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Sandia National Laboratories
Waste Isolation Pilot Plant (WIPP)
Test Plan (TP)

Geophysical Investigation of Shallow Subsurface Waters at the WIPP, Test Plan TP 11-01

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1 DEFINITION OF ABBREVIATIONS AND ACRONYMS, AND INITIALISMS

Abbreviation	Definition
AC	Alternating Current
AIS	Air Intake Shaft
bgs	Below Ground Surface
DBS&A	Daniel B. Stephens and Associates
DC	Direct Current
DOE	Department of Energy
DE&S	Duke Engineering and Services
EM	Electromagnetic
ER	Electrical Resistivity
ES	Exhaust Shaft
FDEM	Frequency-Domain Electromagnetic
GPR	Ground Penetrating Radar
IP	Induced Polarization
M&O	Managing and Operating
MRS	Magnetic Resonance Sounding
PZ	Piezometer
QA	Quality Assurance
SIP	Spectral Induced Polarization
SNL	Sandia National Laboratories
SP	Spontaneous Potential
SP	Specific Procedure
SSW	Shallow Subsurface Water
TDEM	Time-Domain Electromagnetic
TP	Test Plan
WIPP	Waste Isolation Pilot Plant
WRES	Washington Regulatory Environmental Services

2 REVISION HISTORY

This is the original version of this test plan.

Revisions to this test plan will be prepared in accordance with Sandia National Laboratories (SNL) Waste Isolation Pilot Plant (WIPP) Nuclear Waste Management Procedures NP 6-1, NP 6-2, and NP 20-1 (Subsection 2.5).

3 PURPOSE AND SCOPE

Concerns with shallow subsurface water (SSW) began in 1995 when water was first observed leaking into the WIPP Exhaust Shaft (ES) through fractures in its concrete liner at depths of 55 to 85 ft below ground surface (bgs), near the level of the Santa Rosa/Dewey Lake contact (INTERA, 1996). Prior to this, no water had been observed leaking into the ES during construction and mapping activities, which began in 1983 (Holt & Powers, 1986). The initial geologic mapping in the air intake shaft (AIS) did observe water and salt efflorescence at the Santa Rosa/Dewey Lake contact (Holt & Powers, 1990; p. 121). As a result of the observation, geologic, hydrogeologic, geophysical and geochemical investigations were initiated to determine the source of the inflowing water.

Hydrogeologic investigations included water balance studies conducted by Daniel B. Stephens and Associates, which resulted in lining the detention basins at the WIPP site (DBS&A, 2003; 2008). Slug and pumping tests were also conducted in four boreholes (C-2505, C-2506, C-2507 and ES-001) to determine the hydraulic properties of the shallow water-bearing horizons. Electromagnetic (EM) geophysical surveys, dedicated to characterizing the SSW, were conducted to determine (a) the source of the water leaking into ES (INTERA, 1996), and (b) the lateral and vertical extent and depth to the water bearing horizons (Shaw, 2003). The results of the recent Time Domain Electromagnetic (TDEM) survey of SSW conducted by Shaw (2003), with the objective of determining the thickness and lateral extent of the SSW, were inconclusive.

Gravity (with karst-feature focus (Barrows & Fett, 1985)), electrical resistivity (with breccia pipe collapse feature focus (Elliot, 1977)), and seismic (with repository-level focus (Hern et al., 1978)) surveys conducted at and in the vicinity of the site were not motivated by the presence of SSW, and are thus, of limited relevance to detailed characterization of SSW. They do, however, provide a general guide for future work by providing information on possible bounding layers of SSW flow. IT Corporation performed both time- and frequency-domain electromagnetic (TDEM and FDEM) surveys and a ground penetrating radar (GPR) study of the shallow subsurface (INTERA, 1996; Appendix A). A set of 12 piezometers (PZ-1 through PZ-12) were installed (see Figure 1), logged, and sampled to characterize the SSW (DE&S, 1997). Recent geochemical and geologic SSW studies have been performed with the objective of determining the origin of dissolved lead observed in water found in shallow piezometer PZ-13 (DBS&A, 2010).

