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SANDIA NATIONAL LABORATORIES
WASTE ISOLATION PILOT PLANT

Analysis Plan for Optimization and Minimization of the Culebra Monitoring Network for the WIPP

AP-111

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1. Introduction

Monitoring of groundwater levels in the Culebra Dolomite Member of the Rustler Formation is a regulatory requirement for the U.S. Department of Energy's (DOE) Waste Isolation Pilot Plant (WIPP). This Analysis Plan directs the development and application of a method to optimize the locations of wells in such a way as to meet all regulatory requirements while minimizing the total number of wells required to monitor the Culebra near the WIPP site. The method must take into account all regulatory and programmatic requirements for monitoring as well as the established locations of: relatively new fiberglass-cased wells at the beginning of their useful lives, old steel-cased wells near the end of their useful lives, and existing drilling pads where new wells might be more quickly and economically installed than at currently undisturbed locations. The activities performed under this Analysis Plan may be used for Programmatic Decisions.

2. 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 (~35 years), 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.

2.1 EPA Regulatory Drivers

The U.S. Environmental Protection Agency (EPA) standards governing the management and disposal of spent nuclear fuel and 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) 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 meteorologic 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.

2.2 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 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 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 hazardous waste facility permit (HWFP) to the DOE and the 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 Detection-Monitoring Program (DMP), Site Closure Plan, and Site Post-Closure Plan, each of which contained requirements pertaining to groundwater monitoring. These requirements are summarized below.

2.2.1 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 extends to the Culebra Dolomite Member of the Rustler Formation. 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).

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, conserve hydrostatic head, and prevent commingling of subsurface waters. A P&A report is to be submitted to NMED 90 days from the date the DMW is removed from the DMP.

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. This phase must be completed before any hazardous waste is disposed in the WIPP and must contain four sampling rounds performed over a two-year period[1]. In the second phase, groundwater sampling is performed semi-annually (March through May and September through November of each year) 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, the Forty-niner, the Rustler-Salado contact, and the Bell Canyon. Under the DMP, water-level measurements are taken in the seven water-quality wells (WQSP Wells 1 through 6 and Well 6A) and in older wells located at 26 other locations as called out in Attachment L, HWFP. Measurements are made monthly in at least one accessible completion interval at each available location. At locations with two or more wells completed in the same interval, quarterly

1 The water-quality baseline for the WIPP has been established based on 10 rounds of sampling conducted over a five-year period.

measurements are to be taken in the redundant wells. Water levels in the new water-quality wells are measured monthly and, in addition, before each water-quality sampling event.

2.2.2 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.

2.2.3 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. The sampling frequency may be changed to biannually after the final facility closure is completed. The final target analyte list specified in the HWFP for water-quality sampling may also be changed based on the final composition of the waste. The changes would require a modification of the current HWFP approved by the Secretary of the NMED.

3. Current Monitoring Network

The existing well network as of October 2003 includes 52 wells monitoring the Culebra on 38 drilling pads (Figure 1), with three more wells scheduled to be drilled in early FY04 (SNL-1, 5, and 11). Many of these wells were converted geologic core holes or potash resource evaluation holes, so were not constructed or located specifically for characterizing the WIPP groundwater hydrology. In addition, 34 of the existing wells are steel-cased and most were constructed more than 20 years ago. Because of age and the corrosive brine environments in some wells, the steel casings are deteriorating. All steel-cased wells will probably need to be P&A'ed within the next 5 to 10 years. Without replacing at least some of these wells, the remaining network would be inadequate to allow us to quantify flow rate and direction accurately and meet other program requirements.

