SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

AP-186
Revision 0

Analysis Plan for the Optimization of the Culebra Monitoring Network New Well Locations for the WIPP

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1. Introduction and Objectives

Monitoring of groundwater levels in the Culebra Dolomite Member of the Rustler Formation (Culebra) is a regulatory requirement for the U.S. Department of Energy’s (DOE) Waste Isolation Pilot Plant (WIPP). This Analysis Plan (AP) describes the development and application of a method to optimize the locations of new wells in such a way as to best achieve all regulatory requirements. The conclusions of the optimization analyses performed under this AP may be used for programmatic decisions.

1.1 Regulatory Context for Monitoring

Groundwater monitoring and modeling activities at the WIPP are an integral part of the DOE’s broader requirements to demonstrate WIPP operations are performed in a manner that ensures protection of the environment, the health and safety of workers and the public, proper characterization of the disposal system, and compliance of the WIPP with applicable regulations. Continued compliance with regulations must be demonstrated every five years during the operational phase of the WIPP. The monitoring requirements apply not only for the current operational phase but extend through the post-closure phase of the facility to meet applicable regulations. Because of these long-term requirements, DOE’s Carlsbad Field Office (CBFO) has developed a Strategic Plan For Groundwater Monitoring at the Waste Isolation Pilot Plant (DOE, 2003) that describes: relevant regulatory drivers; the current groundwater-monitoring network and how it has evolved over time; current groundwater program elements; strategies for maintaining compliance; methods for implementing the strategies; and roles and responsibilities of monitoring program participants.

1.1.1 EPA Regulatory Drivers

The U.S. Environmental Protection Agency (EPA) standards governing the management and disposal of spent nuclear fuel, high-level, and transuranic (TRU) radioactive wastes are codified in 40 Code of Federal Regulation Part 191 (40 CFR 191) (EPA, 1985; 1993). The WIPP must satisfy these standards to dispose of TRU waste. The portion of the EPA standards that is applicable to groundwater monitoring can be found in Subpart B of 40 CFR §191.14(b) Assurance Requirements, namely:

\[(b) \quad \text{Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.}\]

Under the WIPP Land Withdrawal Act (LWA) of 1992 (Public Law 102-579, 1992; as amended, 1996), the EPA was required to issue, by rule, the criteria for the WIPP certification and subsequent re-certifications of compliance with final disposal regulations. The EPA issued these required criteria as 40 CFR Part 194 (EPA, 1996). The portions of 40 CFR 194 applicable to groundwater monitoring are presented below and can be found in Subpart B Compliance Certification and Re-Certification Applications and Subpart C Compliance Certification and Re-Certification General
Requirements.

Subpart B §194.15 Content of Compliance Re-Certification Application(s)
(a) In submitting documentation of continued compliance pursuant to section 8(f) of the WIPP LWA, the previous compliance application shall be updated to provide sufficient information for the Administrator to determine whether or not the WIPP continues to be in compliance with the disposal regulations. Updated documentation shall include:

1. All additional geologic, geophysical, geochemical, hydrologic, and meteorological information;
2. All additional monitoring data, analyses and results;
3. All additional analyses and results of laboratory experiments conducted by the Department or its contractors as part of the WIPP program;
4. An identification of any activities or assumptions that deviate from the most recent compliance application;
5. A description of all waste emplaced in the disposal system since the most recent compliance certification or re-certification application. Such description shall consist of a description of the waste characteristics and waste components identified in §194.24(b)(1) and §194.24(b)(2);
6. Any significant information not previously included in a compliance certification or re-certification application related to whether the disposal system continues to be in compliance with the disposal regulations; and
7. Any additional information requested by the Administrator or the Administrator's authorized representative.

