivity	
Barrows et al. 1983	A	A	A	A	A	N	A	A	A	A	M	The gravity survey provided no useful results but the report corroborated interpretation of seismic survey results
Borns 1983	A	A	A	A	A	N	A	A	A	A	A	Provided alternative explanations for reservoir formation
Borns et al. 1983	A	A	A	A	A	N	A	A	A	A	A	Provided alternative explanations for reservoir formation and corroborated interpretation of seismic survey results
Borns 1996	A	A	A	A	A	A	A	A	A	A	M	Provided alternative analysis of TDEM data. The original unreviewed memorandum was reviewed and cited in EPA (1998a) as the basis for establishing the upper bound of the mandated PBRINE uncertainty distribution.
Camphouse 2012	A	A	A	A	A	A	A	A	A	A	M	Provided a figure illustrating the PA model grid and an exploratory borehole penetrating a Castile brine reservoir
DOE 2009	A	A	A	A	A	A	A	A	A	A	A	Provided information on the waste area footprint for TDEM uncertainty analysis and documented significance of PBRINE to WIPP PA results
DOE 2011	A	A	A	A	A	N	A	A	A	A	A	Provided general supporting information on waste area footprint for TDEM uncertainty analysis
DOE 2014	A	A	A	A	A	A	A	A	A	A	A	Provided information on borehole plugging, waste panel porosity, and waste panel residual saturation
EPA 1998a	A	A	A	A	A	M	A	A	A	A	A	Documented EPA's 1998 mandated PBRINE distribution
EPA 1998b	A	A	A	A	A	M	A	A	A	A	M	Documented early application of TDEM block model
EPA 2011	A	A	A	A	A	A	A	M	A	A	M	Provided general overview of TDEM method
Gardner-Denver 2015	A	M	A	A	A	A	A	A	A	N	A	Provided information on drilling mud flow rates
Hanson 2003	A	A	A	A	A	A	A	A	A	A	A	Provided information on the depth of the WIPP waste panels
Hurwitz et al. 1999	M	A	A	A	A	A	A	N	A	A	M	Provided general supporting information on use of TDEM method
Jones 1981	A	A	A	A	A	A	A	A	A	A	A	Documented original technical investigation of ERDA 6
Kirchner et al. 2012	A	A	A	A	M	A	M	M	A	A	M	Provided updated drilling data used to bound *p[brine|HCZ]* and is a key reference for the project. Also provided alternative estimates of PBRINE that were not used. The original unreviewed memorandum was reviewed and cited in DOE (2014) as the basis for adopting an alternative approach to estimating PBRINE for the 2014 CRA.

Table E-2 Data Quality Assessment Results (Continued)

Data Source Citation	Data Quality Assessment Factors					Data Quality Indicators						Explanations
	Applicability and Utility	Evaluation and Review	Soundness	Clarity and Completeness	Uncertainty and Variability	Precision	Bias	Representativeness	Completeness	Comparability	Sensitivity	
Popielak et al 1983	A	A	A	A	A	A	A	A	A	A	A	Documented scientific investigations of ERDA 6 and WIPP 12. This is a key reference for the project.
Payne and Teeple 2011	M	A	A	A	A	A	A	N	A	A	M	Provided general supporting information on use of TDEM method
Powers et al. 1996	A	A	A	A	A	A	A	A	A	A	A	Provided topographic map of Castile Formation surface, provided stratigraphic information on brine reservoir encounters, and identified uncertainties in reservoir characteristics and drilling data. Also provided statistical analysis of reservoir occurrence that was not used. Evidence of independent technical review was not found; however, this report was reviewed and cited in DOE's original WIPP CCA as the basis for estimating PBRINE.
SNL 1992	A	A	M	M	A	A	A	A	A	A	A	Provided information on the depth of the top of the Castile Formation beneath the WIPP waste panels
Silva 1996	A	M	A	A	A	A	A	A	A	A	M	Provided corroborating information on uncertainties in drilling data
The Earth Technology Corp 1987	A	A	A	A	A	A	A	A	A	A	A	Described the TDEM geophysical survey, the data analysis, and survey results and uncertainties. This is a key reference for the project.
Wilson et al. 1996	A	A	A	A	A	A	A	A	A	A	A	Provided information on sources of brine in the WIPP waste panels

Notes:
A = Acceptable and used in the analysis;
M = Marginal and used for corroborating purposes in the analysis;
U = Unacceptable and not used in the analysis; and
N = Not Applicable.

Table E-3 Supplemental Quality Evaluation for Key Information Source: *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico* (Popielak et al. 1983)

1. Information Provided:

The report documented geologic, hydrologic, and geochemical investigations of the ERDA-6 and WIPP-12 Castile brine reservoirs, and provided the only comprehensive scientific analyses of such reservoirs.

2. Why is this a key study compared to other studies reviewed for this particular project? *(Check all applicable reasons)*:

X study is extensively used to support project objective

X study is an example of new research

□ study confirms previous key study

□ study replaces weaker previous key study

X best or only available study of its type

□ other ______________________________

3. The different aspects of a study listed below are important to consider in an evaluation of the quality of a key study. In your evaluation of the quality of the key study identified above, check the box that best describes the degree to which the key study addresses these aspects: *Acceptable, Marginal*, or *Unacceptable*. If the aspect is not applicable to the study, check *N/A*. If there is insufficient information available in the study report to evaluate the aspect, check *Indeterminate*.

Acceptable	Marginal	Unacceptable	N/A	Indeterminate	Quality Aspect
X					Clearly stated hypotheses with null and alternate hypotheses indicated
X					Overall design of the study
X					Appropriateness of statistical methods used and reporting of results
X					Specification of the units of analysis
X					Identification and explanation of missing data
X					Consistently reported quantities among abstract, text, tables and graphs
X					Data reported in the study is sufficiently detailed and complete to make the assessment
X					Adequacy of discussion of results, alternative hypotheses, and confounding factors
X					Study conducted at a credible facility, published in a credible peer-reviewed source, subjected to internal peer-review if not published.
					Other:

4. Provide brief comments on less than acceptable ratings (attach additional pages as needed):
No ratings were less than acceptable.

5. If the study uses any data from sources outside of the study, what does the study offer in terms of an assessment of the quality of these data? State any professional opinions one may have about the data in question:
Because the Popielak et al. (1983) study documents the first (and currently the only) comprehensive scientific analysis of Castile brine reservoirs, most sources outside that study only provided comparative, corroborative, or general information that was not specific to Castile brine reservoirs. The only outside source of technical information directly relevant to a Castile brine reservoir cited in the study is Jones (1981), which provided an analysis of geologic data for Borehole ERDA-6. The Popielak et al. (1983) report provided informal assessments of the extent and quality of the information in Jones (1981) and noted that much of that information could not be corroborated because the original drilling core was not available. However, the information presented in Jones (1981) was published by the U.S. Geological Survey, which is professionally known to be a highly regarded source of thoroughly reviewed technical data and there is no reason to doubt the quality of the data presented in that report.

Table E-4 Supplemental Quality Evaluation for Key Information Source: *Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site* (The Earth Technology Corporation 1987)

1. Information Provided:
This report documented the conduct, data interpretation, and results of the TDEM geophysical survey conducted above the WIPP waste panels. It provided the most detailed and comprehensive information on the potential presence of Castile brine reservoirs beneath the WIPP waste panels.

2. Why is this a key study compared to other studies reviewed for this particular project? *(Check all applicable reasons)*:

X study is extensively used to support project objective

X study is an example of new research

☐ study confirms previous key study

☐ study replaces weaker previous key study

X best or only available study of its type

☐ other ______________________________

3. The different aspects of a study listed below are important to consider in an evaluation of the quality of a key study. In your evaluation of the quality of the key study identified above, check the box that best describes the degree to which the key study addresses these aspects: *Acceptable, Marginal*, or *Unacceptable*. If the aspect is not applicable to the study, check *N/A*. If there is insufficient information available in the study report to evaluate the aspect, check *Indeterminate*.