Investigative actions will be conducted with regard to the extent and distribution of the SSW, hydrogeophysical investigations are proposed in this test plan. The investigative actions will include development of a better understanding of formation hydraulic properties, hydrogeologic characterization of the Santa Rosa/Dewey Lake contact, constraining vadose zone hydrologic conditions under and near the lined detention ponds, and determining the lateral extent and continuity of the SSW. To provide the basis for future modeling activities a whole-system conceptual model will be developed. It is important to determine the depth, vertical extent, and connectivity of SSW lenses, and define regional sources of SSW, if any. The depth of the SSW in relation to local stratigraphy could indicate whether SSW is leaking downward into the upper Dewey Lake. The saturated thickness is needed to better constrain the domain of a potential flow model that could be used to quantify the volume and fate of the SSW.

The initial focus of the shallow hydrogeophysical investigation program is to simply determine the areal extent of the SSW using such geophysical techniques as GPR, EM, electrical resistivity (ER), seismic, and the electrokinetic spontaneous potential (SP). Small pilot studies will be conducted to assess which method would be best suited to the objectives of the program. Based on the results of the pilot tests, larger studies would be conducted in conjunction with the well drilling program discussed above.

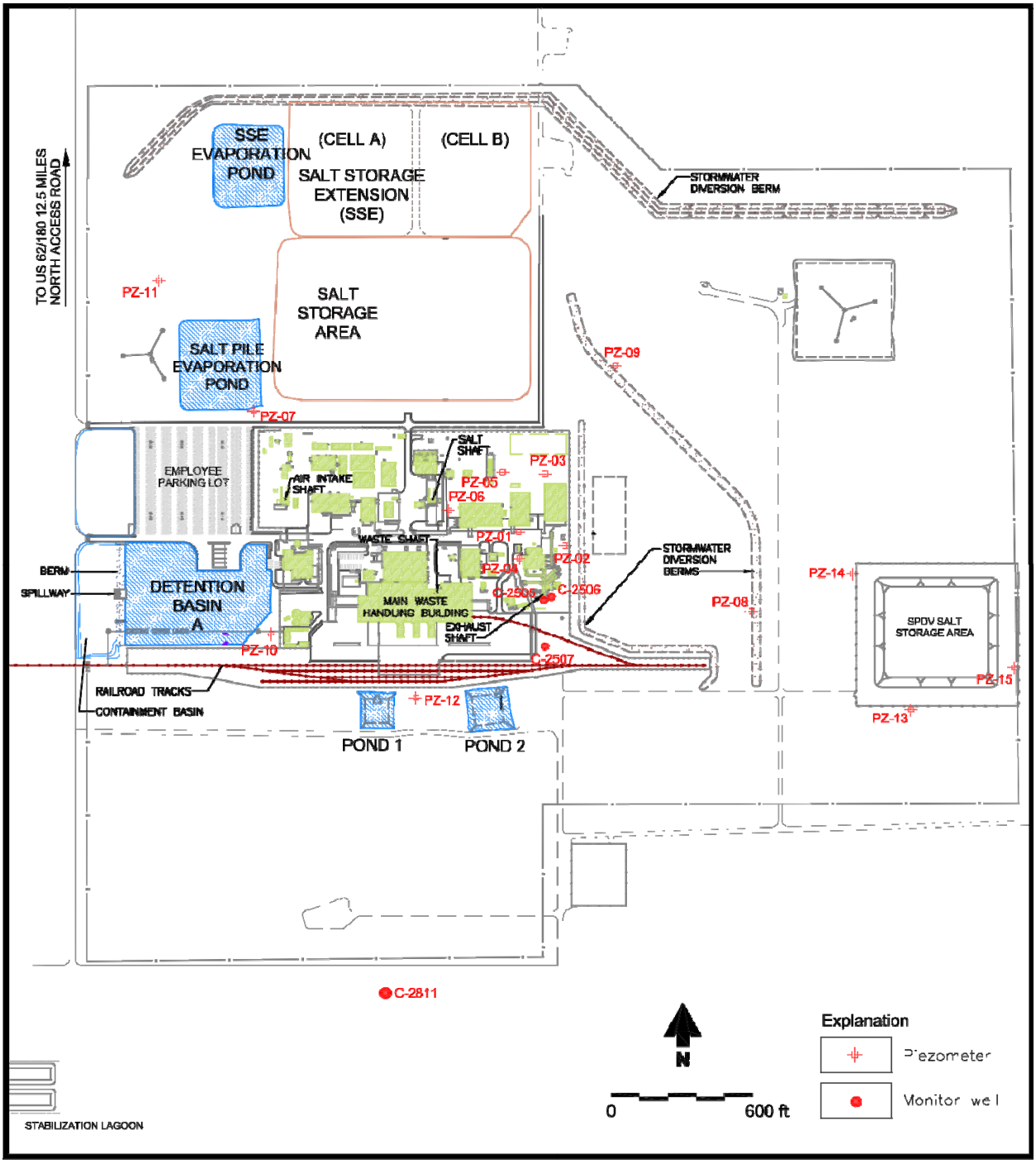

Figure 1. The SSW monitoring network with PZ/well locations; modified from DBS&A (2008).