Subpart C §194.42 Monitoring
(a) The Department shall conduct an analysis of the effects of disposal system parameters on the containment of waste in the disposal system and shall include the results of such analysis in any compliance application. The results of the analysis shall be used in developing plans for pre-closure and post-closure monitoring required pursuant to paragraphs (c) and (d) of this section. The disposal system parameters analyzed shall include, at a minimum:

1. Properties of backfilled material, including porosity, permeability, and degree of compaction and reconsolidation;
2. Stresses and extent of deformation of the surrounding roof, walls, and floor of the waste disposal room;
3. Initiation or displacement of major brittle deformation features in the roof or surrounding rock;
4. Ground water flow and other effects of human intrusion in the vicinity of the disposal system;
5. Brine quantity, flux, composition, and spatial distribution;
6. Gas quantity and composition; and
7. Temperature distribution.

(b) For all disposal system parameters analyzed pursuant to paragraph (a) of this section, any compliance application shall document and substantiate the decision
not to monitor a particular disposal system parameter because that parameter is considered to be insignificant to the containment of waste in the disposal system or to the verification of predictions about the future performance of the disposal system.

(c) Pre-closure monitoring. To the extent practicable, pre-closure monitoring shall be conducted of significant disposal system parameter(s) as identified by the analysis conducted pursuant to paragraph (a) of this section. A disposal system parameter shall be considered significant if it affects the system’s ability to contain waste or the ability to verify predictions about the future performance of the disposal system. Such monitoring shall begin as soon as practicable; however, in no case shall waste be emplaced in the disposal system prior to the implementation of pre-closure monitoring. Pre-closure monitoring shall end at the time at which the shafts of the disposal system are backfilled and sealed.

(d) Post-closure monitoring. The disposal system shall, to the extent practicable, be monitored as soon as practicable after the shafts of the disposal system are backfilled and sealed to detect substantial and detrimental deviations from expected performance and shall end when the Department can demonstrate to the satisfaction of the Administrator that there are no significant concerns to be addressed by further monitoring. Post-closure monitoring shall be complementary to monitoring required pursuant to applicable federal hazardous waste regulations at parts 264, 265, 268, and 270 of this chapter and shall be conducted with techniques that do not jeopardize the containment of waste in the disposal system.

(e) Any compliance application shall include detailed pre-closure and post-closure monitoring plans for monitoring the performance of the disposal system. At a minimum, such plans shall:

(1) Identify the parameters that will be monitored and how baseline values will be determined;

(2) Indicate how each parameter will be used to evaluate any deviations from the expected performance of the disposal system; and

(3) Discuss the length of time over which each parameter will be monitored to detect deviations from expected performance.

1.1.2 NMED Regulatory Drivers

Waste disposed at the WIPP is termed “mixed” waste because it contains both radioactive and hazardous constituents. Disposal of radioactive constituents is regulated by the EPA, as described above. Disposal of hazardous constituents is regulated under the Resource Conservation and Recovery Act (RCRA) (United States Code (USC), 1976).

The RCRA is a statute designed to provide “cradle-to-grave” control of hazardous waste by imposing management requirements on generators and transporters of hazardous wastes and on owners and operators of treatment/storage/disposal facilities. The RCRA requirements are implemented primarily through the 40 CFR Part 260-280 series of regulations with Parts 260-270 consisting of requirements and standards pertaining to solid waste, particularly hazardous waste.

The EPA has delegated authority to the State of New Mexico such that the state hazardous waste
management program has been approved to operate in lieu of the federal RCRA program. Consequently, the New Mexico Environment Department (NMED) has authority over hazardous waste management at the WIPP. The New Mexico Hazardous Waste Act (NMHWA), and regulations promulgated thereunder, form the legal basis for the WIPP hazardous waste facility permit (HWFP). Applicable New Mexico Administrative Code (NMAC, 2000) requirements for groundwater monitoring include:

20.4.1.500 NMAC (incorporating 40 CFR §§264.97 and 264.98)

Specifies the requirements for a Detection Monitoring Program (DMP) to establish background groundwater quality and monitor indicator parameters and waste constituents that provide a reliable indication of the presence of hazardous constituents in the groundwater.

