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Sandia National Laboratories Compliance Monitoring Parameter Assessment For 2018

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Sandia National Laboratories
Compliance Monitoring
Parameter Assessment for 2018

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Executive Summary

This document reports the seventeenth annual derivation and assessment of the Waste Isolation Pilot Plant (WIPP) Compliance Monitoring Parameters (COMPs). The COMPs program is designed to meet certain requirements of the U.S. Environmental Protection Agency's (EPA) long-term disposal regulations (EPA 1993 and 1996). The concept of deriving and assessing COMPs is explained in Sandia National Laboratories (SNL) Activity/Project Specific Procedure, SP 9-8, titled: *Monitoring Parameter Assessment Per 40 CFR 194.42* (SNL 2017).

The comprehensive WIPP monitoring effort is not under the auspice of one program, but is comprised of many discrete elements, one of which was designed to fulfill the EPA's long-term disposal requirements found at 40 CFR Part 191 Subparts B and C, and the Certification Criteria at 40 CFR Part 194. Monitoring parameters that are related to the long-term performance of the repository were identified in a monitoring analysis.[1] Since these parameters fulfill a regulatory function, they were termed Compliance Monitoring Parameters so that they would not be confused with similar performance assessment (PA) input parameters. The 2014 COMPs report (Wagner and Kuhlman 2014) had a data cut-off for information in that report prior to the WIPP Operational accidents of February 2014, and as such, those events were not mentioned in that document. The 2015 COMPs report (Wagner and Thomas 2015) was the first report that dealt with assessing data generated after these events. Because the February 2014 events have restricted access to the WIPP underground, many monitoring activities have been suspended or delayed and data for the geotechnical COMPs have been affected. Monitoring programs continue to be impacted by underground access issues such that some of the monitoring data is still unavailable. This 2018 report identifies the affected COMPs and associated monitoring data collection issues. Although data collected for some COMPs is not possible, there is no indication from the available monitoring data that the WIPP will not perform as predicted.

The Department of Energy (DOE) uses PA to predict the radioactive waste containment performance of the WIPP. COMPs are used to identify conditions that are not within the PA data ranges, conceptual model assumptions or expectations of the modelers and to alert the project of conditions not accounted for or anticipated. COMPs values and ranges were developed such that exceedance of an identified value indicates a condition that is potentially outside PA expectations. These values were appropriately termed "trigger values." Deriving COMPs trigger values was the first step in assessing the monitoring data. Trigger Values were first derived in 1999 and some have since been revised. The derivations and revisions are documented in the *Trigger Value Derivation Report* (Wagner and Thomas 2016).

In the initial Certification Ruling (EPA 1998a), EPA approved 10 COMPs, 2 relating to human activities, 5 relating to geotechnical performance, 2 relating to regional hydrogeology and 1 relating to the radioactive components of the waste. The requirements of 40 CFR § 194.4(b)(3) require the DOE to report any condition that would indicate the repository would not function as predicted or a condition that is substantially different from the information contained in the most

[1] Attachment MONPAR to Appendix MON in the CCA (DOE 1996) documents the analysis of monitoring parameters. The analysis was performed to fulfill 40 CFR § 194.42 requirements.

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recent compliance application. The DOE complies with these EPA requirements by conducting annual assessments of COMPs that monitor the predicted performance of the repository and reporting any condition adverse to the long-term containment performance. This compliance monitoring program is described in greater detail in DOE's *Compliance Monitoring Implementation Plan for 40 CFR §191.14(b), Assurance Requirements* (DOE 2014a)

This 2018 COMPs assessment presents the results and recommendations based on the COMP monitoring data gathered during the most recent annual reporting cycle. This assessment concludes that monitoring results are within expectations and no additional activities are warranted at this time.

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1 Introduction

The WIPP is governed by the EPA's long-term radioactive waste disposal regulations at 40 CFR Part 191 Subparts B and C (EPA 1993) and the WIPP-specific certification criteria at 40 CFR Part 194 (EPA 1996). Monitoring WIPP performance is an "assurance requirement" of these regulations and is intended to provide additional confidence that the WIPP will protect the public and environment (see 40 CFR § 191.14). In the WIPP Compliance Certification Application (CCA; DOE 1996), the DOE made commitments to conduct a number of monitoring activities to comply with the criteria at 40 CFR § 194.42 and to ensure that deviations from the expected long-term performance of the repository are identified at the earliest possible time. These DOE commitments are represented by 10 COMPs, which are listed in Section 2.

The COMPs are an integral part of the overall WIPP monitoring strategy. The DOE's *Compliance Monitoring Implementation Plan for 40 CFR §191.14(b), Assurance Requirements* (MIP; DOE 2014a) describes the overall monitoring program and responsibilities for COMPs derivation and assessment. This report documents the results of the reporting year 2018 COMPs assessment (for most COMPs data, between July 1st 2017 to June 30th 2018). This period matches the reporting period of the annual report that addresses 40 CFR § 194.4(b)(4) requirements (EPA 1996). This COMPs assessment follows the program developed under the original certification baseline using data and PA results from the current certified baseline, the 2014 Compliance Recertification Application Performance Assessment (CRA-2014 PA).

On February 5th of 2014 a fire occurred in the WIPP underground. Nine days later, an unrelated radiological release in the underground occurred (DOE 2014b and c, DOE 2015). Because of these events, waste emplacement ceased and access to the WIPP underground was restricted for a significant period of time. As such, many underground monitoring activities were not performed and data collection for the geotechnical COMPs were affected. This situation continues to impact the assessment of the geotechnical COMPs. This report identifies the impacts on the monitoring programs that generate data for the COMPs that were affected by the February 2014 events. Waste emplacement resumed in January of 2017 such that waste has been emplaced during this reporting period.

1.1 Monitoring and Evaluation Strategy

The Compliance Monitoring Program is an integrated effort between the Management and Operating Contractor (M&OC), the Scientific Advisor and the DOE Carlsbad Field Office (CBFO). The CBFO oversees and directs the monitoring program to ensure compliance with the EPA monitoring and reporting requirements. The Scientific Advisor (currently SNL) is responsible for annually assessing COMPs and the development and maintenance of the trigger values (TVs). An observation beyond the acceptable range of TVs represents a condition that requires further actions but does not necessarily indicate an out-of-compliance condition. This approach assures that conditions that are not consistent with expected repository performance are recognized as early as possible. These conditions may include data inconsistent with parameters, modeling assumptions or conceptual models implemented within PA, or conditions inconsistent with assumptions and arguments used in the screening of Features, Events and Processes (FEPs) for PA.

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1.2 Reporting Cycle

The types of changes that must be reported to EPA are defined in 40 CFR §194.4. Under 40 CFR § 194.4, changes that differ from the activities or conditions outlined in the latest compliance application are defined as either significant or non-significant based on their potential impact on the compliance baseline and potential impact on containment performance. This part of the rule also identified the timeframe to which the DOE is required to report significant and non-significant changes to the EPA. As such, the CCA states (Section 7.2.1) and subsequent recertification applications state that the results of the monitoring program will be submitted annually (DOE 2014d). Additionally, the recertification requirements at 40 CFR §194.15(a)(2) also require inclusion of all additional monitoring data, analysis and results in the DOE's documentation of continued compliance as submitted in periodic Compliance Recertification Applications (CRAs). Monitoring data, the associated parameter values and monitoring information must be reported even if the assessment concludes there is no impact on the repository. The annual monitoring data will be compiled and provided to the DOE to fulfill DOE's monitoring reporting requirements to the EPA. The Scientific Advisor's role in the annual reporting task is to use the monitoring data to derive the COMPs (as necessary), compare the results to repository performance expectations in PA (annually), and to use the new and updated information to make any recommendations for modification to the Compliance Baseline, if merited.

2 Assessment of COMPs

The compliance monitoring program tracks the following 10 COMPs:

1. Probability of Encountering a Castile Brine Reservoir
2. Drilling Rate
3. Subsidence
4. Creep Closure
5. Extent of Deformation
6. Initiation of Brittle Deformation
7. Displacement of Deformation Features
8. Changes in Culebra Groundwater Flow
9. Change in Culebra Groundwater Composition
10. Waste Activity

A periodic review of these COMPs is necessary to meet the intent of 40 CFR §191.14 assurance requirements, which states:

> "(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."

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This section summarizes the results of the 2018 assessment. In the following sections, each COMP is evaluated and compared to the applicable TV. This assessment is performed under Specific Procedure SP 9-8 (SNL 2017). A table for each of the 10 COMPs is used to summarize the evaluation and shows the COMP derivation, related PA parameters and FEPs, the current value for the COMPs as applicable and the TV.

2.1 Human Activities COMPs

The CCA identifies 10 COMPs that the DOE is required to monitor and assess during the WIPP operational period. Two of these parameters monitor "Human Activities" in the WIPP vicinity which include:

- Probability of Encountering a Castile Brine Reservoir
- Drilling Rate

2.1.1 Probability of Encountering a Castile Brine Reservoir

Table 2.1 summarizes data and TV information related to the COMP Probability of Encountering a Castile Brine Reservoir, as well as its implementation in PA. Monitoring activities for Castile brine encounters have identified no brine encounters during this reporting period. The total number of encounters identified since the CCA is 7. These encounters are detailed in Table 2.2. Data used for the CCA were compiled from drilling record searches for the region surrounding the WIPP up to 1995. The results of this initial search recorded 27 drilling encounters with pressurized brine (water) in the Castile Formation. Of these encounters, 25 were hydrocarbon wells scattered over a wide area in the vicinity of the WIPP site; 2 wells, ERDA 6 and WIPP 12, were drilled in support of the WIPP site characterization effort (see DOE 2018a, for a complete listing of brine encounters). The Delaware Basin Drilling Surveillance Program reviews the well files of all new wells drilled in the New Mexico portion of the Delaware Basin each year looking for encounters with pressurized Castile brine. Since the CCA, data have been compiled through August 2017. During this reporting period, no pressurized Castile brine encounters have been reported in the official drilling records for wells drilled in the New Mexico portion of the Delaware Basin (DOE 2018a).