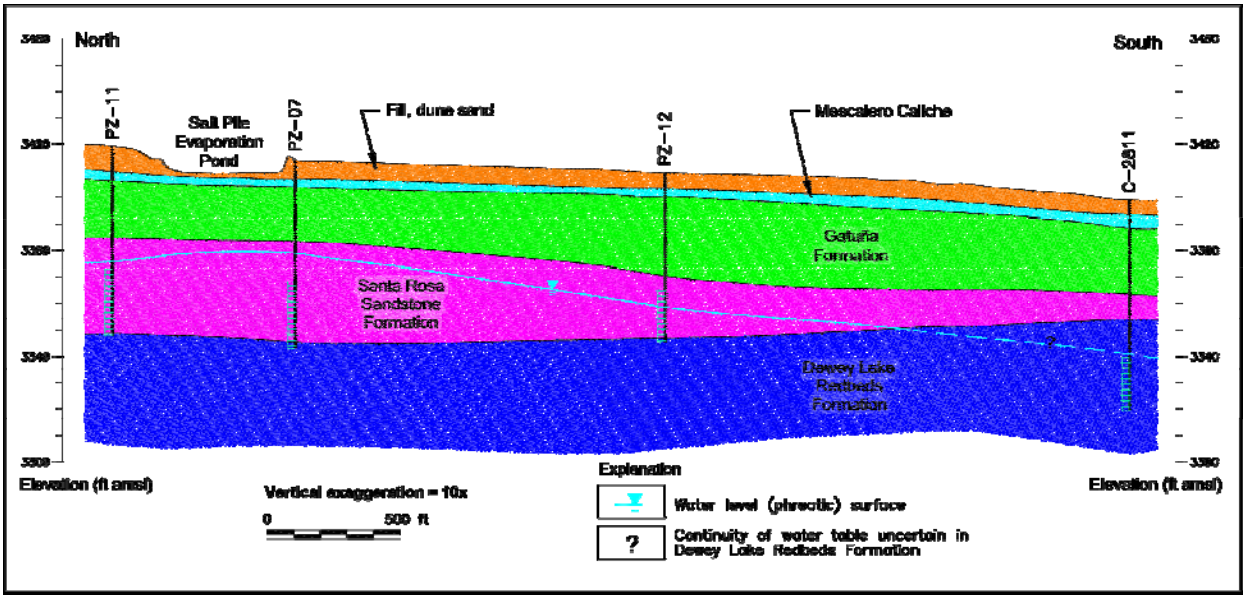

Figure 2. Shallow north-south cross section through WIPP (modified from DBS&A, 2008)

4 EXPERIMENTAL PROCESS DESCRIPTION

4.1 Data Collection and Analysis

Hydrogeophysical data collection will comprise both laboratory and field methods. Laboratory methods will be used to determine material properties that are pertinent to hydrogeophysical processes. Field methods will be used to acquire geophysical data on land surface for in situ hydrogeophysical characterization of the shallow subsurface.

4.1.1 Laboratory Methods

Laboratory experiments will be conducted in support of the hydrogeophysics field methods and to calibrate field test equipment. They will be performed on core samples or cuttings collected from near surface formations including the aeolian sands, Mescalero caliche, Gatuna, Santa Rosa and Dewey Lake formations. The purpose of the experiments would be to determine material properties including bulk densities, elastic properties (Young's moduli and Poisson ratios), dielectric permittivity distribution, hydraulic properties (permeability, porosity), and streaming potential coupling coefficients. Bulk densities, elastic properties, dielectric permittivity and electrical conductivities will be measured using standard procedures. A flow cell and sand tank will be set-up in the laboratory to measure hydraulic properties and streaming potential coupling coefficients.