Acceptable	Marginal	Unacceptable	N/A	Indeterminate	Quality Aspect
X					Clearly stated hypotheses with null and alternate hypotheses indicated
X					Overall design of the study
X					Appropriateness of statistical methods used and reporting of results
X					Specification of the units of analysis
X					Identification and explanation of missing data
X					Consistently reported quantities among abstract, text, tables and graphs
X					Data reported in the study is sufficiently detailed and complete to make the assessment
X					Adequacy of discussion of results, alternative hypotheses, and confounding factors
X					Study conducted at a credible facility, published in a credible peer-reviewed source, subjected to internal peer-review if not published.
					Other:

4. Provide brief comments on less than acceptable ratings (attach additional pages as needed):
No ratings were less than acceptable.

5. If the study uses any data from sources outside of the study, what does the study offer in terms of an assessment of the quality of these data? State any professional opinions one may have about the data in question:
The TDEM study was the first and only geotechnical survey of its kind to investigate the potential presence of Castile brine reservoirs beneath the WIPP waste panels. The only data substantively used from sources outside that study are borehole data from ERDA-9, WIPP-12, and DOE #1. The data from ERDA-9 were used to calibrate the TDEM survey results and the data from WIPP-12 and DOE #1 were used to corroborate the TDEM survey results. The data from these boreholes consisted of depths to stratigraphic horizons and depths to brine encounters. These data were indicated in the study as being approximate but of sufficient quality for use. Borehole data of these types are professionally known to be relatively accurate, generally to within ±1 foot, and are also known to typically be more accurate than geophysical data. Because of this, borehole data are generally accepted for the purposes of calibrating and corroborating geophysical data.

Table E-5 Supplemental Quality Evaluation for Key Information Source: Evaluating the data in order to derive a value for GLOBAL:PBRINE. Memorandum to Records Center. Sandia National Laboratories, Carlsbad, New Mexico. December 11. ERMS 558724. (Kirchner et al. 2012)

1. Information Provided:

The report documented an updated frequency of brine encounters during drilling in the region around the WIPP site.

2. Why is this a key study compared to other studies reviewed for this particular project? *(Check all applicable reasons)*:

□ study is extensively used to support project objective

□ study is an example of new research

□ study confirms previous key study

□ study replaces weaker previous key study

□ best or only available study of its type

X other _Study provides updated information ____________________________

3. The different aspects of a study listed below are important to consider in an evaluation of the quality of a key study. In your evaluation of the quality of the key study identified above, check the box that best describes the degree to which the key study addresses these aspects: *Acceptable, Marginal*, or *Unacceptable*. If the aspect is not applicable to the study, check *N/A*. If there is insufficient information available in the study report to evaluate the aspect, check *Indeterminate*.

Acceptable	Marginal	Unacceptable	N/A	Indeterminate	Quality Aspect
			X		Clearly stated hypotheses with null and alternate hypotheses indicated
			X		Overall design of the study
			X		Appropriateness of statistical methods used and reporting of results
X					Specification of the units of analysis
			X		Identification and explanation of missing data
			X		Consistently reported quantities among abstract, text, tables and graphs
X					Data reported in the study is sufficiently detailed and complete to make the assessment
			X		Adequacy of discussion of results, alternative hypotheses, and confounding factors
X					Study conducted at a credible facility, published in a credible peer-reviewed source, subjected to internal peer-review if not published.
					Other:

Authors' Note: The foregoing evaluation applies only to the updated information obtained from this study and not necessarily to the analyses, conclusions, or other aspects of this study.

4. Provide brief comments on less than acceptable ratings (attach additional pages as needed):
No applicable ratings were less than acceptable.

5. If the study uses any data from sources outside of the study, what does the study offer in terms of an assessment of the quality of these data? State any professional opinions one may have about the data in question:
An evaluation of the data obtained from this study is documented in Section 5.6 of this report. In summary, these data on brine encounters were originally obtained from reports of brine encounters that were noticed and documented by drillers only incidental to reporting their drilling activities and there was no requirement placed on the drillers to document brine encounters. These data are therefore unlikely to have identified all brine encounters relevant to WIPP performance and are expected to underestimate the actual frequency of such encounters. The actual frequency of brine encounters is therefore expected to be higher than determined from drillers' documentation. Because of this expected bias, this source of information is appropriate for establishing a lower bound for the conditional probability *p[brine|HCZ]* because the lower bounding value is intentionally selected to be lower than or equal to the lowest potential value of a distributed parameter. The driller-reported frequency of brine encounters during drilling in the region around the WIPP site is therefore suitable for its intended use in this report.

E.2 External Independent Technical Review Documentation

An independent technical review of the EPA TSD *Probability of Encountering Castile Brine beneath the WIPP Waste Panels using the TDEM Block Method* was conducted by Mr. Michael Wallace. Mr. Wallace reviewed the August 27, 2016 draft of the subject report. His review was conducted following the requirements of the project QAPP and Data Quality Objectives. He provided conclusions on adherence to the QA requirements as well as 35 individual technical comments on October 24, 2016. On November 17, 2016, SC&A provided Mr. Wallace with responses to his conclusions and comments, as well as revised copies of the report and figures with changes made as a result of his comments. Mr. Wallace's final approval of the responses to his comments and of the revised document were received on January 6, 2017.

The following annotated list summarizes the types of information Identified by the Agency for documenting an external technical review (EPA 2012a; 2012b).

Documentation of scope of review: The scope of the review was provided verbally to Mr. Wallace by the SC&A Work Assignment Task Manager Mr. Stephen F. Marschke and is documented in a summary statement by Mr. Marschke provided in Attachment E-1.
Reviewer qualifications: Mr. Wallace's qualifications to perform the review are documented in a summary of his relevant technical experience provided in Attachment E-2.
Reviewer biographical information: Biographical information for Mr. Wallace is included in the qualification documentation provided in Attachment E-2.
Documented results of review: Mr. Wallace's review conclusions and comments are documented in Attachment E-3.
Documentation of project response to review: SC&A's responses to Mr. Wallace's conclusions and technical review comments are documented in Attachment E-3. The changes made to the report in response to his comments are documented in redline copies of the report text and figures archived in SC&A's project file.
Documentation of reviewer acceptance of final project report: Mr. Wallace's acceptance of SC&A's responses to his review comments is documented in Attachment E-3.

References for Appendix E

EPA (U.S. Environmental Protection Agency 2012a. *Elements of a Quality Assurance Project Plan (QAPP) for Collecting, Identifying, and Evaluating Existing Data/Information*, September 12, 2012.

EPA (U.S. Environmental Protection Agency 2012b. *EPA: Guidance for Evaluating and Documenting the Quality of Existing Scientific and Technical Information*. Addendum to: *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (EPA 2003), December 2012.

Attachment E-1. Documentation of Scope of Review

The QAPP was approved and signed by all required persons on August 23, 2016. On August 29, 2016, Mr. Mike Wallace was contacted by telephone by Stephen Marschke, SC&A Task Manager, and emailed the *Probability of Encountering Castile Brine Beneath the WIPP Waste Panels Using the TDEM Block Method* Technical Support Document (PBRINE TSD) so that he could perform an Independent External Technical Review as required by the QAPP. Mr. Wallace had performed a similar role on a pre-QAPP version of the PBRINE TSD, and had submitted a number of comments. The version of the PBRINE TSD sent to Mr. Wallace on August 29, 2016 addressed those previous comments.

Instructions to Mr. Wallace regarding scope were transmitted verbally and he was asked to do a thorough technical review and to review consistency with the applicable QA documents. Mr. Wallace was instructed to first read the QAPP, and then to perform the review in compliance with the instructions given in the QAPP, Section A.6. The relevant part of Section A.6 reads as follows:

The reviewer will:

- Review the documented project information sources;
- Assess the methodology, cross-checking against the DQAs and DQIs, to determine where Castile brine pockets may be located underneath the repository footprint;
- Determine whether the analytical approach and resulting PBRINE parameter are technically defensible; and
- Document the review in a report that identifies any components of the draft report that will need to be modified.

In addition, QAPP, Table 2 provides five assessment factors, each with a number of questions to be answered, taken directly from EPA's Science and Technology Policy Council in *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information,* which should be used to assess the quality of the PBRINE TSD. Finally, Mr. Wallace was asked to ensure that his previous comments on the pre-QAPP version of the PBRINE TSD have been satisfactory addressed.