Of the 7 Castile brine encounters recorded since the 1996 CCA, 6 were identified when WIPP Site personnel performing field work talked to area drillers. These encounters were inconsequential to the drilling process. The other encounter was reported by an operator in an annual survey of area drillers. All the new encounters are located in areas where Castile brine is expected to be encountered during the drilling process. Table 2.2 shows all known Castile brine encounters in the vicinity of the WIPP Site since the CCA.

The impacts of brine encounters are modeled in the PA. The CCA used a 0.08 probability of encountering a Castile brine reservoir. In the Performance Assessment Verification Test (PAVT), the EPA mandated a probability range of 0.01 to 0.60 (uniform distribution). The mean of this parameter is approximately 0.30. This value is significantly more than the 0.08 originally used in the CCA which was based on a geostatistical analysis of actual brine encounters. Results

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of more than 10 years of monitoring drilling encounters have shown that it is unlikely that further monitoring will show a probability near 0.30. The EPA also determined in their first certification sensitivity analysis that this parameter (PBRINE) does not have a significant impact on PA results (EPA 1998b).

Recently, the CRA-2014 recertification application the DOE included a revision to the PBRINE PA parameter based on new drilling data and a statistical analysis. EPA questioned the justification for this parameter distribution during their review of the CRA-2014 and developed their own parameter distribution (EPA 2017a). In the Federal Register Notice outlining their recertification decision (EPA 2017b), the EPA stated that they expect their cumulative distribution function (CDF) for PBRINE to be used as the baseline in future PAs. The EPA CDF equivalent mean is 0.26 or approximately the same as the PAVT parameter (Zietler 2018).

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Table 2.1 Probability of Encountering a Brine Reservoir - 2018:

Trigger Value Derivation				
COMP Title:	Probability of Encountering a Castile Brine Reservoir			
COMP Units:	Unitless			
Related Monitoring Data				
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value	
DBMP(1)	NA	Driller's survey – Field observations	0.06 to 0.19 (normal distribution)(DOE 2014d)	
COMP Assessment Process				
Analysis of encounters of pressurized brine recorded and reported by industry in the 9-township area centered on WIPP.				
Year 2018 COMP Assessment Value - Reporting Period September 2017 to August 2018				
No new data reported in State record during the reporting period; no new report from Field Observations. 34 Total Brine Encounters out of 678 boreholes drilled within the monitored area 27 CCA total occurrences before 1996 0 State Record occurrences since 1996 7 Site Personnel/ Drillers Survey occurrences since 1996				
Related Performance and Compliance Elements				
Element Title	Parameter Type & ID or Model Description	Derivation Procedure	Compliance Baseline	Impact of Change
Probability of Encountering Brine	Parameter PRBRINE	Statistical analysis of drilling data outlined in Kirchner, Zeitler and Kirkes 2012.	6.36E-02 to 1.90E-01Mean 1.27E-01 (Kirchner, Zeitler and Kirkes 2012)	Not a sensitive parameter.
Monitoring Data Trigger Values				
Monitoring Parameter ID	Trigger Value	Basis		
Probability of Encountering a Castile Brine Reservoir	None	After the DOE proposed the brine reservoir probability as potentially significant in the CCA Appendix MONPAR, the EPA conducted analyses that indicate a lack of significant effects on performance from changes in this parameter. For this reason and since the parameter is evaluated for significant changes at least once annually, no TV is needed.		

(1) Delaware Basin Monitoring Program

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Table 2.2. Well Locations Encountering Brine since the CCA[3].

Number	Location	Well Name and Location	Spud Date	Well Information
1	T21S-R31E-Sec 35	Lost Tank "35" - State #4	09/11/2000	Oil Well: Estimated several hundred barrels per hour. Continued drilling.
2	T21S-R31E-Sec 35	Lost Tank "35" - State #16	02/06/2002	Oil Well: At 2,705 ft, encountered 1,000 barrels per hour. Shut-in to get room in reserve pit with pressure of 180 psi. and water flow of 450 barrels per hour. Two days later, no water flow/full returns.
3	T22S-R31E-Sec 2	Graham "AKB" State #8	04/12/2002	Oil Well: Estimated 105 barrels per hour. Continued drilling.
4	T23S-R30E-Sec 1	James Ranch Unit #63	12/23/1999	Oil Well: Sulfur water encountered at 2,900 ft. 35 ppm H_2S was reported but quickly dissipated to 3 ppm in a matter of minutes. Continued drilling.
5	T23S-R30E-Sec 1	Hudson "1" - Federal #7	01/06/2001	Oil Well: Estimated initial flow at 400 to 500 barrels per hour with a total volume of 600 to 800 barrels. Continued drilling.
6	T22S-R30E-Sec 13	Apache "13" - Federal #3	11/26/2003	Oil Well: Encountered strong water flow with blowing gas at 2,850-3,315 ft. 362 ppm H_2S was reported. Continued drilling.
7	T21S-R31E-Sec 34	Jaque "AQJ" - State #7	03/04/2005	Oil Well: Encountered 104 barrels per hour at 2,900 ft. No impact on drilling process.

[3] From DOE 2017a, Table 7

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2.1.2 Drilling Rate

Table 2.3 summarizes data and TV information related to the COMP Drilling Rate parameter and its implementation in PA. The drilling rate COMP tracks deep drilling (> 2,150 ft in depth) activities relating to resource exploration and extraction. Boreholes relating to resources include potash and sulfur core-holes, hydrocarbon exploration wells, saltwater disposal wells and water wells drilled in the Delaware Basin. The first drilling rate, reported in the CCA, was determined using guidance provided in 40 CFR Part 194.33. The drilling rate formula is as follows:

$$D_r = (D_{100} \times 1{,}000 \text{ yrs}) \div A_{DB} \quad (1)$$

where

D_r = Drilling Rate (boreholes per km^2 per 10,000 yrs)
D_{100} = Deep boreholes greater than 2,150 ft depth drilled over the last 100 yrs
A_{DB} = Area of the Delaware Basin (23,102 km^2)

The rate reported in the CCA using this equation was 46.8 boreholes per square kilometer over 10,000 years. Including the time period after the CCA (June 1996 to August 2018) increases the rate to 99.0 boreholes per square kilometer per 10,000 years (DOE 2018a).

As shown in Table 2.4, the drilling rate has risen from 46.8 holes per square kilometer to 99.0 boreholes per square kilometer since 1996. As a result of continuing analysis and monitoring, the TV for this COMP was removed (Wagner and Thomas 2016). No additional actions are recommended at this time.

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Table 2.3. Drilling Rate - 2018:

COMP Title:	Drilling Rate			
COMP Units:	Deep boreholes (i.e., > 2,150 ft deep)/square kilometer/10,000 years			
Related Monitoring Data				
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)		
DBMP	Deep hydrocarbon boreholes drilled	Integer per year		
COMP Assessment Process				
(Total number of deep boreholes drilled/number of years of observations (100)) x (10,000/23,102) [i.e., over 10,000 years divided by the area of the Delaware Basin in square kilometers]				
Year 2018 COMP Assessment Value - Reporting Period September 1, 2017 to August 31, 2018				
(21,582 boreholes on record for the Delaware Basin) Drilling Rate = 99.0 boreholes per square kilometer per 10,000 yrs.				
Related Performance and Compliance Elements				
Element Title	Parameter Type & ID or Model Description	Derivation Procedure	Compliance Baseline	Impact of Change
Drilling rate	Parameter LAMBDAD	COMP/10,000 years	6.73 E-03 per square kilometer per year (CRA-2014 value; DOE 2014d)	Cuttings/cavings releases increase proportionally with the drilling rate. Doubling CRA drilling rate does not exceed compliance limit.
Monitoring Data Trigger Values				
Monitoring Parameter ID	Trigger Value	Basis		
Deep boreholes	None	Revision 2 of the TV Derivation Report (Wagner and Thomas 2016).		

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Table 2.4. Drilling Rates for Each Year since the CCA.

Year	Number of Boreholes Deeper than 2,150 ft	Drilling Rate (boreholes per square kilometer per 10,000 years)
1996 (CCA Value)	10,804	46.8
1997	11,444	49.5
1998	11,616	50.3
1999	11,684	50.6
2000	11,828	51.2
2001	12,056	52.2
2002[4]	12,219	52.9
2002 (revised)	12,139	52.5
2003	12,316	53.3
2004	12,531	54.2
2005	12,819	55.5
2006	13,171	57.0
2007	13,520	58.5
2008	13,824	59.8
2009	14,173	61.3
2010	14,403	62.3
2011	14,816	64.1
2012	15,558	67.3
2013	16,633	72.0
2014	17,937	77.6
2015	19,313	83.6
2016	20,423	88.4
2017	21,582	93.4
2018	22,886	99.0

2.2 Geotechnical COMPs

The CCA lists ten monitoring parameters that the DOE is required to monitor and assess during the WIPP operational period. Five of these parameters are considered "geotechnical" in nature and include:

- Creep Closure
- Extent of Deformation
- Initiation of Brittle Deformation

[4] In Revision 3 of Delaware Basin Monitoring Annual Report (dated 2002), the drilling rate for 2002 was shown as 52.9, with 12,219 deep boreholes. It was later noted that 80 shallow wells in Texas were listed as being deep. Correcting the classification of the 80 boreholes resulted in a reduction of the drilling rate from 53.9 to 52.5 (DOE 2018a).