20.4.1.500 NMAC (incorporating 40 CFR §264.601(a))

Specifies the need for the DMP to demonstrate compliance with the environmental performance standard for the Underground Hazardous Waste Disposal Units (HWDUs). This standard requires prevention of any releases that may have adverse effects on human health or the environment due to migration of waste constituents in the groundwater or subsurface environment.

20.4.1.500 NMAC (incorporating 40 CFR §§264.95, 264.98, 264.601, and 264.602)

Specifies the need to identify the point of compliance relative to the groundwater flow direction and the need for detection monitoring wells.

20.4.1.500 NMAC and 20.4.1.900 NMAC (incorporating 40 CFR §§264.97(a) and (c), 264.98(b), 270.42)

Describes requirements for well location, maintenance, and plugging and sealing.

20.4.1.500 NMAC (incorporating 40 CFR §264.98(a))

Specifies the parameters and constituents to be monitored in the DMP.

20.4.1.500 NMAC (incorporating 40 CFR §264.97(f))

Specifies the need for determination of groundwater surface elevations at monitoring wells and throughout the region.

20.4.1.500 NMAC (incorporating 40 CFR §264.98(e))

Specifies the need for the determination of groundwater flow rate and direction using groundwater surface elevations.
In 1999, the NMED issued a HWFP to the DOE and the Management and Operation Contractor (MOC) to operate a hazardous waste storage and disposal facility at the WIPP (NMED, 1999). Among other terms and conditions of the permit, the NMED required the implementation of a DMP, Site Closure Plan, and Site Post-Closure Plan, each of which contained requirements pertaining to groundwater monitoring. These requirements are summarized below.

### 1.1.2.1 Detection Monitoring Program

The DMP is included as part of the HWFP (i.e., Module V) to establish background groundwater quality and to monitor indicator parameters and waste constituents that provide a reliable indication of the presence of hazardous constituents in the groundwater. Components of the DMP related to groundwater monitoring include:

- Point of compliance
- Well maintenance and plugging and abandonment
- Water quality sampling
- Groundwater level monitoring
- Data evaluation and reporting

The HWFP (Module V.B.) defines the point of compliance as the vertical surface located perpendicular to the groundwater flow direction at the detection monitoring wells (DMWs) that extend to the Culebra. The DMWs are specified to be the WQSP Wells 1 through 6 (completed to the Culebra) and WQSP Well 6A (completed to the Dewey Lake Formation).

Maintenance of the seven DMWs is performed according to the requirements of HWFP Module V.C. The DMWs may be plugged and abandoned (P&A’ed) by submitting a permit modification request to NMED. Plugging and abandonment would be performed in such a manner as to eliminate physical hazards, prevent groundwater contamination, preserve hydrostatic head, and prevent commingling of subsurface waters.

Groundwater quality sampling from WQSP-1 through 6 and 6A is required under the DMP (Module V.D. through V.F.) to establish an accurate and representative groundwater database that is scientifically defensible and demonstrates regulatory compliance. Two separate phases of sampling are identified under the DMP. During the first phase, groundwater sampling and analyses are performed to determine background or existing conditions of groundwater quality prior to waste emplacement. Phase two consists of ongoing groundwater sampling on a routine schedule, as approved by NMED, to determine if groundwater composition is changing or being affected by WIPP activities. The parameters and chemical constituents monitored in both phases are listed in Module V of the HWFP.

The DMP also requires groundwater-level measurements in wells located across the site (Module V.G. and V.H.). Water-level measurements of particular interest are those taken in the Culebra and Magenta Members of the Rustler Formation. However, water-level measurements are also made in monitoring wells completed in other water-bearing zones overlying and underlying the WIPP repository horizon when access to those zones is possible. These zones include, but are not limited to, the Dewey Lake Formation, the Forty-niner member of the Rustler Formation, the
Rustler-Salado Formation contact, and the Bell Canyon Formation. Under the DMP, water-level measurements are taken in the seven water-quality wells (WQSP Wells 1 through 6 and Well 6A) and in other network wells as called out in Attachment L, HWFP. Measurements are made monthly at each available location.