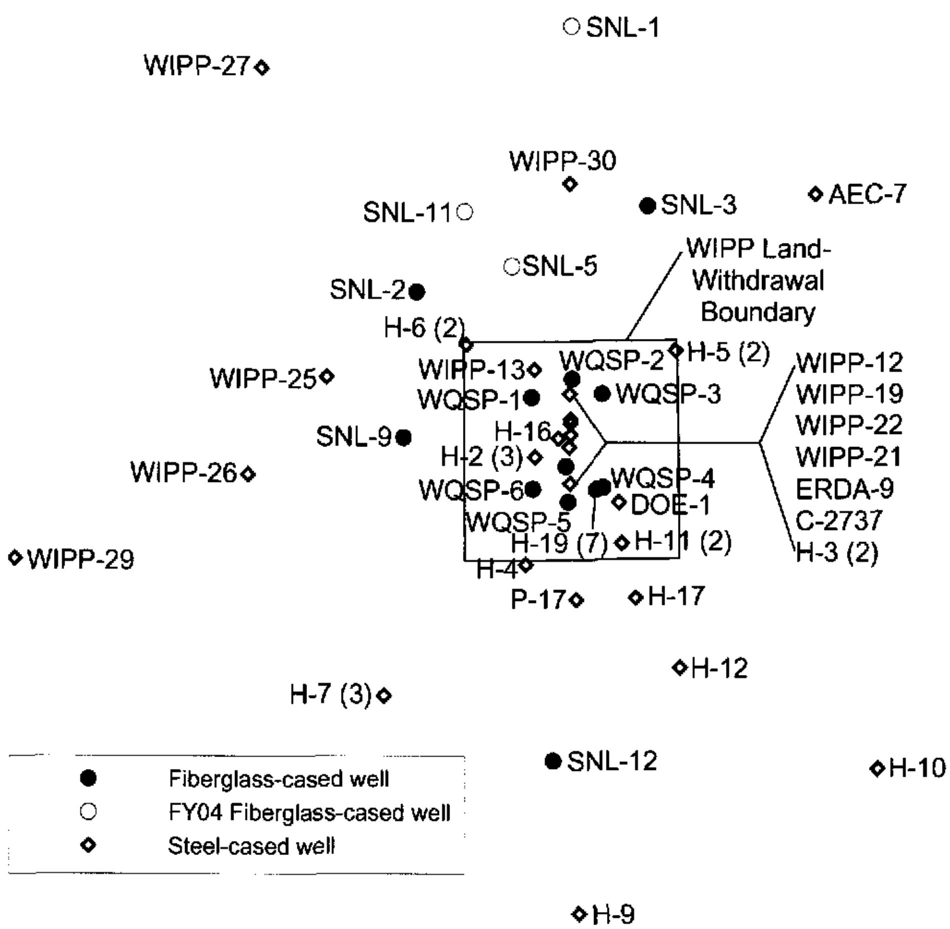

Figure 1. Current Culebra monitoring network.

Issues of current well location, age, and P&A suggest that wells will need to be replaced and, in some cases, relocated. These issues raise the question of what constitutes an adequate network of wells for monitoring WIPP hydrology. In a homogeneous medium under steady-state conditions, three wells along the northern WIPP boundary and three wells along the southern boundary might be adequate to define groundwater flow direction and velocity across the site assuming the hydraulic gradient trends north to south. The Culebra, however, is not a homogeneous medium, nor does it appear to be at steady-state. The transmissivity of the Culebra varies over six orders of magnitude from east of the WIPP site to Nash Draw located west of the site. This heterogeneity causes both flow direction and velocity to be highly variable and location-specific. In order to understand flow patterns on the WIPP site, more wells are needed than simply three upgradient and three downgradient. In addition, monitoring since the time of the CCA has shown that water levels in the Culebra (and other strata) change in response to a variety of stresses originating off the WIPP site. If the monitoring network were restricted to wells only on the WIPP site, there would be little chance of understanding why water levels were changing. Wells also need to be located in areas where they can provide information that can be used to determine boundary conditions for the flow model used in WIPP performance assessment calculations. Thus, an optimized monitoring network should include wells both on the WIPP site and several miles from the WIPP site in key locations.

4. Monitoring Network Objectives and Optimization Considerations

The optimized and minimized Culebra monitoring network must meet three primary objectives:

1. It must continue to allow the determination of the direction and rate of groundwater flow across the WIPP site (NMED and EPA requirement);

2. It must continue to provide data needed to infer causes of changes in water levels that might be observed (EPA requirement); and

3. It must continue to provide spatially distributed head data adequate to allow both defensible boundary conditions to be inferred for Culebra flow models and defensible calibration of those models (PA requirements).

The degree to which these objectives can be reduced to quantitative measures will be evaluated as the work described in this Analysis Plan proceeds.

The optimized and minimized monitoring network will not be created without regard to where wells currently exist, or without regard to our current understanding of the hydrology of the Culebra. The optimization and minimization 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. Identify existing well locations that are not needed

4. Known T variations and geologic boundaries

5. Where feasible, locate new wells where conceptual model assumptions (e.g., low T east of halite margins, high T where upper Salado dissolution has occurred) can be tested

6. Where feasible, locate new wells in areas of high groundwater flow and/or particle travel time model sensitivity

5. Optimization and Minimization Approach

Optimization and minimization of the Culebra monitoring network will involve a combination of three different sets of calculations:

1. A geostatistical analysis aimed at minimizing the average variance in head estimations across the model domain;

2. An analysis to identify the best locations for new wells to define the magnitude and orientation of the hydraulic gradient more accurately using a three-point estimation technique; and

3. A sensitivity analysis to identify where model outputs (e.g., travel time from above the WIPP disposal panels to the land-withdrawal boundary) are most sensitive to model estimates (head, transmissivity).