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- Displacement of Deformation Features
- Subsidence

Data needed to derive and evaluate the geotechnical COMPs are available from the most recent annual Geotechnical Analysis Report (GAR; DOE 2018b) and the annual Subsidence Monument Leveling Survey (DOE 2017). Three of the geotechnical parameters lend themselves to quantification: creep closure, displacement of deformation features, and subsidence. In contrast, the extent of deformation and initiation of brittle deformation are qualitative or observational parameters.

The WIPP GARs have been available since 1983 and are currently prepared by the M&OC on an annual basis. The purpose of the GAR is to present and interpret geotechnical data from the underground excavations. These data are obtained as part of a regular monitoring program and are used to characterize current conditions, to compare actual performance to the design assumptions, and to evaluate and forecast the performance of the underground excavations during operations. Additionally, the GAR fulfills various regulatory requirements and through the monitoring program, provides early detection of conditions that could affect operational safety, data to evaluate disposal room closure, and guidance for design changes. Data are presented for specific areas of the facilities including: (1) Shafts and Keys, (2) Shaft Stations, (3) Northern Experimental Area, (4) Access Drifts, and (5) Waste Disposal Areas. Data are acquired using a variety of instruments including convergence points and meters, multipoint borehole extensometers, rock bolt load cells, pressure cells, strain gauges, piezometers and joint meters. All of the geotechnical COMPs involve analyses of deformations/displacements, so the most pertinent data derived from the GAR are convergence and extensometer data. The most recent GAR (DOE 2018b) summarizes data collected from September through October of 2017.

Subsidence monitoring survey reports are also prepared by the M&OC on an annual basis and present the results of leveling surveys performed in 2016 for nine vertical control loops comprising approximately 15 linear miles traversed over the ground surface of the WIPP site. Elevations are determined for 48 current monuments and 14 National Geodetic Survey vertical control points using digital leveling techniques to achieve Second-Order Class II loop closures or better. The data are used to estimate total subsidence and subsidence rates in fulfillment of regulatory requirements. The most recent survey (DOE 2017) summarizes data collected between September and October of 2017.

Comparisons between available geotechnical COMP related data and the TVs allow evaluation of the most recent geotechnical observations for the COMPs program. The cited reports and programs provide a good evaluation of all observations where deviations from historical normal occurrences are recorded. This process, as engaged for COMPs assessments, not only focuses attention on monitored parameters, it allows for reassessment of the proposed TVs. Notable deviations are addressed in the GAR and other references, and are reexamined here in the context of COMPs and TVs.

Geotechnical COMPs can be derived from or related to the repository's operational safety monitoring program, which has been implemented to ensure worker and mine safety. By nature, changes in geotechnical conditions evolve slowly; however, they are monitored continuously and

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reported annually. Since pertinent data from the underground reflect slowly evolving conditions, relationships that correlate to geotechnical COMPs also evolve slowly. Therefore, geotechnical conditions warranting action for operational safety will become evident before such conditions would impact long-term waste isolation. Monitoring underground response allows continuing assessment of conceptual geotechnical models supporting certification. In effect, these annual comparisons of actual geotechnical response with expected response serve to validate or improve models.

The GAR reporting period is from July 1, 2016 to June 30, 2017 which is one year earlier than most of the other COMPs reporting periods.

2.2.1 Creep Closure

Table 2.5 summarizes data and TV information related to the COMP parameter Creep Closure, and its implementation in PA. The GAR compiles all geotechnical operational safety data gathered from the underground. The most readily quantifiable geomechanical response in the WIPP underground is creep closure. The GAR routinely measures and reports creep deformation, either from rib-to-rib, roof-to-floor, or extensometer borehole measurements. With the exception of newly mined openings, rates of closure are relatively constant within each zone of interest and usually range from about 1-5 cm/yr. A closure rate in terms of cm/yr can be expressed as a global or nominal creep rate by dividing the displacement by the room dimension and converting time into seconds. Nominally these rates are of the order of 1×10^{-10}/s and are quite steady over significant periods. From experience, increases and decreases of rates such as these might vary by 20 percent without undue concern. Therefore, the "trigger value" for creep deformation was set as one order of magnitude increase in creep rate.

Extensive GAR data suggest that a possible TV could be derived from creep rate changes. The WIPP underground is very stable, relative to most operating production mines, and deformation is steady for long periods. However, under certain conditions creep rates accelerate, indicating a change in the deformational processes. The coalescence of microfractures into an arch-shaped fracture (or macrofracture) that extends into (or intersects) an overlying clay seam might create the onset of the roof beam de-coupling and increase the measured closure rate. Phenomena of fracture coalescence and damaged rock zone (DRZ) growth comprise important elements of PA assumption confirmation. Therefore, a measured creep rate change over a yearly period constitutes the COMP TV for creep closure. Rate changes are necessarily evaluated on a case-by-case basis since closure is related to many factors such as age of the opening, location in the room or drift, convergence history, recent excavations, and geometry of the excavations.

The creep deformation COMP is addressed by examining the deformations measured in specific regions of the underground including: (1) Shafts and Shaft Stations and (2) Access Drifts and Waste Disposal Areas. Figure 2.1 shows the current configuration of the WIPP underground with specific elements and regions annotated for reference. Information used for all geotechnical COMPs is derived from the GAR which has a reporting period ending June 30, 2016. For this reporting period, Panels 1 through 7 had been fully excavated and Panel 8 mining was partially mined. Figure 2.1 shows all areas mined as of June 30, 2017. At that time, CH waste had progressed to Panel 7, Room 7 and RH waste had been emplaced in Panel 7, Room 6. In Panels

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1 through 6, waste disposal operations had ceased, and the entry drifts had closures/barriers installed to prevent access. Waste emplacement restarted during the reporting period of the GAR (ending June 30, 2017). A total of 228 m^3 of CH was emplaced in the repository after the restart. No RH was emplaced.

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Table 2.5 Creep Closure - 2018:

COMP Title:	Creep Closure			
COMP Units:	Closure Rate (s^{-1})			
Related Monitoring Data				
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value	
Geotechnical	Closure	Instrumentation located throughout the underground.	Multi-mechanism deformation creep model developed by Munson and Dawson	
COMP Assessment Process - Reporting Period July 2016 through June 2017				
Evaluate GAR for centerline closure rates, compare to previous year's rate. Account for drift dimensions and convert to creep rate. If closure rate increases by greater than one order of magnitude, initiate technical review.				
Related Performance and Compliance Elements				
Element Title	Parameter Type & ID or Model Description	Derivation Procedure	Compliance Baseline	Impact of Change
Repository Fluid Flow	Creep Closure	Porosity Surface, waste compaction, characteristics, waste properties, evolution of underground setting	SANTOS, porosity surface calculations	Provides validation of the creep closure model.
Monitoring Data Trigger Values				
Monitoring Parameter ID	Trigger Value	Basis		
Creep Closure	Greater than one order of magnitude increase in closure rate.	The closure rate increase signals potential de-coupling of rock.		

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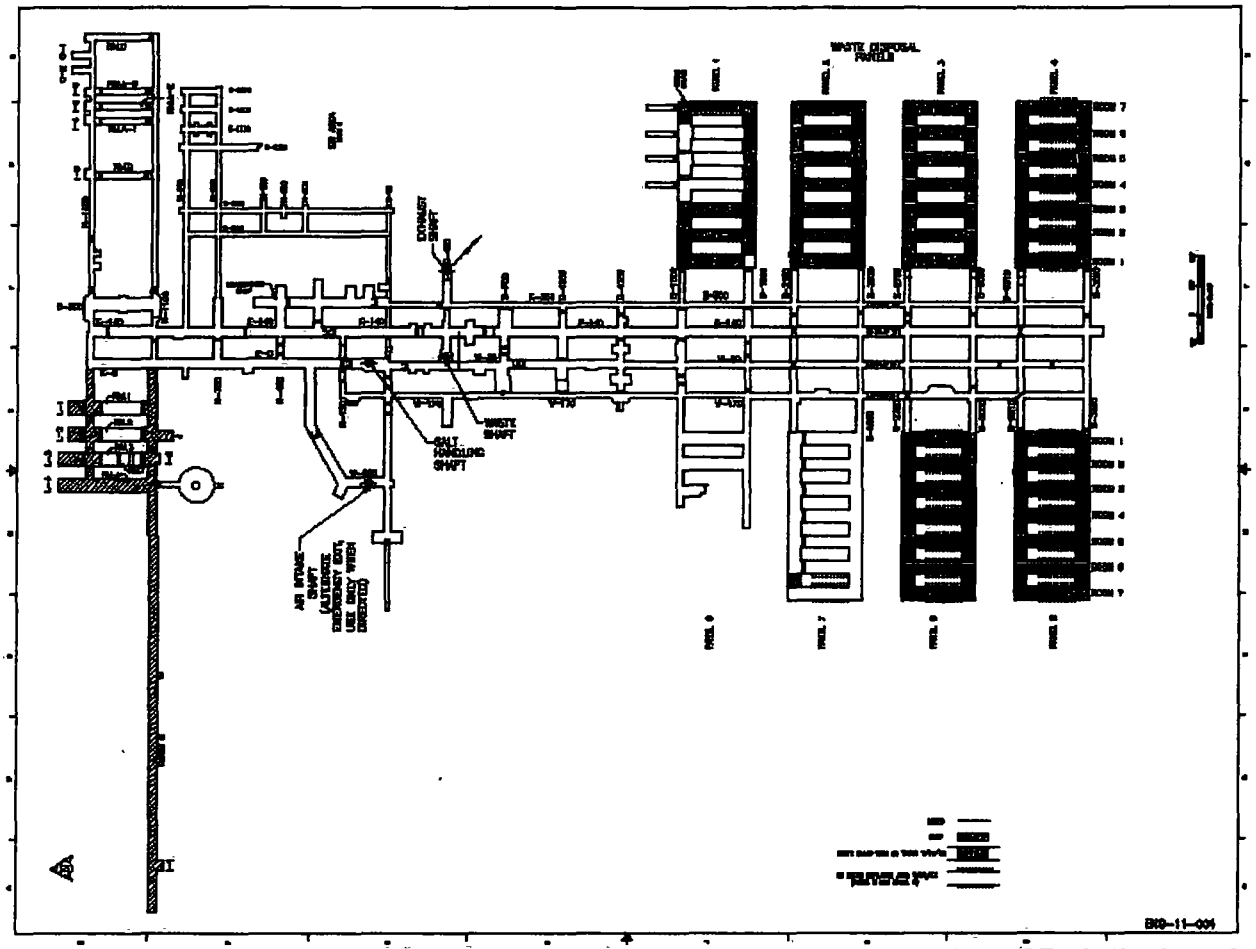