On August 30, 2016, Mr. Wallace emailed back his signed QAPP Acknowledgment Form, indicating the he had read and understood the general definition and goal of quality on the project, as well as specific provisions that apply to his performance as the PBRINE TSD Independent External Technical Reviewer. At which point Mr. Wallace was asked to proceed with his review of the PBRINE TSD.

On October 24, 2016 Mr. Wallace emailed SC&A the comments resulting from his review of the PBRINE TSD, which included his response to all of the questions posed in the QAPP, Table 2 five assessment factors, as well as 35 additional technical comments. On November 17, 2016 SC&A provided Mr. Wallace with responses to his comments, including a revised the PBRINE TSD text and figures. Finally, on January 6, 2017 SC&A received Mr. Wallace's full concurrence with each and every response to the comments he had previously provided on the PBRINE TSD.

Attachment E-2. Reviewer Qualifications and Biographical Information

Michael Wallace & Associates (MW&A)
7820 Hendrix Rd. NE
Albuquerque, NM 87110
Phone: 505-401-3785
mwa@abeqas.com

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Summary of Relevant Professional Experience

Mr. Michael Wallace is a practicing hydrologist who is also enrolled in a Ph.D. program in the Department of Nanoscience and Microsystems at the University of New Mexico. He founded MW&A in the early 1990s to provide advanced hydrologic and programming capabilities toward solutions of modeling and stochastic challenges in the earth sciences.

He has extensive experience in performance assessment related studies for a number of geologic repositories which have been implemented and/or planned for the long term sequestration of radioactive waste. These include the Waste Isolation Pilot Plant (WIPP), the Yucca Mountain Project (YMP), and nuclear disposal projects in Finland and Sweden. He also has contributed to a number of Combined Operating and Licensing Applications (COLAs) for domestic nuclear power plants (River Bend and Fermi) in regard to similar performance assessment concerns. His work has extended to evaluation activities towards subsurface mines (including potash mines in the Delaware Basin and near Esterhazy, Canada) and storage projects, including numerous artificial salt caverns for the strategic and operational storage of petroleum products. He has also evaluated several storage failure cases for government and commercial clients. One project was conducted for the New Mexico Oil Conservation Division (NMOCD) regarding a rash of brine cavern collapses in the Delaware Basin. Those caverns were originally excavated via solution mining of relatively shallow locations of the Salado Formation. His hydrogeologic work for those cases typically included evaluation of underlying and overlying evaporite rich strata including the Castile Formation.

Mr. Wallace has extensive experience specific to WIPP, as well as additional experience with hydrogeologic studies of the host Delaware Basin (and its evaporite components) where WIPP is located. He was the principal analyst in a groundwater flow and transport modeling effort for the WIPP PA program. He was the principal investigator on an effort to explore the potential impacts of potash mining-induced subsidence upon the hydrologic long-term containment capabilities of the WIPP repository. In addition, Mr. Wallace developed the first water table contour surface interpretation for the WIPP vicinity while he was a principal investigator on seven scenario screening efforts for WIPP. He served as a co-investigator in a 3D paleohydrological/climate change consequence modeling study of the upper groundwater system and its relation to surface water flow in the WIPP region. This included the modification of the MODFLOW code to implement a novel-free surface boundary condition. Mr. Wallace also co-developed a numerical simulator using and modifying the SUTRA (variable density groundwater flow) code that analyzed the coupled processes of salt creep and brine inflow related to excavations into the Salado Formation at WIPP.

For the YMP, Mr. Wallace conducted numerous simulator (code) qualification and model validation activities. These included testing of the geostatistical software package GSLIB, testing of the ASHPLUME code, and peer review of the YMP saturated zone hydrogeologic flow model. Mr. Wallace also developed an original award-winning simulator (DIRECT; Dike Intersection with Repository, Explicit Characterization and Tabulation) to assist YMP volcanologists in their probabilistic risk assessments of the potential for a dike or volcano conduit to penetrate the proposed repository over its design lifetime. That evaluation had nominally similar challenges to the PBRINE effort, given the goals to estimate the likelihood of an intersection of the repository footprint by a risk factor from a deeper subsurface origin. Finally, Mr. Wallace led a staff of approximately ten earth scientists to technically review the most recent hydrologic infiltration (recharge) study of Yucca Mountain, following past efforts led by the U.S. Geological Survey (USGS).

Attachment E-3. Documentation of Review Results, Project Response, and Reviewer Acceptance

Michael Wallace & Associates (MW&A)
7820 Hendrix Rd. NE
Albuquerque, NM 87110 (*please note this is a revised address from orig. memo)*
Phone: 505-401-3785
mwa@abeqas.com

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6 January, 2017

To: Stephen Marschke
WA Task Manager
Sandy Cohen & Associates, Inc.(SC&A)
1608 Spring Hill Road, Suite 400
Vienna, VA 22182

CC: Charlie Wilson, SC&A
Kathleen Economy, U.S. EPA/OAR/ORIA/RPD
David Back, SC&A

Subject: FINAL CONCURRENCE: Independent Technical Review of 2016 Draft Report: PROBABILITY OF ENCOUNTERING CASTILE BRINE BENEATH THE WIPP WASTE PANELS USING THE TDEM BLOCK METHOD 150519/C.R. Wilson

Hello Stephen,
This memo documents my full concurrence with each and every Author response to the Subject document. I've included my original memo in **Attachment 1** which immediately follows. I have incorporated the dated Author responses as red underlined text following each of my original 35 comments.

I appreciate the importance of this document and the thorough and thoughtful work conducted by the Authors. Please let me know if there are any additional tasks you require to close on this document review.

Sincerely,

Michael Wallace
Principal MW&A

ATTACHMENT 1

Original Independent Technical Reviewer (ITR) memo with subsequent Author Responses captured via red underlined dated text inserts

(note that footer pagination changes from original have occurred due to the insertion of responses)

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24 October, 2016

To: Stephen Marschke
WA Task Manager
Sandy Cohen & Associates, Inc.(SC&A)
1608 Spring Hill Road, Suite 400
Vienna, VA 22182

CC: Charlie Wilson, SC&A
Kathleen Economy, U.S. EPA/OAR/ORIA/RPD
David Back, SC&A

Subject: Independent Technical Review of 2016 Draft Report: PROBABILITY OF ENCOUNTERING CASTILE BRINE BENEATH THE WIPP WASTE PANELS USING THE TDEM BLOCK METHOD 150519/C.R. Wilson

Hello Stephen. In accordance with the tasks you have assigned to me under Contract CRAE4/502 and CRAE4/512, I have conducted an External Technical Review of the Subject Report. I find this report to be technically comprehensive and defensible in each and all of its products and conclusions, with the possible exception of sensitivity exercises. I do have a small number of additional comments, and a possible way to address the apparent sensitivity study gap through some alternate conceptual models, which I include towards the end of this memorandum.

My review was conducted in accordance with the goals and outlines from the governing QAPP document (USEPA, 2016) that you provided me, including the Data Quality Assessment (DQA) factors and the Data Quality Indicator (DQI) criteria. The categories and subcategories of these criteria are extensive, but I note that the QAPP does not expect my memo to follow any of those particular forms. My review was therefore conducted with the intent that should I encounter a condition that appears to have the potential to fail to meet any of the DQA or DQI criteria, I would simply address the item of concern in sufficient detail for the authors to address. Through this approach, I am able to reduce the size of this report.

To document my review in an organized fashion I attempt to follow the questions posed in the DQA with my review conclusions and any added context if I felt that this added value. These assessment points are taken directly from Table 2 of the QAPP. For each item, I first list the Assessment Factor item, followed by an indented line with my response for clarity. My responses directly follow below. A separate section provides additional specific comments and two alternative conceptual models for consideration.

Assessment Factor: Applicability and Utility

Is the purpose of the data or study consistent with prescribed design?

> YES. From the initial data development and conceptual model building to the final tabular products, this document appears to be fully consistent with the prescribed design.

Are the methods or models employed to develop the information reasonable and consistent with sound scientific theory or accepted approaches?

YES. Given the diversity of observations and conceptual models, there are many alternative approaches possible, and that is perhaps one reason for the long history of revisions to the development of the PBRINE parameter and its auxiliary indexes. This latest revision retains straightforward logical methods to reduce a limited knowledge base to a working probabilistic framework.