4.1.2 Field Methods

Field methods will be used to acquire geophysical data on land surface for in situ hydrogeophysical determination of the lateral extent and continuity of the shallow subsurface water. Several methods are proposed to provide complementary data sets as well as provide a wide array from which the most suitable methods would be selected depending on field conditions.

Streaming potential method: The spontaneous potential (SP) method is an emerging hydrogeophysical approach, where electric potentials associated with near surface electrokinetic phenomena are measured at the land surface and inverted directly for physical parameters (Malama et al., 2009). The SP method considered here is based on streaming potentials associated with streaming currents generated by the flow of water through porous or fractured media to a discharge or injection point. This method, therefore, unlike most other near-surface geophysical methods, requires an associated well (the source) that can be pumped to generate flow in the formation of interest. Pumping tests conducted in association with SP surveys will follow TP-03-01, and the monitoring of water levels will follow TP-06-01.

Ground Penetrating Radar (GPR): This is a geophysical method for characterizing the near surface with high resolution. It is highly sensitive to soil moisture content and is thus suitable for locating the water table and for determining the lateral extent and continuity of shallow subsurface water. It has been used widely to define the water table and to characterize moisture content and variability in the vadose zone (Bradford et al., 2009; Bradford, 2008; Doolittle et al., 2006; Nakashima et al., 2001). However, due to the restriction to frequencies ranging from 50 MHz upward, the method has limited depth penetration, being typically restricted to depths of up to about 50 m (Davis & Annan, 1989; Blindow, 2009). The depths at which the shallow sub-

surface water levels intersect boreholes in the area of interest are close to the GPR depth penetration limit. Nevertheless, due to the high resistivities of the Gatuna and Santa Rosa sandstone formations, GPR may definitively resolve the lateral extent and continuity of the shallow subsurface water.

Magnetic Resonance Sounding (MRS): The advantage of MRS over traditional geophysical methods is that it measures a magnetic resonance signal generated directly by subsurface water molecules (Lubczynski and Roy, 2003; 2004). It is specifically sensitive to groundwater, which generates the resonance signal. Significant depth penetration is achievable, being proportional to the effective diameter of the surface source current loop. Because of its sensitivity to the presence of groundwater and significant depth penetration, the method can be used to detect the presence of, and to determine depth and lateral extent and continuity of SSW.

Electrical Resistivity (ER): This is a simple surface geophysical approach where an array of voltage electrodes are placed into the ground surface, while two current electrodes are used to apply a fixed DC current. The method is repeated with different electrode array configurations. The result of the interpretation of the data is a two-dimensional section (depth and length along the voltage electrode transect) of estimated formation resistivity (Linde et al., 2006). Formation resistivity is related to formation water content, water chemistry, and geology. Applied to the SSW problem at and around the WIPP site, the method would be used to map the resistivity structure of the subsurface, where low resistivity areas should correlate to water bearing layers and/or lenses.

Seismic Methods: Seismic refraction and reflection surveys will be conducted with a source that targets the layer interfaces observed in drill logs. The shallow caliche layer at the site may pose difficulties for refraction surveys, hence the proposal here to couple refraction with reflection surveys. Seismic surveys have the advantage of great depth penetration, but, owing to the low source frequencies, have the disadvantage of low resolution. Typically, the presence of groundwater increases seismic wave velocities, and this fact may be exploited to locate the water table and determine the lateral continuity of SSW.

Electromagnetic (EM): EM methods are sensitive to variations in the electrical properties of the subsurface and are useful for mapping regions of enhanced electrical conductivity owing to the presence of groundwater, or metallic mineralization. These methods (TDEM & FDEM) have been used to characterize the SSW near WIPP with limited success (Shaw 2003). EM methods yield distributions of subsurface electrical conductivity, and since the presence of groundwater tends to significantly increase conductivities of highly resistive substrata, they may be used to characterize the structure of SSW.

Induced (IP) and Spectral Induced (SIP) Polarization: These methods involve analysis of the temporal decay of electric potential in the subsurface after a source current is turned off. In IP the source current is direct current (DC), whereas it is alternating current (AC) in SIP. The decay rate of the electric potential and the chargeability of the subsurface can be related to electrical properties of subsurface material. Empirical relations between IP and hydraulic conductivity have been developed in the hydrogeophysics literature and may be used to hydraulically characterize the shallow subsurface (Binley et al., 2005).