Figure 2.1. Configuration of the WIPP Underground for Geotechnical COMPs (after DOE 2018b; through June 30, 2017).

Shafts and Shaft Stations

The WIPP underground is serviced by four vertical shafts including the following: (1) Salt Handling Shaft, (2) Waste Shaft, (3) Exhaust Shaft, and (4) Air Intake Shaft. At the repository level (approximately 2,150 ft below ground surface), enlarged rooms have been excavated around the Salt Handling and Waste Shafts to allow for movement of equipment, personnel, mined salt and waste into or out of the facility. The enlarged rooms are called shaft stations and assigned designations consistent with the shaft they service (e.g., Salt Handling Shaft Station).

Shafts. Except for the Salt Handling Shaft, the shafts are configured nearly identically. From the ground surface to the top of the Salado Formation, the shafts are lined with un-reinforced concrete. Reinforced concrete keys are cast at the Salado/Rustler interface with the shafts extending through the keys to the Salado. Below the keys, the shafts are essentially "open holes" through the Salado Formation and terminate either at the repository horizon or at sumps that extend approximately 40 m below the repository horizon. In the Salt Handling Shaft, a steel liner is grouted in place from the ground surface to the top of the Salado. Similar to the three other shafts, the Salt Handling Shaft is configured with a reinforced concrete key and is "open-hole" to its terminus. For safety purposes, the portions of the open shafts that extend through the Salado are typically supported using wire mesh anchored with rock bolts to contain rock

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fragments that may become detached from the shaft walls. Within the Salado Formation, the shaft diameters range from 3.65 m to 7.0 m.

Data available for assessing creep deformations in the salt surrounding the shafts are derived exclusively from routine inspections and extensometers extending radially from the shaft walls. These data are reported annually in the GAR. Piezometers and earth pressure cells were also installed in the shafts during construction to monitor fluid pressure behind the shaft liners and key sections. The Salt Handling Shaft, Waste Shaft, and Air Intake Shaft are inspected weekly by underground operations personnel. Although the primary purpose of these inspections is to assess the conditions of the hoisting and mechanical equipment, observations are also made to determine the condition of the shaft walls, particularly with respect to water seepage, loose rock, and sloughing. In contrast to the other three shafts, the Exhaust Shaft is inspected quarterly using remote-controlled video equipment. These inspections have focused on salt build-up in the Exhaust Shaft and the impacts this build-up has on cabling and (currently not in use) air and water lines in the shaft. Based on these visual observations, all four shafts are in satisfactory condition and have required only routine ground-control activities during this reporting period.

Shortly after its construction, each shaft was instrumented with extensometers to measure the inward movement of the salt at three levels within the Salado Formation. In addition to COMPs assessment, measurements of shaft closure are used periodically as a calibration of numerical models and have been used in shaft seal system design. The approximate depths corresponding to the three instrumented levels are 330 m, 480 m and 630 m. Three extensometers are emplaced at each level to form an array. The extensometers comprising each array extend radially outward from the shaft walls and are equally spaced around the perimeter of the shaft wall. Over the years, most of these extensometers have malfunctioned. As a result, reliable data are not available at some locations. The DOE currently has no plans to replace failed instrumentation installed in any of the shafts because monitoring data acquired to date have shown no unusual shaft movements or displacements.

Shaft Station. Shaft station openings are typically rectangular in cross-section with heights ranging from approximately 4 to 6 m and widths ranging from 6 to 10 m. Over the life-time of the individual shaft stations, modifications have been made that have altered the dimensions of the openings. In the past, portions of the Salt Handling Shaft Station have been enlarged by removing the roof beam that extended up to anhydrite "b". In the Waste Handling Shaft Station, the walls have been trimmed to enlarge the openings for operational purposes. No major modifications were performed at the shaft stations during this reporting period. Ground control, bolt replacement, bolt trimming and cable shoe anchor replacement were performed as routine maintenance.

The effects of creep on the shaft stations are assessed through visual observations and displacement measurements made using extensometers and convergence points. Because of the modifications made over the years, many of the original instrumentation has been removed or relocated. In addition, some instruments have malfunctioned or have been damaged and no longer provide reliable data. Displacement rates from existing and functional instrumentation listed in the GAR for the current reporting period (2016-2017) and the previous reporting period (2015-2016) are summarized in Table 2.6. Most of the measurements are for vertical closure.

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Based on shaft station convergence data, the current vertical displacement rates range from 0.2 to 1.7 in/yr (0.51 to 4.32 cm/yr). Dividing convergence rates by the average room dimension (approximately 6 meters) and expressing the results in units of 1/s yields vertical creep rates between approximately 2.68×10^{-11}/s to 2.28×10^{-10}/s. An examination of the percentage changes in displacement rates shown in Table 2.6. Based on the extensometer and convergence data, as well as the limited maintenance required in the shaft stations during the last year, creep deformations associated with the WIPP shaft stations are considered acceptable and meet the TV requiring creep deformation rates to change by less than one order of magnitude in a one-year period.

Table 2.6. Summary of Closure Rates for WIPP Shafts and Shaft Stations.

Location	Inst. Type[a]	Displacement Rate (in/yr)		Change In Rate (%)
		2015–2016	2016-2017	
Salt Handling Shaft Station				
E0 Drift – S18 (A-E)	CP	2.6	0.9	-65
E0 Drift – S18 (B-D)	CP	2.7	1.1	-59
E0 Drift – S18 (F-H)	CP	2.1	0.8	-62
E0 Drift – S30 (A-C)	CP	2.6	1.7	-35
E0 Drift – S65 (A-C)	CP	2.3	1.1	-52
Waste Shaft Station[b]				
S400 Drift – W30 (Vert. CL)	Ext	0.0	N/A[d]	N/A[d]
S400 Drift – E32 (Vert CL)	Ext	0.30	N/A[d]	N/A[d]
S400 – E32 (Horizontal)	CP	N/A[d]	N/A[d]	N/A[d]
S400 – E85 (Horizontal)	CP	N/A[d]	N/A[d]	N/A[d]
Air Intake Shaft Station[b]				
S65 Drift – W620 (Vert CL)	Ext	0.20	0.20	0[c]
N95 Drift – W620 (Vert CL)	Ext	0.20	0.30	50[c]

(a) Instrument Type: Ext = extensometer; CP = convergence point.
(b) CL = Centerline
(c) Anchor at maximum range
(d) Not monitored during this reporting cycle

Access Drifts and Waste Disposal Area

Access Drifts. The access drifts are comprised of four north-south drifts extending southward from near the Salt Handling Shaft to the entries into the waste disposal panels and have several short cross-drifts intersecting these major drifts. The access drifts are typically rectangular in cross-section with heights ranging from 4.0 m to 6.4 m and widths ranging from 4.3 m to 9.2 m.

Minimal waste emplacement occurred during the current reporting period for the GAR (July 2016 to June 2017), the last waste disposal was in Room 5 of Panel 7. Waste emplacement restarted in April of 2017. Mining of Panel 8 started in September of 2013. Mining was

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interrupted by the two February 2014 underground events. No additional mining occurred during this reporting period.

Panels 3 and 4 were excavated at a slightly higher stratigraphic position (2.4 m) than either Panels 1 or 2. The roof of these panels coincides with Clay G. As such, Panels 1, 2, 7 and 8 will be at the original horizon and Panels 3, 4, 5 and 6 approximately 2.4 m higher in elevation (roof at Clay G). Trimming, scaling, floor-milling and rock-bolting operations were performed as necessary during the reporting period. To provide a more stable floor over the expected lifetime of Panel 7, a wide channel was excavated in the floor of the panel to remove stiff bedded polyhalite and a hard anhydride bed. These stiffer beds would resist the lateral stress caused by creep and bow upward into the mined opening. The floor was backfilled with run-of-mine salt to the original floor height.