Do the results compare with existing scientific or economic theory and practice?

YES. I note that the adoption in this study of well established and relatively powerful yet simple theories and practices, such as the Bernoulli process for some estimations, the maximum entropy method for others, and additional, sometimes necessarily subjective implementations, make this a fully traceable set of exercises for the most part. Also, the areas of knowledge deficiency are articulated as clearly as it seems possible. Those gaps in knowledge are filled through considered rationales that are mindful of the diversity of peer reviewed and related literature on the topics of concern.

Are the assumptions, governing equations and mathematical descriptions employed scientifically and technically justified?

YES. I have reviewed all equations and spot checked several against data inputs and outputs and I have considered the context of the results.

Is the study based on sound scientific principles?

YES.

How internally consistent are the study's conclusions with the supporting information?

The study appears to be consistent with most of the supporting information as much as that is possible. There are limits to this goal because much of the supporting information is diverse enough that consistencies of brine occurrences with structural interpretations have not been established, among other examples.

Having said that, I have included two new alternate conceptual models that may also be consistent with the data and conceptual models. There is nothing mandatory which would stem from these alternate models, but I have included them for completeness.

Assessment Factor: Evaluation and Review

Has there been independent verification or validation of the data study method and results?

YES, with this review in addition to the sum of previous reviews that supported the components of previous investigations that have been retained for this study.

To what extent has independent peer review been conducted of the study method and results?

This review has considered each methodology and the associated results covered in the study. Within the major topics, the review has extended to the supporting information from literature to confirm numerous interpretations, values and parameter ranges. In many cases, prior calculations that were sufficiently straightforward, were independently compared to simple spreadsheet or other stochastic exercises to roughly confirm the conclusions. Those calculations include hydraulic test analyses, structural interface values both by cross sections and structure contour maps, variograms, additional contour fields, and probabilistic equations.

Has the model been used in similar peer reviewed studies?

This is a new variation upon a previous study that was itself peer reviewed (but not published in an external peer reviewed journal, and this is acceptable).

To what extent has independent evaluation and testing of the model code been performed and documented?

Development of the TDEM contours was independently replicated. A variogram was also developed from this information.

Development of numerous conclusions from the range of sources and figures were independently reproduced.

The R code implementation was partially tested. The documentation of the input files and the output files were spot checked and no errors were discovered. Moreover, the program description, psuedo code, and actual code were reviewed. No concerns were uncovered, as this implementation appeared straightforward. Also the project was installed on a personal computer and some of the functionality was replicated with the latest version of R (3.3.1). Finally the output from the code was compared successfully to Figure 9. in Appendix C.

Assessment Factor: Soundness

Is the purpose of the study reasonable and consistent with its design?

Yes.

How do the study's design and results compare with existing scientific theory, principles and practices?

The study's design and results are consistent with these assessment factors.

Are the assumptions, governing equations and mathematical descriptions employed scientifically and technically justified?

Yes.

How internally consistent are the study's conclusions with the data and results presented?

The study's conclusions are largely consistent with the data and results presented.

Assessment Factor: Clarity and Completeness

To what extent does the documentation clearly and completely describe the underlying scientific theory and the analytic methods used?

The documentation appears to be complete for these factors.

To what extent have key assumptions, parameter values, measures, domains and limitations been described and characterized?

These items appear to be adequately characterized.

To what extent are the results clearly and completely documented as a basis for comparing them to results from other similar tests?

The results are adequately documented in a manner sufficient for comparison to other sources.

If novel or alternative theories or approaches are used, how clearly are they explained and the differences with accepted theories or approaches highlighted?

No novel or alternate theories and approaches are used. However more clarity would be beneficial regarding the implementation of the conditional probability parameter. I have added comments and two alternative conceptual models for review by the Authors in response to this concern.

Are there confidentiality issues that may limit accessibility to the complete data set?

No.

To what extent are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

The descriptions of the study are clear, complete and sufficient for reproducibility, and in my spot checks I have reproduced every item that I tested.

Have the sponsoring organization(s) for the study/information product and the author(s) affiliation(s) been documented?

Yes.

Assessment Factor: Uncertainty and Variability

To what extent have appropriate statistical techniques been employed to evaluate variability and uncertainty?

These techniques have been employed to a more than adequate extent. I have registered comments and two proposed alternative conceptual models, which are directed to the possibility that the techniques may have been over-applied. In short, after developing a convincing coverage of P(HCZ), that parameter is then multiplied by another conditional probabilistic range which is based on somewhat subjective assignments and logic. This may lead to non-conservative bounds, which are less defensible. However, much deference is given to the Authors on their subject matter expertise for decisions within that challenging component of the analyses, and so my comments are not mandatory.

To what extent have the sensitive parameters of models been identified and characterized?

There is extensive discussion throughout the document which is relevant to the question of sensitivity of the model outputs to the model inputs and to the conceptual underpinnings, and that may satisfy this condition to a great extent.

However, I searched for examples of ranges of model results as a function of perturbations of various input parameters as a quantitative demonstration of sensitivity analyses. I did not find that, and accordingly it appears that this study does include such analyses. I have in a related capacity produced comments including two suggested alternate conceptual models which might also work to satisfy this gap. However, those are not mandatory comments.

To what extent do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the study? What are the potential sources and effects of error and bias in the study design?

These questions cannot be addressed, in part because no sensitivity analyses was conducted. It does appear overall that more conservatism in the implementation might be merited for the development of the conditional parameter P(BRINE|HCZ). However that is only a preliminary perception.

The development of the parameter P(HCZ) does appear to be adequately bounded (with regard to uncertainty and variability) to me, based on my comparisons of the data to the cited sources and to other outside information.

Did the study identify potential uncertainties such as those due to inherent variability in environmental and exposure-related parameters or possible measurement errors?

The study is replete with discussions of potential uncertainties for all of the identified important features.

Assessment Factor: Uncertainty and Variability

Can the data be compared across datasets provided by reporting entities?

Yes.

Can comparisons be made between and among different entities, organization or companies that collected the data ?

Yes.

DRAFT COMMENT RESPONSES 161117/CW & HC
Independent Technical Review ADDITIONAL COMMENTS
(Please note: These are comments and responses for this TSD in regards to the independent peer review, just for reference. These are not internal/deliberative EPA comments on the TSD; all comments and revisions have already been incorporated.)

Report Authors' Notes:

Thank you for your careful review. The comments you provided are good and have allowed us to clarify key aspects of the methodology described in this report.

The responses to the following comments refer to figure numbers and text locations as presented in the review copy. Additional figures and text have been added in response to the comments received and some figure numbers and text locations in the comment response copy are therefore different from those in the review copy.

I have some additional technical comments which I've documented below, in no particular order.

Comment 1. Annotations would add transparency to Figure 14. I believe it would add value to include overlays of the boundaries of the TDEM survey and of the waste panel outline to the Seismic Time Structure figure (from the Borns et al., 1983 reference).

Authors' Response: A notation has been added to the figure identifying the small box in the center of the figure as the approximate location of the waste panels. The authors believe that also adding the TDEM survey boundary to this figure would detract and possibly mask a primary result of the seismic survey, that a significant, localized synformal structure was identified directly beneath the waste panel locations [Charles Wilson, 11/17/2016].

Comment 2. I recommend that for each Appendix, all subsections, figures, tables, and references be given an appendix prefix. This will reduce confusion particularly because some identical figures exist in the main body of the text.

Authors' Response: A section prefix has been added to all subsection, table and figure numbers in the appendices [Harry Chmelynski, 11/17/2016].

Comment 3. I recommend that a scatterplot or a related coverage be developed to display the simulated brine intrusion locations across the rendered panel domains in at least one figure. I suggest this be applied to Figure 4 of Appendix C, or that a new Figure be included for this purpose. In such a figure, the high elevation versus low elevation brine cutoff boundaries could be included for ease of review.

Authors' Response: A new figure has been added to Appendix C to show the simulated borehole outcomes in Panel 2 as an example [Harry Chmelynski, 11/17/2016].