1.1.2.2 Site Closure Plan

The Site Closure Plan describes the activities necessary to close the WIPP individual units and facility and includes plans for underground panel closure, surface storage unit closures, shaft sealing, and activities related to groundwater. The operational phase of the facility will be followed by a decontamination and decommissioning phase and final closure. Closure will likely occur approximately 35 years after the date waste was first received. During the closure phase, monitoring wells no longer in use will be P&A’ed according to applicable regulations as provided for in the Closure Plan. Those wells remaining in the network during the closure phase (i.e., those not P&A’ed) will be monitored at the same frequency and level of effort described in the DMP for the operational phase, or as approved by the NMED.

1.1.2.3 Site Post-Closure Plan

The Site Post-Closure Plan describes the activities required to maintain the WIPP after completion of facility closure and to implement institutional controls to limit access. Post-closure groundwater monitoring will continue in accordance with the DMP, or as approved by the NMED.

1.2 Optimization History

An optimization analysis was previously performed under AP-111 Revision 0 (Beauheim and McKenna, 2003) and AP-111 Revision 1 (Kuhlman, 2008), and documented in associated analysis reports McKenna, 2004 and Kuhlman, 2010, respectively.

AP-111 was recalled and is being replaced with AP-186, Revision 0 to include the following significant changes:

1. Several steel-cased Culebra monitoring wells have been plugged and abandoned without replacements, removing them from the monitoring network, as proposed in Thomas (2016) *Five Year Projection for the Waste Isolation Pilot Plant Integrated Hydrology Program*. The removal of the steel-cased wells will be reflected in the optimization analysis to verify that the impact of the well removals will have minimal impact on the Culebra flow model.

2. A change is being proposed to the WIPP underground footprint (Hansen, 2020), including additional mined panels to the west of the existing mined area, making well coverage in the western half of the network a priority.

The optimization analysis is being performed to account for the changes made to the monitoring network in the past 10 years and to incorporate modifications made to the methodologies included in AP-111 Revision 1, detailed below:
• Universal kriging and cokriging are not included in this analysis plan. Instead, the ordinary kriging method used in the AP-111 Revision 1 analysis report is the only kriging method prescribed.

• The sensitivity analysis performed for the 2010 report will not be repeated in AP-186 Revision 0, because the Culebra flow model and transmissivity field have not changed since the Kuhlman (2010) report.

• The focus of AP-186 is to ascertain the need for an additional well (or wells) to the monitoring network.

1.3 Current Monitoring Network

The existing well network as of September 2020 includes 44 wells completed in the Culebra, 32 of which are used to gather water level data monthly (Figure 1). There are multiple Culebra completed wells located on the H-19 well pad, including H-19b0 and H-19b2 through H-19b7. Well H-19b0 is monitored monthly, and the remaining six wells are monitored quarterly as the nested wells provide similar water levels unless there is active pumping in the Culebra near the wells. Monthly measurements, while providing valid data, would be highly redundant.
An addition to WIPP has been proposed that would include additional panels to the west of the existing footprint (Hansen, 2020). This proposed change raises the question of whether adequate well coverage exists in the western half of the network. The proposed change to the WIPP underground footprint will potentially create new pathways of particles hypothetically released into the Culebra above the additional panels. Potential new release points were evaluated in the Culebra Release Point Reassessment Analysis Report (Kushnereit et al., 2020), but the report did not address well locations.

Culebra transmissivity ($T$) varies over ten orders of magnitude from east to west in the area shown in Figure 1 (Hart et al., 2008). This heterogeneity causes both flow direction and magnitude to vary highly across the Culebra model boundary. In order to understand the flow in the Culebra
and estimate the hydraulic gradient, an adequate number of wells spaced on and around the WIPP site are required. Monitoring since the time of the compliance certification application has shown that water levels in the Culebra (as well as other strata) change in response to a variety of stresses originating both at and away from the WIPP site (DOE, 2014 & DOE, 2019). If the monitoring network were restricted to wells only on the WIPP site, there would be little chance of understanding why water levels have and are changing. Adequately spaced wells also contribute data that support the determination of boundary conditions for the Culebra flow model used in WIPP performance assessment calculations. Thus, an optimized monitoring network should include wells both on the WIPP site and wells surrounding the WIPP site in key locations.