Assessment of creep deformations in the access drifts is made through the examination of extensometer and convergence point data reported annually in the GAR. Table 2.7 summarizes the vertical and horizontal displacement data reported in the most recent GAR (DOE 2018b). There were few vertical displacement and no horizontal displacement data reported in last year's GAR. Table 2.7 examines percentage changes between displacement rates measured during the current and previous annual reporting periods and breaks these percentage changes into ranges (e.g., <0% which includes negative values, 0 to 25%, 25 to 50%, etc.). The numbers shown in the tables represent the number of instrumented locations located on the drift vertically or horizontally that fall within the range of the indicated percentage change. In general, convergence rate accelerations continue to be minor in most locations. Most of the rate changes for the 2017 COMPs data were low or near zero. For this 2018 COMPs report, most of the data are still in the lower two ranges. As was done since the 2014 COMPs report, the convergence data and extensometer data were combined. The maximum displacement rates corresponding to these data for the current reporting period are given below:

Maximum Vertical Displacement Rates along Access Drifts:

15.0 cm/yr

Maximum Horizontal Displacement Rates along Access Drifts:

7.0 cm/yr

Using a typical average drift dimension of 5 m and the maximum displacement rates shown above, the inferred maximum vertical creep rate is approximately 9.47×10^{-10}/s. This rate is based on the maximum displacement which is not representative of the behavior of the system. This rate is more than last year's rate of 4.42×10^{-10}/s.

Creep deformations associated with the Access Drifts are acceptable and meet the TV requiring creep deformation rates to change by less than one order of magnitude in a one-year period. High displacement rates observed at a few locations have little effect on safety as geotechnical engineering provides continuous ground-control monitoring and remediation on an as-needed basis.

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Waste Disposal Area: The Waste Disposal Area is located at the extreme southern end of the WIPP facility and is serviced by the access drifts described above. Eventually, the Waste Disposal Area will include eight disposal panels, each comprising seven rooms (the major north-south access drifts servicing the eight panels may also be used for waste disposal and would make up the ninth and tenth panels). Panel 1 was constructed in the late 1980s, Panel 2 constructed during the 1999-2000 time period, Panel 3 constructed during the 2002-2004 time period and the completion of Panel 4 during 2006. Mining for Panel 5 was completed in February of 2008 and Panel 6 was completed in April of 2010. Mining of Panel 7 began April 24, 2010 and was completed in January of 2013 and Panel 8 has been partially excavated. Figure 2.1 shows the state of waste emplacement and mining for the GAR reporting period.

The waste emplacement rooms are rectangular in cross-section with a height of 4 m and a width of 10 m. Entry drifts that provide access into the disposal rooms are also rectangular; the exhaust entry to the panel has a height of 3.65 m and a width of 4.30 m while the air intake entry to the panel is 4.0 m by 6.0 m.

Table 2.7. Summary of Changes in Vertical and Horizontal Displacement Rates of the WIPP Access Drifts and Waste Disposal Area Openings.

Location	Number of Instrument Locations Where the Indicated Percentage Change has Occurred					
	Percentage Increase in Displacement Rate for Measurements Made During the 2015-2016 and 2016-2017 Reporting Periods					
	< 0%	0 – 25%	25 – 50%	50 – 75%	75 – 100%	100 – 200%
Access Drifts						
Vertical	110	102	5	0	3	2
Horizontal	18	3	0	0	0	0
Waste Disposal Area Panel 7						
Vertical	41	9	4	1	1	3

Assessment of creep deformation in the waste disposal area is made through the examination of extensometer and convergence point data reported annually in the GAR. Tables 2.6 and 2.7 (presented previously) summarize, respectively, the vertical and horizontal displacement data reported in the most recent GAR (DOE 2018b). Panels 1, through 5 were previously closed and are no longer accessible. Panel 5 was closed in July of 2011. No new convergence points were installed during this reporting period. Table 2.7 examines percentage changes between displacement rates measured during the current and previous reporting periods. In addition, extensometer data are based only on displacements of the collar relative to the deepest anchor. Since most control points are vertical for the panels, only the vertical displacement rate is calculated. For this year's report, only data from Panel 7 was monitored during this reporting cycle. The maximum displacement rate corresponding to these data are given below.

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Maximum Vertical Displacement Rates along Waste Disposal Area:

5.90 cm/yr

Using a nominal disposal-area-opening dimension of 8 m and the maximum displacement rates shown above, the inferred maximum creep rate is approximately 2.33×10^{-10}/s. This rate is less than last year's rate of 3.44×10^{-10}/s and is consistent with previous COMPs report rates. Maximum creep rates for the waste disposal areas are all associated with newer excavations. Due to the events of February 2014, new convergent point data has been limited. As such, displacement rates reported in this year's COMPs report may not be as representative of the conditions in the repository as has been reported previously. With less ground control activities being performed annually, it is likely that actual displacement rates have been greater than what is reported here.

2.2.2 Extent of Deformation

Table 2.8 summarizes the data and TV information relating to the COMP parameter Extent of Deformation, as well as its implementation in PA. The extent of brittle deformation can have important implications to PA. As modeled in PA, the DRZ releases brine to the disposal room while properties of the DRZ control hydrologic communication between disposal panels. Therefore, extent of deformation is related to a conceptual model used in performance determinations. If characteristics could be tracked from inception, the spatial and temporal evolution of the DRZ would provide a validation benchmark for damage calculations.

Measurements in the GAR include borehole inspections, fracture mapping and borehole logging. These observations are linked closely to other monitoring requirements concerned with initiation of brittle deformation and displacement of deformation features. A more in-depth discussion of the condition of the mined areas is found in the "Ground Control Annual Plan for the Waste Isolation Pilot Plant, (DOE 2016). This document discusses ground conditions and the operational monitoring program that is used to assess these conditions.

The Geotechnical Engineering Department at WIPP has developed a database that compiles back-fracturing data. The supporting data from past-year GARs contained isometric plots of fractures for active waste panels. Fracture development is most continuous parallel to the rooms and near the upper corners. These fractures are designated "low angle fractures" relative to the horizontal axis. The original excavation horizon results in a 2.4 m-thick beam of halite between the roof and Clay Seam G. Low-angle fractures arch over rooms and asymptotically connect with Clay Seam G. Although the preponderance of monitoring information derives from the roof (back), buckling extends into the floor to the base of Marker Bed 139, which is located about 2 m below the disposal room floors. Fracture mapping thus far is consistent with expectations and tracks stress trajectories derived from computational work. At this time, a comprehensive model and supporting data for model parameters for damage evolution has not been developed for PA.

Excavation of Panel 3 raises the waste disposal panels by 2.4 m such that the roof of the disposal rooms will be coincident with Clay Seam G and the floor will be an additional 2.4 m above Marker Bed 139. Additionally, part of the floor in Panel 7 was milled and backfilled with run-of-mine salt to replace the stiff bedded polyhalite and hard anhydride beds. These stiffer beds

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likely would resist the lateral stress caused by creep closure and bow upward into the mined opening. These changes will likely alter the typical fracture patterns observed to date and may cause subtle changes in how the DRZ develops. Effects of excavation to Clay Seam G have been evaluated by finite element analyses to assess possible impact to PA (Park and Holland 2003). Their modeling shows that the DRZ does not extend below MB139 at the new horizon, as it does at the original horizon. The rise in repository elevation otherwise causes no discernible change to the porosity surface used in PA. Data provided in past-year GARs suggest that brittle deformation extends at least 2.4 m (to Clay Seam G where present) and perhaps as much as 4.5 m (to Clay Seam H) above the roof of the WIPP openings. In addition, brittle deformation extends below the floor of the openings to at least the base of Marker Bed 139 (approximately 2 to 3 m).

The activities of the WIPP geoscience program were not performed during this reporting period due to logistical issues associated with the February 2014 incidents. As such there is no new data for this COMP. Fracture maps are not provided in the 2018 GAR (DOE 2018b) for comparison to maps in the previous year's report. Similarly, the previous year's GAR did not include fracture mapping.

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Table 2.8. Extent of Deformation - 2018:

COMP Title:	Extent of Deformation			
COMP Units:	Areal extent (length, direction)			
Related Monitoring Data				
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value	
Geotechnical	Displacement	Meters	Not Established	
COMP Assessment Process - Reporting Period July 2016 through June 2017				
Extent of deformation is deduced from visual inspections and fracture mapping which are examined yearly for active cross sections. Anomalous growth is determined by yearly comparison.				
Related Performance and Compliance Elements				
Element Title	Parameter Type & ID or Model Description	Derivation Procedure	Compliance Baseline	Impact of Change
DRZ Conceptual Model	Micro- and macro-fracturing in the Salado Formation	Constitutive model from laboratory and field databases.	Permeability of DRZ was originally assigned a constant value of 10^{-15} m^2 for the CCA; per EPA direction, a uniform distribution from 3.16 x 10^{-13} to 3.98 x 10^{-20} m^2 was used for all subsequent PAs	DRZ spatial and temporal properties have important PA implications for permeability to gas, brine, and two-phase flow.
Monitoring Data Trigger Values				
Monitoring Parameter ID	Trigger Value	Basis		
Fractures at depth	None	TV Derivation Report, Revision 2 (Wagner and Thomas 2016)		

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2.2.3 Initiation of Brittle Deformation

Table 2.9 summarizes data and TV information relating to the COMP parameter Initiation of Brittle Deformation, as well as its implementation in PA. Initiation of brittle deformation around WIPP openings is not directly measured and is therefore a qualitative observational parameter. By nature, qualitative COMPs can be subjective and are not prone to the development of well-defined TVs. In addition, this COMP is not directly related to a PA parameter. Brittle deformation eventually leads to features that are measured as part of geotechnical monitoring requirements, such as the extent and displacement of deformation features. Initiation of brittle deformation is expected to begin immediately upon creation of an opening. The ongoing geotechnical program will help quantify damage evolution around WIPP openings. Initiation, growth and extent of the DRZ are important considerations for the operational period panel closures as well as compliance PA calculations.