Comment 4. I note that Bell Canyon is a brine disposal unit. I do not know any further information regarding the anticipated long term head changes in that strata across the repository footprint. Accordingly, pressures in Bell Canyon may rise over time. Perhaps that would factor into the TDEM based approach to P(HCZ). This could be discussed for completeness in descriptions of the strategy to discriminate between the two potential brine sources (Bell Canyon vs. Castile).

Authors' Response: The reason for not considering the Bell Canyon as a potential source of repository brine is discussed in Section 5.2. The Bell Canyon has been eliminated as a potential source not because of a lack of pressure but because the only borehole plugging pattern that allows long-term flow of Castile brine to enter the repository includes a long-lived plug between the Bell Canyon and the Castile. That plug would be placed upon borehole abandonment, which is assumed in WIPP PA to occur immediately after drilling. Brine pressures in the Bell Canyon are lower than in the Castile but are sufficient to lift brine to the repository elevation. However, as long as this plug is in place, brine cannot flow into the repository from the Bell Canyon and pressure fluctuations in the Bell Canyon will therefore have no impact [Charles Wilson, 11/17/2016].

Comment 5. I note that a predecessor report (Powers et al., 1996) applied extensive geostatistical analyses, including variogram constructions applied to drilling records of brine flows, to develop estimates of the spatial continuity of brine reservoirs in the region. However, the Kirchener et al. (2012) document claims to address a similar population (only updated) yet disregards those geostatistical techniques in addressing that data.

It may be that the variogram sill occurs at a lag of 1000 m (the apparent purpose of their circles in Figure 5). However, no quantitative basis has been demonstrated for the assertions that brine reservoirs are universally limited to less than 1000 m in lateral extent, found in this document. The document's only rationalization for the 1000 m brine reservoir "patch size" appears to be the statement that the radius "appears reasonable".

However, this is not intended to negate the components of the study which are clearly reproducible, including the ratio of brine hits to total boreholes in the Delaware Basin and the sub-zones which are addressed in that report and which are partially utilized in this report.

Authors' Response: One of the difficulties with Kirchner et al.'s (2012) TDEM approach is that it relies on the somewhat arbitrary reservoir lateral extent identified in this comment. Tom Kirchner has verbally expressed concern over this assumption to us and identified it as one of the reasons he preferred the alternative approach, also described in Kirchner et al. (2012), of estimating PBRINE based only on the frequency of driller-reported brine encounters. We do use data taken from Kirchner et al. (2012) on the frequency of driller-reported brine encounters in our estimation of PBRINE. We do not rely only on those data and we also use them in a different way than they were used by Kirchner et al. (2012). We have accepted Kirchner et al.'s drilling frequency data as factual and their use is explained and justified in Section 5.6 of our report. However, our acceptance of those data as factual does not imply that we accept Kirchner et al.'s methodology and use of those data as appropriate for their intended purpose [Charles Wilson, 11/17/2016].

Comment 6. Please see the final paragraph of Section 5.6. I feel there are a number of logical challenges to the rationale as it is currently written. Among other things the statement appears to contradict itself by implying that the Agency does and does not rely upon the drilling data. To me, this appears to be due in part to an assertion about exploratory boreholes that does not appear to be correct and also due in part to an incomplete response to a subjective representation by Kirchener of the drilling patterns.

I likely misunderstood the statement because exploratory boreholes are often, if not primarily, relied upon to develop estimates of reservoir geometries and extents. Second, had Kirchener followed the stochastic approach exercised by Powers et al., 1990, for example, then there would be a better basis for more expansive use of that drilling data.

Authors' Response: We have made changes to the paragraph in question to help clarify its meaning. Explained in another way, drilling records of brine encounters are not complete so some brine encounters are not documented. The actual frequency of brine encounters is therefore higher than the drilling records would indicate so using *only* drilling records to calculate PBRINE (as is done in Kirchner et al.'s (2012) preferred method) would make the value of PBRINE too low. However, to calculate a lower *bounding* value for a distribution you want a value that you can demonstrate is low and that even lower values would be unlikely. Because we can demonstrate through incomplete documentation that drilling records underestimate the actual frequency of brine encounters, they can be used to establish a lower *bounding* value for the frequency of brine encounters. Additionally, we agree that other options were open to Kirchner in developing a distribution for PBRINE based on TDEM data, but that goes beyond the scope of this report [Charles Wilson, 11/17/2016].

Comment 7. There appear to be inconsistencies in the development described in Section 5.7. First, it does not appear logical to assert that adopting the possibility of an ERDA-6 styled reservoir is somehow conservative, but that section appears from my perspective to claim such a relation. Those ERDA-6 styled cases are of isolated vertical fractures and naturally lead to lower probabilities of a hit, not higher probabilities (since most boreholes have been vertical).

Also the proposal then recommends that a drilling density other than that found at the region surrounding ERDA-6 be implemented. This appears to somewhat challenge the favorable view of ERDA-6 just described. I have included an appendix AR1 to my review document which explores these inconsistencies in the context of some alternative models which I have sketched therein.

Authors' Response: We have modified Section 5.7 to better explain the relevance of the fracture network at ERDA-6 to the WIPP site and to establishing a lower bound for the distribution of p(BRINE|HCZ). You are correct that ERDA-6 styled cases do lead to lower probabilities of a borehole hit and that is why those cases can be used to support a lower bound. The question then is which set of drilling data to use? The region around ERDA-6 provides a higher frequency of a hit but we cannot be sure this region is representative of deformation beneath the WIPP site. We therefore chose the lower, regional frequency to better assure that we are actually using a lower value for the distribution that is indeed bounding.

We have added a new Section 5.8 that describes alternative models for estimating PBRINE and includes the alternative Kirchner et al. (2012) TDEM and drilling data approaches identified in your Appendix AR1. Our approach does share some similarities with Kirchner's TDEM approach (both approaches use TDEM data) but our approach is completely different from Kirchner's drilling data approach that was used in the CRA-2014 WIPP PA. We do acknowledge the special region of higher frequency brine encounters to the northeast of the WIPP Land Withdrawal Boundary (LWB) in our report but we don't use the data from that region in our analysis. The rationale for not using those data is hopefully better explained in the modified text in Section 5.7 and also in the first paragraph of the response to this comment.

Although your comments regarding alternative models are identified as non-mandatory, we have provided the following detailed discussion of the models you present in Appendix AR1. We agree that both WIPP-12 and ERDA-6 appear to penetrate antiformal structures in the Castile. Your Figure RA 2 illustrates a possible structural connection between the two boreholes but does not suggest that this same antiformal structure extends beneath the WIPP site to the south. The most detailed information we have found regarding the structure of the Castile beneath the WIPP site comes from the seismic data in Figure 14, which is the subject of your first comment. Those data show synformal structures rather than antiformal structures beneath the site. We could hypothesize that the synformal structures beneath the site (and also at the location of WIPP-13) are related to the antiformal structures at WIPP-11 and WIPP-12 because the synformal depressions may reflect source areas for the antiformal ridges or domes; however it is not at all clear that the rate/density/pattern of brine hits beneath the WIPP site would be the same as at WIPP-12, or as the ERDA-6 area, or as the regional frequency because even if the structures were similar, the degree of deformation and the nature of fracturing could be quite different as illustrated by the dramatic differences between fracturing at WIPP-12 and ERDA-6. Because of this uncertainty we have elected to provide a broad distribution for p(BRINE|HCZ), ranging from a high of 1.00 based on the WIPP-12 fracture model to a low of 0.05 based on the regional frequency of drilling encounters and the ERDA-6 fracture model. However, we have included the alternate lower end of the range (0.13) suggested in your comment as an alternative model, as explained in Section 5.7 and in the new Section 5.8 [Charles Wilson, 11/17/2016].

Comment 8. There are various typos and particularly I have seen many cases where there is only one space between sentences.

Authors' Response: We would appreciate any help you can provide in identifying typos. Using one space between sentences is intentional. When writing a column for a local newspaper, I (Charlie) was told that one space was preferable to the two spaces I had been using because it was functionally adequate and also more space-efficient. I took that to heart and have been using one space ever since [Charles Wilson, 11/17/2016].

Comment 9. Many of the legacy figures which are included have extensive regions and text features which are difficult to read. I was able to complete my review in spite of that, but I recommend for greater traceability and transparency that the key features of each of those figures be rendered more clearly. This may be possible most efficiently through simple annotations overlain onto the figures of concern, where these appear most germane to the document. Alternately, perhaps better scans could be made from any good available hardcopies.