1.4 Monitoring Network Objectives and Optimization Considerations

The optimized Culebra monitoring network must meet three primary objectives.

1. Continue to allow the estimation of the direction and rate of two-dimensional groundwater flow across the WIPP site (NMED and EPA requirement), which are dependent on the hydraulic head gradient, transmissivity ($T$), and porosity.
2. Continue to provide data needed to infer causes of temporal changes in water levels that might be observed (EPA requirement).
3. Continue to provide spatially distributed head data adequate to allow defensible calibration of Culebra groundwater flow models (PA requirements).

The optimized monitoring network will be created with regard to where wells currently exist, and with regard to our current understanding of the hydrology of the Culebra. The optimization process must take the following factors into consideration:

1. Optimize around (i.e., preserve) existing locations of fiberglass-cased wells;
2. Preserve existing locations of steel-cased wells where feasible to minimize pad/road construction, permitting, and survey costs;
3. Known $T$ variations (from modeling results and pumping test analyses) and geologic structures or boundaries (from borehole data and mapping);
4. Where feasible, locate new wells where conceptual model assumptions (e.g., high $T$ pathways in the southeast, where low $T$ would normally be expected, where significant halite exists, and where high $T$ and upper Salado Formation dissolution has occurred in the west) can be tested; and
5. Where feasible, locate new wells in areas that correspond to faster groundwater flow and/or particle travel time model parameter sensitivity;

2. Approach

Optimization of the Culebra monitoring network will involve a combination of two different sets of calculations:

1. A geostatistical analysis aimed at minimizing the average kriging variance associated with estimates of hydraulic head and its gradient across the model domain;
2. A geometrical analysis which investigates the effects of shape and size of hydraulic gradient triangles on the ability to estimate the hydraulic gradient.

These calculations are explained more fully in the task descriptions presented below. An analysis report will be prepared describing the optimization procedure and results.

3. **Software List**

The following computer programs may be used for different tasks associated with optimization and minimization of the Culebra monitoring network:

Commercial off-the-shelf software:

- Mathworks MATLAB R2010a (commercial off-the-shelf software)
- Python 3
- Surfer v. 9.11.947

Qualified software:

- KT3D v. 2.0 (acquired; routines qualified under NP 19-1)

Commercial off-the-shelf spreadsheet programs such as Microsoft Excel 365, may also be used for data manipulation and plotting. Any new programs written to perform specific tasks or pre- or post-processors needed for data manipulation and transfer between codes will also be qualified as part of the analysis package. Data and calculations completed by any of the above software are subject to Quality Assurance review.

4. **Tasks**

The tasks, responsible personnel, and estimated task schedule are summarized below in Table 1.

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Approximate Completion Date</th>
<th>Responsible Individuals</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Geostatistical Analysis</td>
<td>2/15/2021</td>
<td>Tingting Yan, Michael Farinacci, Arun Wahi</td>
</tr>
<tr>
<td>2</td>
<td>Geometrical Analysis</td>
<td>2/15/2021</td>
<td>Tingting Yan, Michael Farinacci, Arun Wahi</td>
</tr>
<tr>
<td>3</td>
<td>Combined Analyses</td>
<td>2/15/2021</td>
<td>Tingting Yan, Arun Wahi</td>
</tr>
</tbody>
</table>


4.1 Task 1—Geostatistical Analysis

The geostatistical analysis considers the estimation variance associated with kriged heads across the monitoring network. The estimation variance is also known as the kriging variance or the estimation error. This task will involve fitting a mathematical model of spatial variability (variogram) to the measured head values. These variogram model and the measured heads will be used to geostatistically estimate the head values and estimation variance across the model domain using kriging. The goal of this analysis will be to determine locations where additional monitoring wells will create the greatest reduction in the overall kriging estimation variance, with a focus on locations within the WIPP land withdrawal boundary. It is expected that the head correlation lengths will be small compared to the entire 28.3 × 30.6 km domain size (Hart et al., 2008) and that this approach to locating monitoring wells will be most effective within the WIPP Land Withdrawal Area.