The activities of the WIPP geoscience program were limited during this reporting period due to logistical issues associated with the February 2014 incidents. As such there is limited new data for this COMP. Only borehole data in a small section of E-140 were monitored this reporting period. No issues were noted as part of this monitoring.

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Table 2.9. Initiation of Brittle Deformation - 2018:

COMP Title:	**Initiation of Brittle Deformation**			
COMP Units:	**Qualitative**			
Related Monitoring Data				
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value	
Geotechnical	Closure	Observational	Not Established	
COMP Assessment Process - Reporting Period July 2016 through June 2017				
Qualitative and pertinent to operational considerations. Captured qualitatively in association with other COMPs				
Performance and Compliance Elements				
Element Title	Parameter Type & ID or Model Description	Derivation Procedure	Compliance Baseline	Impact of Change
Not directly related to PA as currently measured	NA	NA	NA	NA
Monitoring Data Trigger Values				
Monitoring Parameter ID	Trigger Value	Basis		
Initiation of Brittle Deformation	None	Qualitative COMPs can be subjective and are not prone to the development of meaningful TVs.		

2.2.4 Displacement of Deformation Features

Table 2.10 summarizes data and TV information relating to the COMP parameter Displacement of Deformation Features, as well as its implementation in PA. The displacement of deformation features primarily focuses on those features located in the immediate vicinity of the underground openings. As discussed previously, fracture development is typically continuous sub-parallel to the surface of the openings and terminating near the corners. These fractures tend to propagate or migrate by arching over and under the openings and, thus are designated "low-angle fractures" relative to the horizontal axis. Typically, the fractures intersect or asymptotically approach lithologic units such as clay seams and anhydrite stringers. As a result, salt beams are formed. In the roof, the beams are de-coupled from the surrounding formation requiring use of ground support. In the floor, the beams sometimes buckle into the openings requiring floor milling and trimming. Lithologic units of primary interest are Clays G and H. These features are located approximately 2.4 m and 4.5 m respectively, above the roof of Panels 1, 2, 7 and 8. Marker Bed 139 (anhydrite) is located approximately 2 m below the floor of these panels. For Panels 3

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through 6, the panels are mined up to Clay G. Clay H is therefore located 2.1 m above the roof of these panels and Marker Bed 139 is located approximately 4.4 m below the panel floors.

Table 2.10. Displacement of Deformation Features - 2018:

COMP Title:	Displacement of Deformation Features			
COMP Units:	Length			
Related Monitoring Data				
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value	
Geotechnical	Delta D/D_o	Observational	Not established	
COMP Assessment Process - Reporting Period July 2016 through June 2017				
No data on observation boreholes is available for this reporting period.				
Related Performance and Compliance Elements				
Element Title	Parameter Type & ID or Model Description	Derivation Procedure	Compliance Baseline	Impact of Change
Not directly related to PA	N/A	N/A	N/A	N/A
Monitoring Data Trigger Values				
Monitoring Parameter ID	Trigger Value	Basis		
Borehole diameter closure	None	TV Derivation Report Revision 2 (Wagner and Thomas 2016)		

Monitoring of these deformation features is accomplished through visual inspection of observation boreholes (OBH) drilled from the openings through the feature of interest. In general, these boreholes are aligned vertically (normal to the roof and floor surfaces) because of the location and orientation of the fractures and lithological units of interest. All of the OBHs are 7.6 cm (3 in) in diameter, and many intersect more than one deformation feature. The ages of the OBHs vary from more than 20 years to recent.

The deformation features in OBHs are classified as: 1) offsets, 2) separations, 3) rough spots and 4) hang-ups. Of the four features, offsets are the principle metric for this COMP and are quantified by visually estimating the degree of borehole occlusion created by the offset. The direction of offset along displacement features is defined as the movement of the stratum nearer the observer relative to the stratum farther from the observer. Typically, the nearer stratum moves toward the center of the excavation. Based on previous observations in the underground, the magnitude of offset is usually greater in boreholes located near the ribs as compared to boreholes located along the centerline of openings.

Limited monitoring activities were performed during this reporting period due to logistical issues associated with the February 2014 incidents. There were tent OBHs monitored along an

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approximately 700 ft. section of the E-140 main drift during this reporting period. No offsets were found in these boreholes.

2.2.5 Subsidence

Table 2.11 summarizes data and TV information relating to the COMP parameter Subsidence, as well as its implementation in PA. Subsidence is currently monitored via elevation determination of 48 existing monuments and 14 of the National Geodetic Survey's vertical control points. Approximately 15 miles of leveling was performed in 2017 for 9 control loops (see Figure 2-2). To address EPA monitoring requirements, the most recent survey results (DOE 2017) are reviewed and compared to derived TVs. Because of the low extraction ratio and the relatively deep emplacement horizon (2,150 ft), subsidence over the WIPP is expected to be much lower and slower than over the local potash mines. Maximum observed subsidence over potash mines near the WIPP is 1.5 m, occurring over a time-period of months to a few years after initial mining. In contrast, calculations show that the maximum subsidence predicted directly above the WIPP waste emplacement panels is 0.62 m assuming emplacement of Contact Handled Transuranic (CH-TRU) waste and no backfill (Backfill Engineering Analysis Report [BEAR; WID 1994]). Further considerations, such as calculations of room closure, suggest that essentially all surface subsidence would occur during the first few centuries following construction of the WIPP, so the maximal vertical displacement rates would be approximately 0.002 m/yr (0.006 ft/yr). Obviously, these predicted rates could be higher or lower depending on mining activities as well as other factors such as time after mining. Because the vertical elevation changes are very small, survey accuracy, expressed as the vertical closure of an individual loop times the square root of the loop length, is of primary importance. For the current subsidence surveys, a Second-Order Class II loop closure accuracy of 0.033 ft $\times$ $\sqrt{}$mile or better was achieved in all cases. This year's measured accuracy ranged from <0.001 to 0.007 ft$\sqrt{}$mile (DOE 2017).

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Table 2.11. Subsidence - 2018:

COMP Title:	Subsidence		
COMP Units:	Change in surface elevation in meters per year		
Related Monitoring Data			
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value
Subsidence Monitoring Leveling Survey (SMP)	Elevation of 62 original monitoring monuments	Decimal (meters)	Not Established
SMP	Change in elevation over year	Decimal (meters)	Not Established
COMP Assessment Process – 2018; Data acquired between September through October of 2017			
Survey data from annual WIPP Subsidence Monument Leveling are evaluated. Elevations of 48 monitoring monuments in nine loops are compared to determine changes.			

Related Performance and Compliance Elements				
Element Title	Parameter Type & ID or Model Description	Derivation Procedure	Compliance Baseline	Impact of Change
Subsidence	FEP [W-23]	Predictions are of low consequence to the calculated performance of the disposal system – based on WID (1994) analysis and EPA treatment of mining.	Maximum total subsidence of 0.62 m (2.0 ft) above the WIPP.	Predicted subsidence will not exceed existing surface relief of 3 m – i.e., it will not affect drainage. Predicted subsidence may cause an order of magnitude rise in Culebra hydraulic conductivity (CRA-2009 Appendix PA, Attachment SCR, Section SCR-6.3.1.4) – this is within the range of hydraulic conductivity modeled in PA. Predicted WIPP subsidence is below that predicted for the effects of potash mining (0.62 m vs.1.5 m; DOE 2009).

Monitoring Data Trigger Values		
Monitoring Parameter ID	Trigger Value	Basis
Change in elevation per year	1.0×10^{-2} m (3.25×10^{-3} ft) per year subsidence	Based on the most conservative prediction by analyses referenced in the CCA.

Several monuments have also been included in various annual surveys but were not included in the current surveys because the monuments no longer exist or have been physically disturbed. Table 2.12 lists these monuments. Historically, the surveys were conducted by private

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companies under subcontract to DOE; however, since 1993, the WIPP M&OC has conducted the surveys using a set of standardized methods. Starting with the 2002 survey, the M&OC has been following WIPP procedure WP 09-ES4001 (NWP 2016).