Authors' Response: We agree with your concern and have reviewed all figures to help assure that the important aspects of each figure are legible and have inserted annotations to Figures 7 and 14 in response to this comment and to Comment 1. We have also searched for the clearest copies of legacy figures available but many are from scanned copies of printed originals that come with the notation that the scanning was performed on the best available copy. The wellhead elevations on Figure 13 were so tiny as to be nearly illegible even when an enlarged view of the digitized copy is selected but the important aspects of that figure to this report are the contours showing areas of structural deformation, which are clearly evident. For the remaining figures we found that even annotations that are not important to the message of the figure become legible when the figure is enlarged [Charles Wilson, 11/17/2016].

Comment 10. As anticipated in my first comment, it would be beneficial if all maps which could show this, included overlays of both the waste panel footprint and the TDEM boundary.

Authors' Response: We have reviewed the figures with maps and added annotations to Figures 7 and 14 that identify the waste panel areas. As in the response to Comment 1, we are concerned that adding additional information such as the footprints of individual panels or the TDEM boundary would unnecessarily clutter the figures and detract or possibly mask what the figure is intended to show [Charles Wilson, 11/17/2016].

Comment 11. Please provide individual CDF tables of the data used for each curve in Figures 3 and 4. It would be suitable to include those in one of the appendices rather than in the main body of the text. You can use Table B.1 as a template, I believe.

Authors' Response: The requested tables have been added to Appendix B [Harry Chmelynski, 11/17/2016].

Comment 12. In Figure 2 of Appendix C (Figure 10 of main text), the array consists of square cells, yet the row and column spacings are not identified to be constant and so do not lead to square geometries. Clarification is needed, unless perhaps I missed this information.

Authors' Response: The difference between the schematic drawing in Figure C-2 and the true-to-scale representation in Figure C-5 are now noted in the main text and in Appendix C [Harry Chmelynski, 11/17/2016].

Comment 13. I believe that clarity might be added by discriminating between probabilities and frequencies. While it is true that almost all of the probability parameters are derived from related frequencies, there are cases where discrimination might help.

For example, please see first full paragraph on page 2, Section 5. Perhaps the wording can be revised to clarify what is meant by 'bounding'. Although lowering the low point does produce a wider spread of PBRINE values, it doesn't appear to expand the capture of uncertainty, at least not from a conservative perspective. However if this phrasing of bounding were changed to describe the range of frequencies of probability outcomes, then the arguments might be more clear.

Authors' Response: We have searched the document assure that the word 'frequency' is consistently used in the context of how often an event occurs while the word 'probability' is consistently used in the context of a statistical function.

We were unable to identify the location of your example in the text. Section 5 does not begin until page 13 and the first use of the term 'bounding' is on page 4. However, we have included an explanation of 'bounding' at its first use to clarify its meaning [Charles Wilson, 11/17/2016].

Comment 14. Type I and Type II errors are mentioned in Section 2, but not formally introduced. Although that is acceptable, I think some additional information and perhaps a reference would be helpful.

Authors' Response: The terms "Type I" and "Type II" were replaced with self-descriptive terms "false-positive" and "false-negative," respectively [Harry Chmelynski, 11/17/2016].

Comment 15. At the top of page 6, the TDEM survey is described. It would help to clarify that the survey results that are used do not include the relative magnitudes of EC. Rather, a high EC and a low EC were defined and the depths to each were identified for each survey point. (and no low ECs were identified).

Authors' Response: Good point. The requested clarification was made in Section 2 where the use of TDEM depth data is first discussed [Charles Wilson, 11/17/2016].

Comment 16. I consider this comment extremely low priority but include it for completeness. Because of the rendering of the walls, many of the key surface elevations (northeast quadrant) are obscured in Figure 3. This figure is of course important as legacy information, but perhaps if not too much trouble it could be rendered without the vertical walls in order to display the hidden TDEM surfaces? Also the datum for the elevations should be described. I believe it is sea level, which is the depicted zero value on the vertical axis. The dimensions of the two horizontal axes should also be described. I believe this is all to scale (all dimensions) and the units are meters then.

Authors' Response: We believe this comment is referring to Figure 2, which provides a schematic illustration of the block model. We have modified the figure to include two illustrations. The figure on the left is similar to the original, but viewed from the southeast rather than the southwest to more clearly reveal the structure in the northeast quadrant. The walls are included in this view to emphasize that only the first or uppermost high electrical conductivity zone surfaces are identified by the TDEM soundings.

On the right is a laminar view of only the upper surfaces with the vertical walls removed. This view depicts the level of the uppermost reflecting layer, and reveals layers that are hidden in the original view. We noted that the elevation datum is sea level. The depths of all soundings are available to an interested reader on Figure 7 [Harry Chmelynski, 11/17/2016].

Comment 17. Given that ERDA-9 only penetrates the top of the Castile, there is an inconsistency in Figure 9. In that figure, the ERDA-9 borehole appears to extend to the top of the Anhydrite I of the lower Castile.

Authors' Response: You are correct and we therefore noted in the text that ERDA-9 was only drilled to the top of the Castile. We have expanded our discussion of Figure 9 to point out that the extension of the line representing ERDA-9 in the figure is misleading [Charles Wilson, 11/17/2016].

Comment 18. In the text below Table 2, a combination of Figures 7 and 11 is described, but there is no resulting figure.

Authors' Response: We have added the resulting figure to the text immediately following Figure 11 [Charles Wilson, 11/17/2016].

Comment 19. The entire opening paragraph of Section 5.2.2 is related to other comments I have provided as well as to my additional proposed alternate conceptual models. But in any case, the opening includes a confusing, possibly redundant sentence: "Because the current sampled value of PBRINE only provides a probability that brine is encountered, an additional sampling is conducted in WIPP PA to determine whether or not brine is actually encountered." I recommend that this be clarified if it can be. I do believe however that this is indicative of the challenge of rationalizing the addition of this final conditional probability parameter.

Authors' Response: The text has been modified to help clarify the difference between the probability of an event happening and the event actually happening. This difference is independent of whether or not a conditional distribution is involved [Charles Wilson, 11/17/2016].

Comment 20. At the bottom of page 16 it is stated: "The distributions of PBRINE for individual waste panels shown in Figure 4 can be used to explain the process of first randomly selecting a waste panel and then sampling from the PBRINE distribution for that panel." This seems inconsistent with the Appendix C description of calculation order sequence which states, an elevation for depth to conductor is first selected and then waste panels are addressed.

Authors' Response: The text has been modified to clarify that the description is of a conceptual process of how a sampled value of PBRINE can be used in WIPP PA, and not a description of the process for calculating the value of PBRINE in the first place. Appendix C describes how PBRINE is calculated, and the cited text on page 16 describes how PBRINE can be conceptually implemented in PA [Charles Wilson, 11/17/2016].

Comment 21. Please ensure that when describing uniform random sampling, that the 'random' word is included, otherwise the meaning of the term is significantly different.

Authors' Response: We searched the report for 'uniform sampling' and were unable to locate where this problem occurs [Harry Chmelynski, 11/17/2016].

Comment 22. In Section 5.4, "Borns" is misspelled.

Authors' Response: Thank you for the catch. The misspelling has been corrected [Charles Wilson, 11/17/2016].

Comment 23. In the first paragraph of Section 5.5.3, WIPP-11 and WIPP-13 are mentioned. However the wording may be interpreted to indicate that those wells are northeast of WIPP-12. Some clarification might help, but this is not mandatory.

Authors' Response: Again a good catch. The text has been changed to indicate the area of complex structure is northwest of WIPP-12 [Charles Wilson, 11/17/2016].

Comment 24. In the end of Section 5.5.3. it is stated that more porous rocks favor the formation of Castile brine reservoirs. However as indicated elsewhere, higher porosity might indicate fewer brine transmitting fractures, given the multiporosity model.

Authors' Response: Higher porosities could result from higher degree of fracturing as well as higher intergranular porosities, however both would result in elevated brine content and the text has been changed accordingly [Charles Wilson, 11/17/2016].