These calculations are explained more fully in the task descriptions presented below. Sean McKenna (6115) will be the analyst responsible for the tasks. An analysis report will be prepared describing the optimization and minimization procedure and results. The tasks (including reporting) should be completed by March 1, 2004.

5.1 Task 1—Geostatistical Analysis

The geostatistical analysis is an analysis of the estimation variance of the heads across the site. The estimation variance is also known as the kriging variance or the estimation error. This task will involve the calculation and model fitting of variograms on the measured head values for a given measurement time, or for multiple measurement times. These variograms and the measured heads will be used to estimate the head values across the model domain geostatistically using kriging. The kriging results provide the estimates of head at every point on a predefined grid or arbitrarily chosen set of points. In addition to the head estimates, kriging also provides the estimation variance at every location. The goal of this analysis will be to determine locations where additional monitoring wells will create the greatest reduction in the overall estimation variance. This analysis will be focused on identifying those locations where wells could be placed within the WIPP land withdrawal boundary as it is expected that the head correlation lengths will be small compared to the entire 20x30-km domain size and that this approach to locating monitoring wells will be most effective within the WIPP site area. The same set of results can be used to determine redundancies in the current monitoring well network by examining which wells can be removed from the current monitoring network that result in the minimum increase in the overall estimation variance.

The calculation of the estimation variance is relatively straightforward. However, there are a number of issues that must be addressed in this estimation. The kriging equations are non-parametric and therefore the estimated head value and the estimation variance do not define a specific statistical distribution shape. If it will improve the interpretation and understanding of the results, a variant of kriging called multiGaussian kriging can be employed to produce kriging results for which the estimated value and the estimation variance define the mean and variance of a Gaussian distribution, respectively. The properties of the Gaussian distribution are well known and may provide improved understanding and interpretation of the results.

Kriging estimates are made under the assumption of a stationary random function model. Groundwater levels at the WIPP site are non-stationary as heads in the north are higher than those south of the WIPP site. For previous modeling purposes, a trend model has been fit to the head data; the residuals between this model and the measured heads are calculated and used in the variogram modeling and subsequent kriging. The estimated residual values are then added back to the trend model to produce the estimated heads. This trend removal process allows for modeling of stationary residuals, but it does not reproduce the true estimation variance. Other approaches for producing accurate estimation variance values with non-stationary data, such as kriging with external drift, will be evaluated.

5.2 Task 2—Three-Point Estimators

A plane can represent the potentiometric surface in a confined aquifer, 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. This analysis is focused directly on the

NMED and EPA requirements that the direction and rate of ground water flow in the Culebra be determined and can provide relatively highly resolved 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 the ability of any three-point estimator, or triangle, to provide accurate estimates of the hydraulic gradient is mainly a function of the triangle size and shape as well as the water-level-measurement error relative to the head drop across the estimator. Prior to using the three-point estimator to determine optimal monitoring well locations, scoping calculations will be completed to determine the acceptable level of measurement error relative to the head drop across the triangle and the acceptable triangle shapes. "Acceptable" will be defined here as those triangles that provide estimates of the magnitude of the hydraulic gradient with no more than ±10% uncertainty caused by measurement error and estimates of the orientation of the hydraulic gradient with no more than ±30 degrees uncertainty. Completion of these scoping calculations will result in a set of rules for the Culebra that define the acceptable triangle shape and amount of measurement error relative to head drop. These rules will be applied to the current Culebra monitoring network to determine the number of valid three-point estimators that can be generated from the existing wells. Then each point in the domain will be sequentially examined to determine how many new, valid three-point estimators could be generated by placing a new monitoring well at that location. The result of this analysis will be a map showing the increase in the total number of valid three-point estimators for the addition of a single monitoring well at each location. The reverse of this technique can also be used by sequentially removing each existing well from the network and determining which well(s) reduces the total number of valid triangles by the least number, or leaves a large area of the domain without a valid triangle.

An assumption inherent in the use of the three-point estimator is that the transmissivity within the triangle defined by the three wells is homogeneous. We know that this is not the case for the Culebra. However, this assumption can be met in a heterogeneous field if the triangle encloses a small amount of the aquifer in which the transmissivity variability is relatively small or if the triangle is very large and encompasses at least eight to ten correlation lengths of the transmissivity in which case a single average value of transmissivity can be applied. In the former case, small triangles can lead to small head drops across the triangle in which case measurement error plays a more significant role and may make the triangle unacceptable for gradient estimation. The effects of transmissivity variance and correlation length on the ability of three-point estimators to identify the orientation and magnitude of the gradient correctly will be examined by using the results of the calibrated T fields developed by McKenna and Hart (2003). A series of triangles will be selected and used to determine the orientation and magnitude of the gradient within the triangle. This orientation will be compared to a flux-weighted average orientation and magnitude as calculated from all of the model cells enclosed within the selected triangle. Results of these numerical simulations will serve as a guide to the amount of error that can be expected when making magnitude and orientation estimates from three-point estimators in the Culebra and define the minimum and maximum size triangles that give accurate orientation and magnitude estimates.