Table 2.12. Monuments No Longer Surveyed

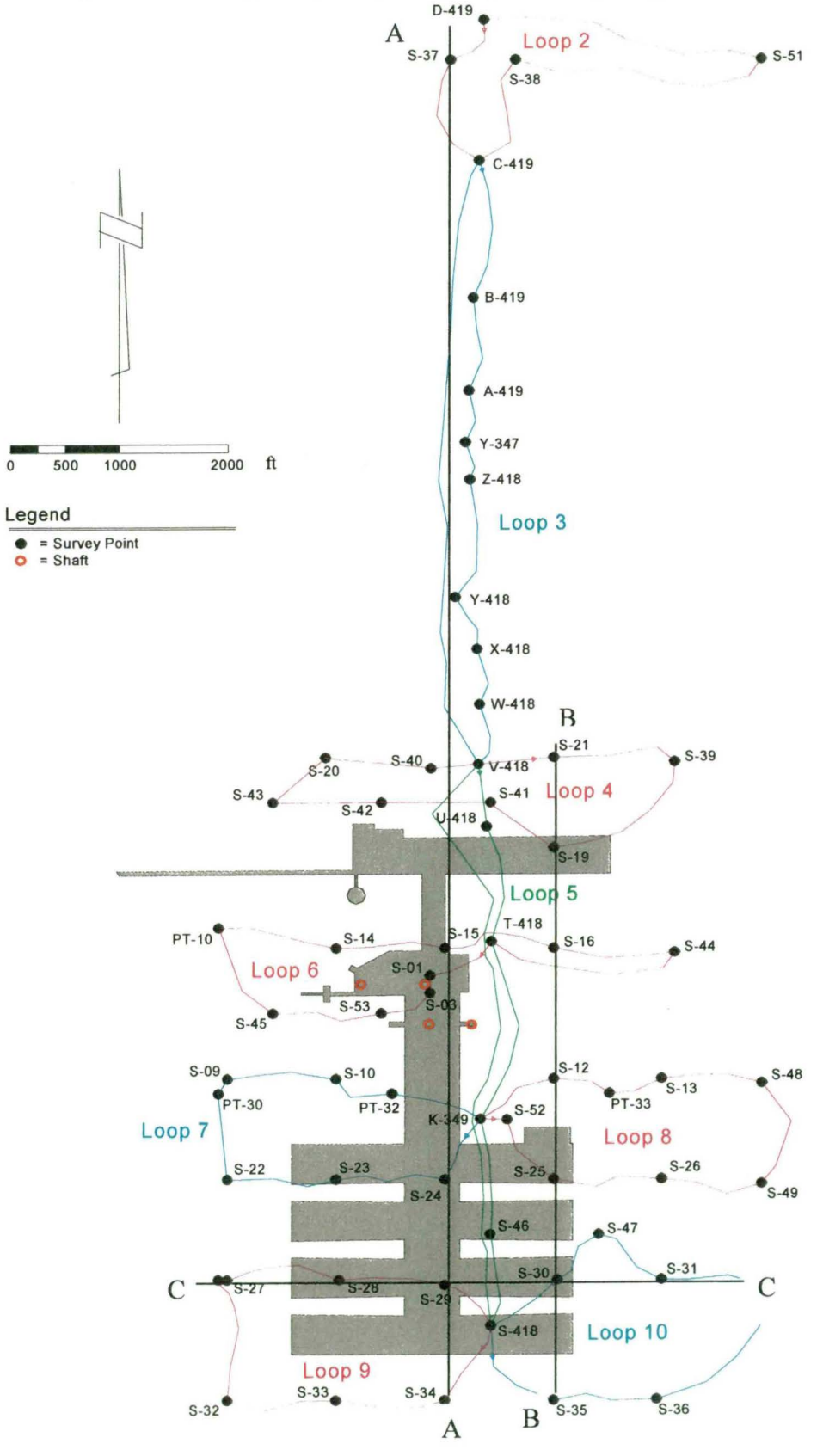
Monument	Fate	Date Last Surveyed
S-02	No longer exists	1992
S-11	No longer exists	1992
S-17	No longer exists	2003
S-18	No longer exists	2003
S-54	No longer exists	1992
PT-30	Physically Disturbed	1997
PT-31	Physically Disturbed	2003

The current surveys comprise nine leveling loops containing as few as 5 to as many as 10 monuments/control points per loop as shown in Figure 2.2 (Surveys of Loop 1 benchmarks have been discontinued because only two benchmarks comprise this loop and these benchmarks are redundant to other survey loops). Elevations are referenced to Monument S-37 located approximately 7,700 ft north of the most northerly boundary of the WIPP underground excavation. This location is considered to be far enough from the WIPP facility to be unaffected by excavation-induced subsidence expected directly above and near the WIPP underground. The elevation of S-37 has been fixed at 3,423.874 ft for all of the subsidence leveling surveys conducted since 1993. Survey accuracy for all loops was within the allowable limits (DOE 2017). Adjusted elevations are determined for every monument/control point by proportioning the vertical closure error for each survey loop to the monuments/control points comprising the loop. The proportions are based on the number of instrument setups and distance between adjacent points within a survey loop.

The adjusted elevations for each monument/control point are plotted as functions of time to assess subsidence trends. Figures 2.3 through 2.7 provide, respectively, elevations for selected monuments including those located (1) directly above the first waste emplacement panel, (2) directly above the second waste emplacement panel, (3) directly above the north experimental area, (4) near the salt handling shaft, and (5) outside the repository footprint of the WIPP underground excavation. As expected, subsidence is occurring directly above the underground openings (Figures 2.3 through 2.6); however the magnitude of the subsidence above the repository is small ranging from about -0.023 ft (D-419 and S-38) far north of the repository to -0.560 ft (S-46) directly over the waste panels.

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Figure 2.2. Monuments and vertical control points comprising WIPP subsidence survey loops.



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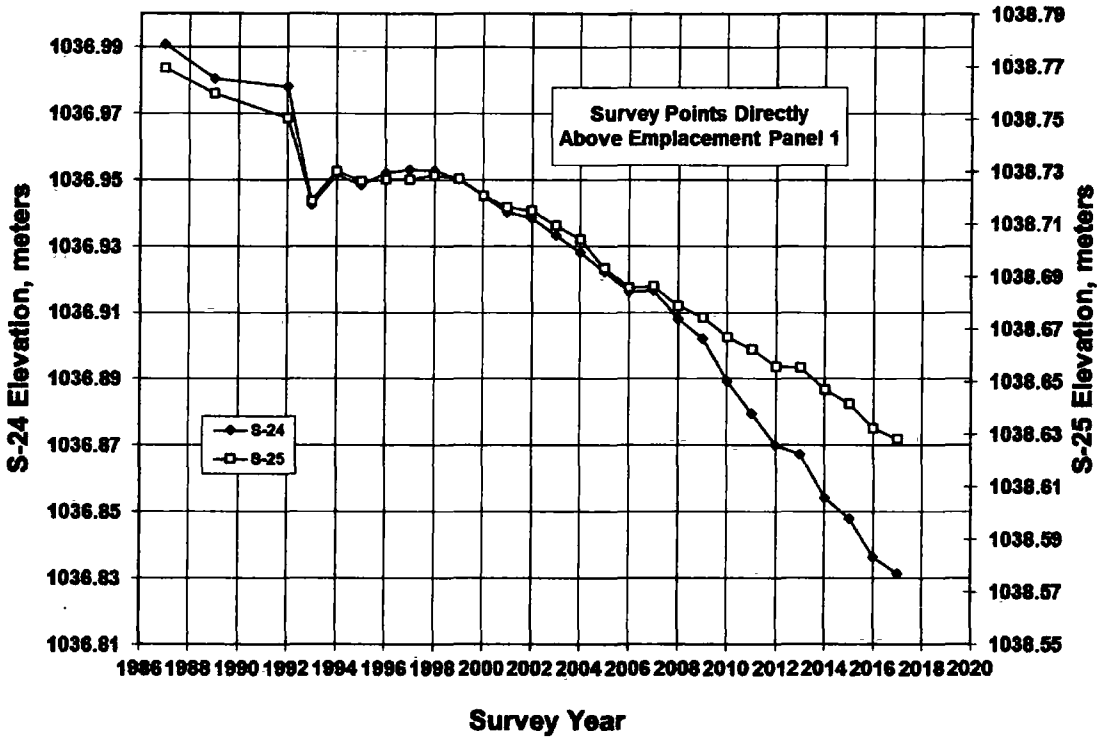


Figure 2.3. Elevations of WIPP monuments S-24 and S-25 located directly above emplacement Panel 1

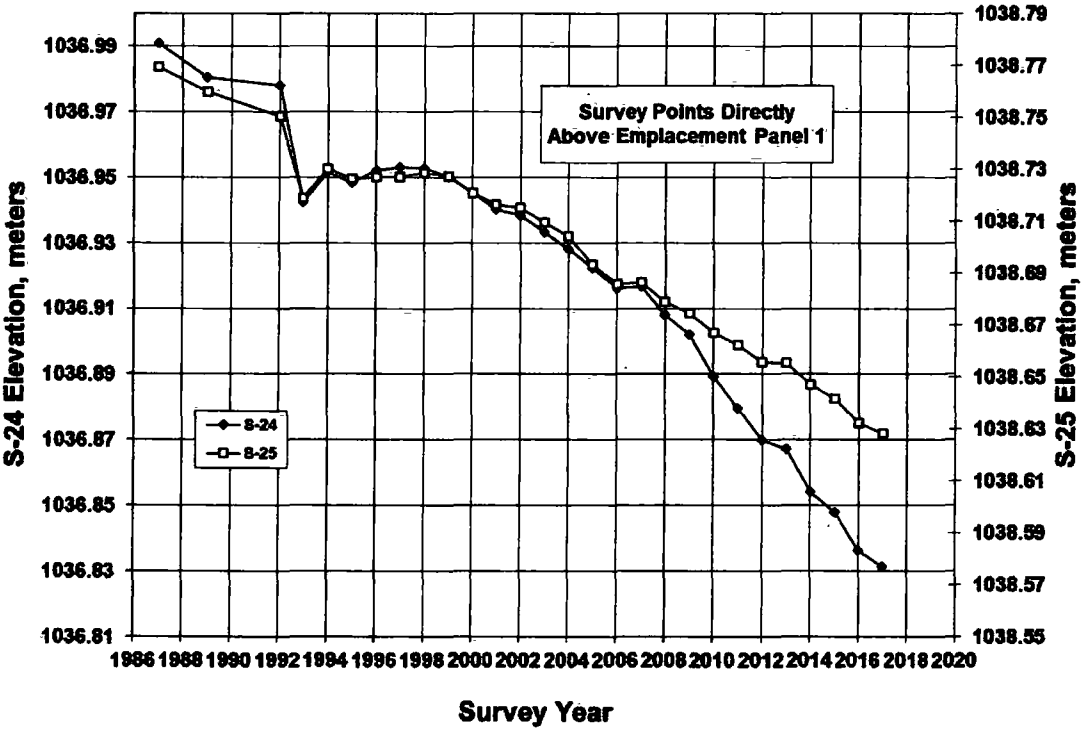


Figure 2.4. Elevations of WIPP monuments S-46 and S-47 located directly above emplacement Panel 2.