Comment 25. Regarding Item 8 of Section A.2: Figure 6 displays a PDF (actually a binned frequency histogram), not a CDF.

Authors' Response: Another good catch. The reference has been changed to Figure 5, which does display a CDF [Charles Wilson, 11/17/2016].

Comment 26. I recommend that in describing Sigma, that the appropriate symbol **σ** be utilized primarily after it is first defined. This same comment applies for other terms where symbols are conventionally used.

Authors' Response: Since (*S*) is used both here and elsewhere in the report as a symbol for standard deviation, the associated reference to sigma has been removed [Charles Wilson, 11/17/2016].

Comment 27. Something appears to be inconsistent for the first several rows of Table B.1 in comparison to Figure 6. According to that figure, the first three PBRINE densities should be ~ .004, .002, and.008. I also checked the last three entries and those do appear to be consistent with the chart.

Authors' Response: The original version of Figure 6 was a histogram that binned the first two PBRINE values into one bin, resulting in the apparent inconsistency. It was replaced by a new figure using a dropline plot to show all individual values of PBRINE. The new figure agrees with Table B-1 [Harry Chmelynski, 11/17/2016].

Comment 28. Some of the section descriptions in Appendix C do not appear to summarize the actual section contents or section titles as well as might be possible. For example, section 8 is largely about the equations that relate to the results, and the results are hardly addressed except by reference to other figures and tables.

Authors' Response: Some section titles have been revised and introductory sections modified to better reflect section contents [Harry Chmelynski, 11/17/2016].

Comment 29. Figure 5 of Appendix C is a very helpful figure. However it lacks a legend for the color patterns (and I'm not certain of the value of the cyan color field over a simple white background) and a north-south designation.

Authors' Response: A legend and north arrow were added to the figure. Cyan color was retained to identify the Salado [Harry Chmelynski, 11/17/2016].

Comment 30. In Appendix C, Section 2.3 it is stated that the sounding values reflect the thicknesses of those columns in Figure 3. However, my understanding is that the sounding values are the depth from the land surface to the high EC zone, and that Figure 3 simply represents the elevation above sea level of the high EC zone. I think you state that more or less, but given the accessory vertical walls rendered in Figure 3, I'm afraid the description might be misinterpreted to mean the height of the blocks above the -500m datum of that figure.

Authors' Response: Figure C-3 and the discussion of the TDEM "blocks" have been revised to make it clear that the measured soundings are depths to the first reflecting layer [Harry Chmelynski, 11/17/2016].

Comment 31. In Appendix C, Table 1, the panel areas tabulated here are somewhat different in magnitude than the same tabulations from Table 1 of the Kirchener et al. (2012) reference.

Authors' Response: We based our panel areas on the current estimates used in WIPP PA. The areas of Panels 1 – 8 were calculated from dimensions shown on the DBR grid reproduced in Figure 10 and we enlarged the areas of Panels 9 and 10 to match the total final waste area footprint of 1.115 x 10^5 m^2 documented in DOE's CRA-2009 PA. Our approach is described in Section 4.4. The panel areas in Kirchner et al.'s Table 1 were taken from a 1991 report that described a slightly smaller total waste area footprint of 1.09354 x 10^5 m^2. We surmise that this smaller area was taken from an earlier repository design and was slightly enlarged in the final design [Charles Wilson, 11/17/2016].

Comment 32. In Appendix C at the end of Section 8.3, maybe clarification would help because there are not 1000 rows in the file blok7_pbrinePF.txt.

Authors' Response: Clarification of the content of the files blok7_phczPF.txt and blok7_pbrinePF.txt was added to Sections C.8.2 and C.8.3. These files contain the frequency distribution of the 1000 simulated values, not the individual values [Harry Chmelynski, 11/17/2016].

Comment 32. In Appendix C Reference section, the formats at least of the EPA references are not consistent with the references for the main text section. The second reference appears to be for the main body of this document and therefore should not be referenced in this manner.

Authors' Response: The format of references has been revised to match the main text. No references were removed so that Appendix C would also serve as a stand-alone document [Harry Chmelynski, 11/17/2016].

Comment 33. In Attachment B, title page, a sentence or two to describe each file here would be helpful. I am able to trace, but now must search back and forth.

Authors' Response: A brief description of each file was added to the title pages of Attachments A and B of Appendix C [Harry Chmelynski, 11/17/2016].

Comment 34. In Appendix D, a legend or footnote should define the meaning of the two shadings It also appears that this is a figure and not a true table. I tried to insert comments but could not for that reason. In any event, I have spot checked some of these values and have found no errors from that.

Authors' Response: An explanatory note has been added to the figure [Harry Chmelynski, 11/17/2016].

Comment 35. In the text following Table E-2, the Kirchener study was also a key source.

Authors' Response: The Kirchner study has been added as a key source for this study [Charles Wilson, 11/17/2016].

My thanks again for this opportunity to review an important component of the WIPP PA. If I can do any more to clarify and/or correct, please let me know at your convenience.

Sincerely,
Michael Wallace
Principal, MW&A
505-401-3785

REFERENCES

Beauheim, R.L. and R.M. Holt, HYDROGEOLOGY OF THE WIPP SITE. undated, no other reference provided for this document that I retrieved via an online keyword search.

Borns, D.J., Barrows, L.J., Powers, D.W., and Snyder, R.P. 1983. Deformation of Evaporites near the Waste Isolation Pilot Plant (WIPP) Site: SAND82-1069, Sandia National Laboratories, Albuquerque, NM.

Kirchner, T, T. Zeitler and R. Kirkes 2012. Evaluating the data in order to derive a value for GLOBAL:PBRINE. Memorandum to Records Center. Sandia National Laboratories, Carlsbad, New Mexico. December 11. ERMS 558724.

Powers, D., J. M. Sigda and R. M. Holt 1996. Probability of intercepting a pressurized brine reservoir under the WIPP. Sandia National Laboratories, Albuquerque, NM. ERMS 523414.

USEPA, 2016, Quality Assurance Project Plan for Data and Literature Analysis EPA's Study: PROBABILITY OF ENCOUNTERING CASTILE BRINE BENEATH THE WIPP WASTE PANELS USING THE TDEM BLOCK METHOD. S. Cohen & Associates, Vienna Virgina, August 10, 2016

Appendix R1. Alternate Conceptual Model I for Regional Castile Brine Reservoir Distributions

This appendix is written purely in context of the review of the QAPP Document. It is assumed that any reader is thoroughly familiar with that document and accordingly, only novel references and figure adaptations are added here where needed for minimal traceability.

The current approach to developing a new PBRINE distribution shares some similarities with the proposed SNL 2014 WIPP PA approach (Kirchener et al., 2012). One similarity of relevance is the shared recognition of a special region to the northeast of the WIPP Land Withdrawal Boundary (LWB). This region was outlined by a blue oval and was intended to identify a subpopulation of boreholes in the Delaware Basin that are documented to express a higher than average number of penetrations (within the Delaware Basin) through pressurized Castile brine.

I have reproduced a segment of Figure 20 here as Figure RA 1 which highlights features supporting an alternate model. In this figure the oval is replicated along with the known boreholes of candidate interest. Red dots are boreholes which qualify as "brine hits" and the black dots are those boreholes which do not qualify.

The subsequent image, labeled Figure RA 2 (adapted from Figure 7 of Beauheim and Holt, 1990) is roughly the same scale, but includes a structure contour map of the Top of Halite II within the Castile Formation. The region around ERDA-6 appears to form a dome or ridge structurally, regardless of the causes. I have not explored the literature in detail, but it may be that others have described this apparent anticline or structural dome as a region which is targeted by oil and gas drillers for its structural trapping qualities. That would imply that the deeper units are in structural conformation to this marker unit.

Regardless of the most suitable interpretation, this population appears to be relevant to the current document and the Kirchener reference. Both state that the density of brine hits for this oval boundary population is 0.127, which indicates that the count within the oval is 19 brine hits out of 150 wells. It would be geologically acceptable under certain contexts to infer that the observed patterns of brine occurrence within such a structural dome might be similar within a nearby dome of comparable structure and hydrogeological setting.