Determination of optimal locations for additional monitoring wells through the use of three-point estimators is done sequentially. The question may arise as to where the next *k* monitoring wells should be located simultaneously. If this type of optimization becomes necessary and *k* becomes large, different objective function formulations could be defined and then solved using machine learning algorithm approaches such as simulated annealing or a genetic algorithm. If *k* remains relatively small (e.g., 3), then 3 separate sequential optimizations will be done where the next best location is found for a monitoring well, a well is assumed to be placed there, and then the next best place for a well is determined and so forth up to *k* new wells.

5.3 Task 3—Sensitivity Analyses

Sensitivity analysis is used to determine the sensitivity of a performance measure (e.g., travel time) to estimated properties (e.g., transmissivity or head) at all locations in the Culebra model domain. Those areas to which the performance measure is most sensitive are areas where the estimated property needs to be well understood in order to make accurate predictions of the performance measure. These areas of high sensitivity are selected as locations for additional monitoring wells. These sensitivity calculations will use the calibrated transmissivity fields and the travel times from these fields as input and determine the rank correlation across all fields between the travel time and the transmissivity for each location in the model. Additionally, the correlation between the travel time and the modeled head will also be calculated. The strength of the rank correlation serves as a measure of the sensitivity of the performance measure to the estimated transmissivity or head. This analysis will provide static maps of sensitivity. This approach cannot be used in an iterative manner to determine changes in the results with addition or subtraction of wells from the monitoring network as can be done with the Geostatistical and Three-Point Estimator analyses. This limitation is mainly due to the large computational cost of developing the calibrated transmissivity fields.

A second, more limited, sensitivity analysis will be done to examine the effect of the fixed-head boundary conditions on the calculated travel times from the repository to the WIPP boundary. These analyses will be done to determine areas where additional wells should be located to provide defensibility for the boundary conditions used in the Culebra models (the third primary objective in Section 4). These analyses will consist of multiple forward runs of **MODFLOW-2000** and **DTRKMF** on the average calibrated transmissivity field to determine the steady-state groundwater heads and the particle travel times. Each of these forward runs will be done with a perturbation to the fixed-head boundaries along the north, east, and south sides of the model. No perturbations will be made along the no-flow boundary on the west side of the model or in the inactive cells to the west of the high-transmissivity zone. Each perturbation of the fixed head will be a 5-meter increase in the fixed head centered on a single cell along the fixed-head boundary. The head perturbation will be smoothly distributed to adjacent model cells by using the spatial covariance function of the heads as determined in the previous variogram analysis. The result of this analysis will be a map of the fixed-head boundary cells showing the increase or decrease in travel time due to the head boundary perturbation relative to the travel time calculated on the average transmissivity field using the original fixed heads. Boundary locations where the head perturbation makes a significant change in travel time will be examined for additional monitoring well placement.

5.4 Task 4—Combining Analyses

Each of the different optimization analyses will produce a different map indicating locations to place new monitoring wells. These different maps need to be combined into a single set of selected candidate monitoring well locations. This selection will be done by scientific judgment and additional factors will be included in the selection process including the expense involved in locating new wells at certain locations (e.g., presence of an existing well pad, road construction, site preparation, permitting). The Geostatistical and Three-Point Estimator analyses will also produce separate lists of wells that could be removed from the network based on these wells providing redundant information. These two lists will also be combined using scientific judgment. The combination and final selection of which wells to removed will take into account other factors such as the age and construction materials of the wells under consideration for removal.

6. Software List

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

- ESRI ArcInfo 8.1 (off-the-shelf software);
- GSLIB v. 2.0 (acquired; routines qualified under NP 19-1);
- Mathcad 11 (off-the-shelf software);
- MODFLOW-2000 v. 1.6 (qualified under NP 19-1);
- PEST v. 5.5 (qualified under NP 19-1); and
- DTRKMF (qualified under NP 19-1).

Off-the-shelf spreadsheet programs, such as Excel 2000, and graphing programs, such as Grapher 3 or SigmaPlot, may also be used for data manipulation and plotting. Any new codes 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.

7. Special Considerations

No special considerations have been identified.

8. Applicable Procedures

All applicable NWMP 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*.

9. References

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