4.2 Coordination with Organizations Providing Inputs or Using the Results

The WIPP managing and operating (M&O) contractor (Washington TRU Solutions) and/or its affiliates (Washington Regulatory Environmental Services –WRES) will be involved in the planning and execution of all surface activities at the WIPP site. SNL will either perform the geophysical surveys using its own equipment and personnel or sub-contract them to appropriate contractors, requiring that all involved parties follow guidelines the M&O contractor has in place for work on the site and the SNL QA program as appropriate.

4.3 Sources of Uncertainty

Sources of error and uncertainty in this TP include:

- voltage measurement uncertainty
- current measurement uncertainty
- head and flow rate measurement uncertainty
- unknown nature of subsurface heterogeneity

Measurements of water levels and flow rates associated with pumping tests are outlined in TP 03-01, and the specific procedures (SP) indicated therein. Geophysical studies carried out by SNL personnel using SNL equipment will follow appropriate SP that will be developed as needed.

5 SAMPLE CONTROL

The sample control for the work under this Test Plan will follow NP 13-1. Each sample will be appropriately labeled. Sample preparation, utilization, and final disposition will be documented. When samples are not in the possession of individuals designated as responsible for their custody, they shall be stored in a secure area with associated documentation (e.g. SNL WIPP Activity/Project Specific Procedure (SP) Form SP 13-1-1, “Chain of Custody”).

6 DATA QUALITY CONTROL

6.1 Measuring and Test Equipment (M&TE)

A calibration program will be implemented for the work described in this TP in accordance with NP 12-1, "Control of Measuring and Test Equipment." This M&TE calibration program will meet the requirements in procedure NP 12-1. In addition, NP 13-1 and SNL Activity/Project Specific Procedures (SP) 13-1, "Chain of Custody," identify requirements and appropriate forms for documenting and tracking sample possession. Computer-based data handling will follow NP 9-1, "Analyses."

6.2 Data Acquisition Plan

Quality control of the Scientific Notebooks will be established by procedures described in NP 20-2 "Scientific Notebooks." Methods for justification, evaluation, approval, and documentation of deviation from test standards and establishment of special prepared test procedures will be documented in the Scientific Notebooks. Procedures including use of replicates, spikes, split samples, control charts, blanks and reagent controls will be determined during the development of experimental techniques.

Numerical data obtained will be transferred from data printouts, electronic media, and scientific notebooks to data files that will be compatible with analysis using qualified or commercial off-the-shelf software (e.g., Microsoft Excel or MATLAB). Data transfer and reduction shall be performed in such a way to ensure that data transfer is accurate, that no information is lost in the transfer, and that the input is completely recoverable. A copy of each resulting file will be included with the scientific notebook and/or as a NP 9-1 Routine Calculation, as appropriate.

6.3 Data Qualification

All calculations performed as part of the activities of this test plan will be documented in scientific notebooks. The content and organization shall follow NP 20-2, "Scientific Notebooks." The notebooks will be reviewed periodically for technical and QA content and adequacy, as explained in procedure NP 20-2, and/or as a NP 9-1 Routine Calculation, as appropriate.

6.4 Justification, Evaluation, Approval, and Documentation of Deviations from Test Standards or Establishment of Specially Prepared Test Procedures

All deviations from this test plan and/or SPs will be recorded in the scientific notebook, or instrument logbook where applicable. Significant deviations from SPs and/or this test plan require prior QA and technical review before proceeding. Sample preparation procedures, which may vary from sample to sample as work scope evolves, will be detailed in scientific notebooks, in accordance with procedure NP 20-2.

7 TRAINING

All personnel involved in the experiments described in this TP will be trained and qualified for their assigned work. This requirement will be implemented through procedure NP 2-1, “Qualification and Training.” Evidence of training will be documented through Form NP 2-1-1, “Qualification and Training” and/or Form NP 2-1-2, “Training Record.”

8 HEALTH AND SAFETY

All of the health and safety requirements relevant to the work described in this TP and the procedures that will be used to satisfy these requirements are described in ES&H standard operating procedures. SP473548, “ES&H Standard Operating Procedure,” describes the nonradiological hazards associated with these experiments and describes the procedures to deal with those hazards, including all the training requirements for personnel involved in conducting the experiments.

9 PERMITTING/LICENSING

There are no special licenses or permit requirements for the work described in this Test Plan.

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