Notably, it appears from Figure RA2, and from basic understanding of the Delaware Basin, that the domal/synclinal feature associated with WIPP 12 (which is here outlined in a green oval of the same size as the original blue oval) might be similar in geometry and basic hydrogeological setting to the ERDA - 6 dome[1].

Perhaps someday sufficient numbers of wells will be drilled within the green oval to reduce uncertainty of the PBRINE parameterization. Currently, the PBRINE implementation proposal anticipates utilizing the entire Delaware Basin dataset (of relevance to Castile penetrations) for the parameter p(BRINE|HCZ) of 34 brine hits out of 678 wells, for a density value of 0.05.

Given the considerations above, a plausible rationale might be made that the WIPP-12 centered anticline structure would host a similar rate/density/pattern of brine hits as seen for the ERDA-6 centered anticline. Accordingly, it might add confidence to consider an alternate implementation of parameter p(BRINE|HCZ) in which the lower end of the range is assigned to be 0.13 rather than 0.05.

Appendix R2. Alternate Conceptual Model II for Regional Castile Brine Reservoir Distributions

This appendix is written purely in context of the review of the QAPP Document. It is assumed that any reader is thoroughly familiar with that document and accordingly, only novel references and figure adaptations are added here where needed for minimal traceability.

The proposed implementation of Global:PBRINE involves two independent approaches which are then merged. In the first effort, the relative portion of the waste panel footprint which is believed to overlie pressurized pockets of Castile hosted brine, is estimated. Random boreholes are then simulated in a Monte Carlo process, and a composite CDF is constructed from 10,000 of these simulated borehole - Castile Brine intersections (and misses).

In the second effort, the probabilities (only for those cases conditioned upon a borehole passing through a Castile brine pocket) are multiplied by an additional probability. That probability currently is given a range from 0.05 to 1.0. If the value is 1(not the majority of cases) then the original probability is unchanged. If the value is anything other than one, then the original probability is reduced. That is a non-conservative impact which requires a supporting rationale.

The rationales supporting the conditional probabilities of the second effort are stated in section 5.6 and 5.7 of the current document. However those rationales focus on the occurrences of brine hits from relatively remote distances in comparison to the information already believed to be reliable directly underneath the repository.

Although the rationales for the current approach are convincing in some ways, they appear to disregard a commonly employed assumption in many branches of earth sciences. This assumption is that information that is closest to a study location can be relied upon to reflect local conditions with more confidence than information that comes from more remote locations. In fact, this principal/practice is a key feature that can be discerned from a typical variogram (in space) or an autocorrelation vector (in time).

[1] This is not to say that any Castile fracture flow domains are identical. The current document includes extensive literature sources that clearly show that the fracture flow specific features of the two wells are different.

In the current approach of the added conditional probability, a reader might understandably develop an impression that remote features are used to supercede, or at least unduly weight, local information in a non-conservative manner. This seems to be a straightforward conclusion which is missing from the documentation. That is because any conditional probability less than 1 will be multiplied against the P(HCZ), and that will decrease the ultimate probability of a brine hit(s). This covers most cases, since the only neutral value would be 1 and that is seldom sampled randomly.

It appears to follow that, under the current approach, there are no conditional probabilities which would raise the ultimate probability of a brine hit(s). Something like an increase might have been possible if the probability wasn't conditional on a borehole first penetrating a Castile brine zone, but that wasn't done. These arguments suggest again that the added conditional probability term will be hard to justify as a conservatism.

In light of these concerns, an alternate conceptual model which simply does not include the final conditional probability step might be merited. The information on remote sites needn't be discarded however. Rather, that information could be used to compare to the locally based PBRINE results. This would be consistent with many analyses which reserve some subset of the total information for comparison to a model which is based on the majority of that information.

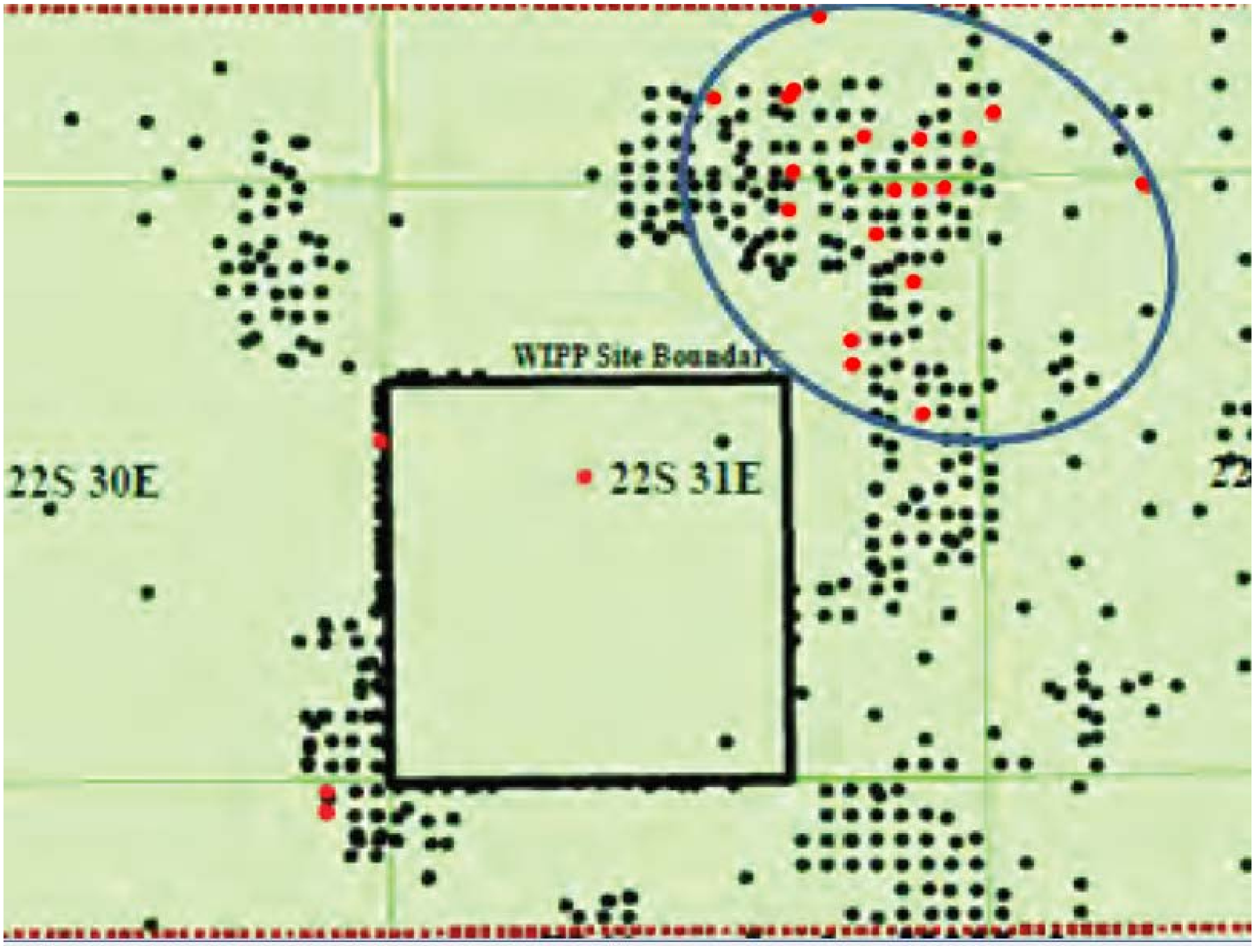

Figure RA 1.


22S 30E
(11) ERDA-6
140
524
254
450
WIPP-11
1018
1000
WIPP-13
100
(12)
417
WIPP-12
286
ERDA-9
WIPP SITE
300
100
200
106
98
DOE-1
77
178
353
253
-45

Figure RA 2.

SIGNATURE PAGE

In accordance with the SC&A's *Quality Management Plan* and/or the *Quality Assurance Project Plan for Determining PBRINE Parameter*, Section A.4.1, this document has been reviewed and approved by the following individuals:

SC&A Work Assignment Task Manager:	Stephen F. Marschke	Date:	6/21/2017
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EPA Quality Assurance Manager:	~~Jonathan Walsh~~ Jennifer Mosser	Date:	6/29/2017

Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	January 2017	Initial issue
1	June 2017	Edited for clarity