Ordinary kriging estimates are made under the assumption that the underlying stochastic process being estimated is stationary (i.e., the variogram is not a function of location, only separation – Isaaks and Srivastava, 1989). Groundwater levels in the WIPP monitoring network area are non-stationary as heads in the north are higher than those south of the WIPP site. Gradients in head are also non-stationary, as there is an east-west region of steeper gradients running across the middle of the WIPP LWB. In previous analyses, a trend was fit to the head data; the residuals between this trend and the measured heads were used in the variogram modeling and subsequent kriging. The estimated residual values were then added back to the trend model to produce the estimated heads. This trend removal process allowed for modeling of stationary residuals and this analysis will continue using this approach.

This task will produce maps showing the change of average estimation variance over the area of interest due to one additional monitoring well. Locations with largest reduction of average variance are considered the most impactful through the addition of a monitoring well.

4.2 Task 2—Geometrical Analysis

A geometric plane can represent the potentiometric surface in a confined aquifer with two-dimensional flow, and the orientation of this plane can be completely defined by a set of three elevation measurements on that plane. Therefore, any combination of three wells measuring the water level can serve as an estimator of both the magnitude and the orientation of the hydraulic gradient. The analysis of this task is focused directly on the NMED and EPA requirements that the direction and rate of groundwater flow in the Culebra be determined and can provide relatively high-resolution information for understanding the causes of changes in observed water levels, as also required by EPA.

Initial scoping calculations and work by other authors have shown that triangles calculated by measured water-level data can provide accurate estimates of the hydraulic gradient. These estimates are controlled by the triangle size and shape as well as the assumed water-level-measurement error relative to the observed head drop across the estimator. This task focuses on the geometric quality of the monitoring network by utilizing a unique set of non-overlapping triangles formed by wells in the network which comprise a Delaunay triangulation (using the
Quickhull algorithm, implemented in Matlab). The average ratio of the largest and smallest interior angles of triangles across the domain will be calculated to quantify the quality of the triangles. The average angle ratio weighted by the triangle size will be calculated based on the current Culebra monitoring network. Then each point in the domain will be added one at a time as an additional well to determine the relative change in the overall weighted angle ratio across the domain caused by the addition.

The result of this analysis will be maps showing changes of area-weighted angle ratio for triangle network due to one additional well. Locations with the largest angle ratio increase indicate these are ideal locations to add a monitoring well for better triangle quality and improved ability of the network on hydraulic gradient estimation.

4.3 Task 3—Combined Analyses

The Task 1 and Task 2 optimization analyses will produce differing two-dimensional result fields, used as criteria in the placement of new monitoring wells. These mapped results will be combined into a single result set to guide the selection of candidate monitoring well locations. This selection will be made using a combination of scientific judgment and additional factors, including, but not limited to, the expense involved in constructing a new well at a specific location, geological factors, presence of an existing well pad, road construction, site preparation, and permitting.

5. Special Considerations

None.

6. Applicable Procedures

All applicable WIPP quality-assurance procedures will be followed for these analyses. Training of personnel will be done in accordance with the requirements of NP 2-1, Qualification and Training. Analyses will be performed and documented in accordance with the requirements of NP 9-1, Analyses, and NP 20-2, Scientific Notebooks. All software used will meet the requirements of NP 19-1, Software Requirements. The analyses will be reviewed following NP 6-1, Document Review Process. All required records will be submitted to the WIPP Records Center in accordance with NP 17-1, Records.

7. References


Kuhlman, K.L. 2008 Analysis Plan AP-111 Revision 1: Analysis Plan for the Optimization and minimization of the Culebra Monitoring Network for the WIPP. Sandia National Laboratories, Carlsbad, NM


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