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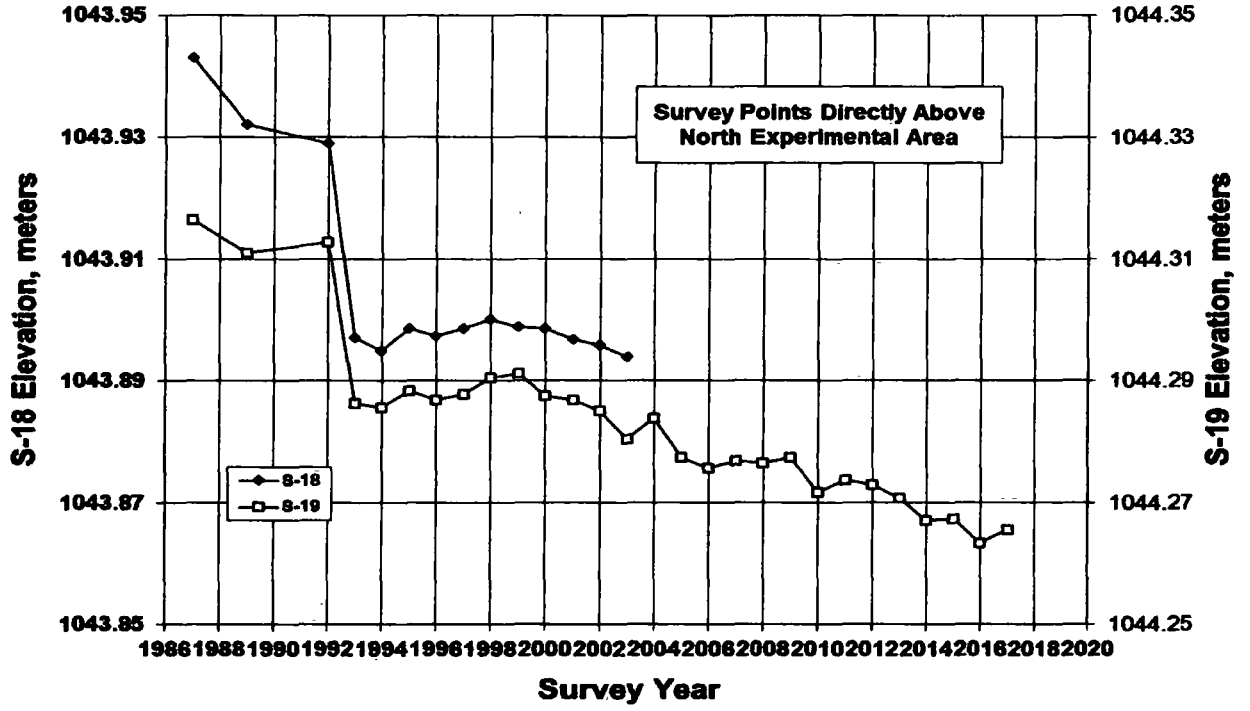


Figure 2.5. Elevations of WIPP monuments S-18 and S-19 located directly above the north experimental area.

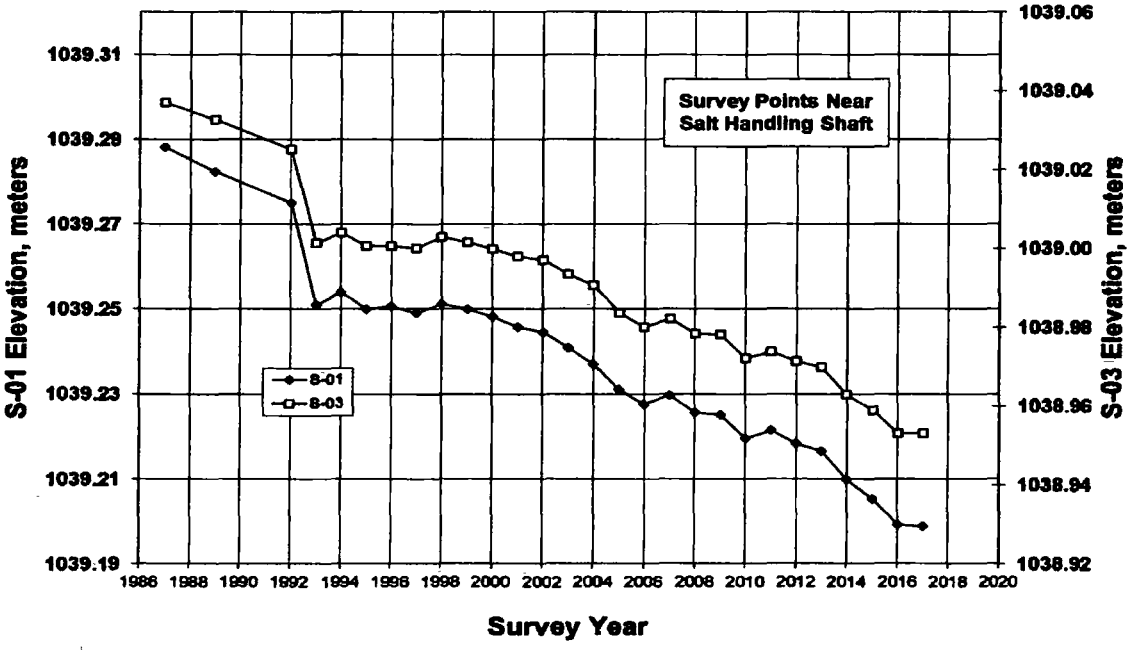


Figure 2.6. Elevations of WIPP monuments S-01 and S-03 located near the Salt Handling Shaft.

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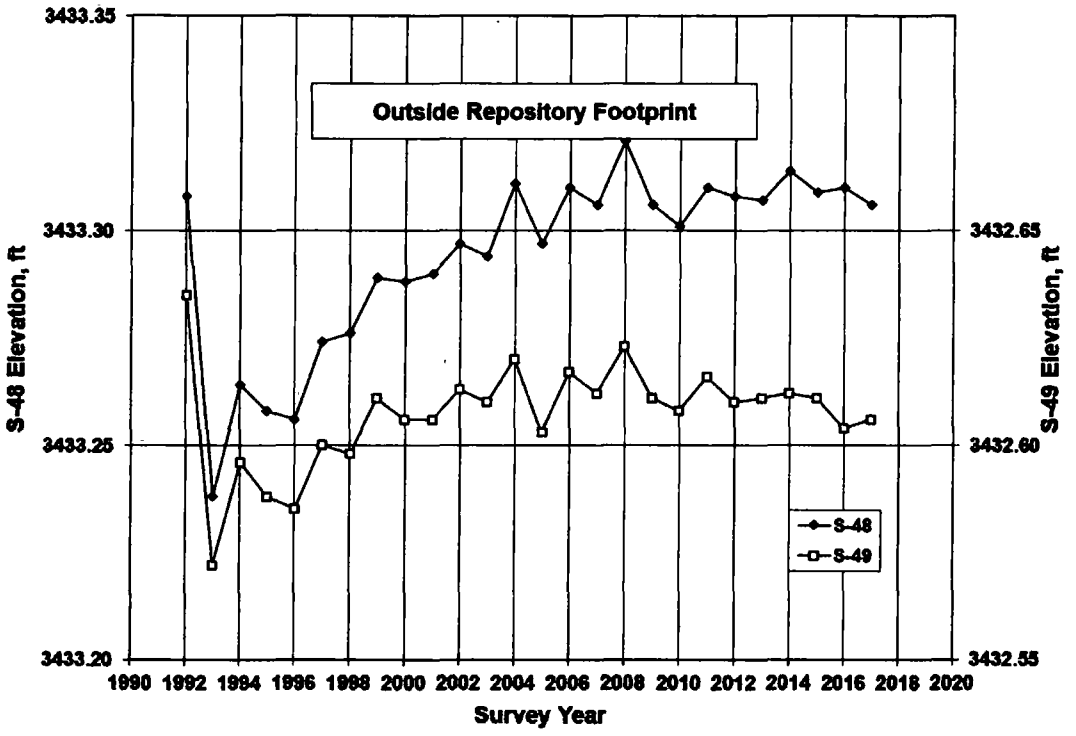


Figure 2.7. Elevations of WIPP monuments S-48 and S-49 located outside the repository footprint.

As time passes, subsidence is expected to be most pronounced directly above the WIPP underground excavations and will be minimal away from the repository footprint. Early results suggest this pattern is already occurring, as shown in Figures 2.8 through 2.10 for the following subsidence profiles (shown in plan view in Figure 2.2):

- Section A-A′, North-South section extending through the WIPP site
- Section B-B′, North-South section extending from the north experimental area through the south emplacement panels
- Section C-C′, East-West section extending through Panel 1

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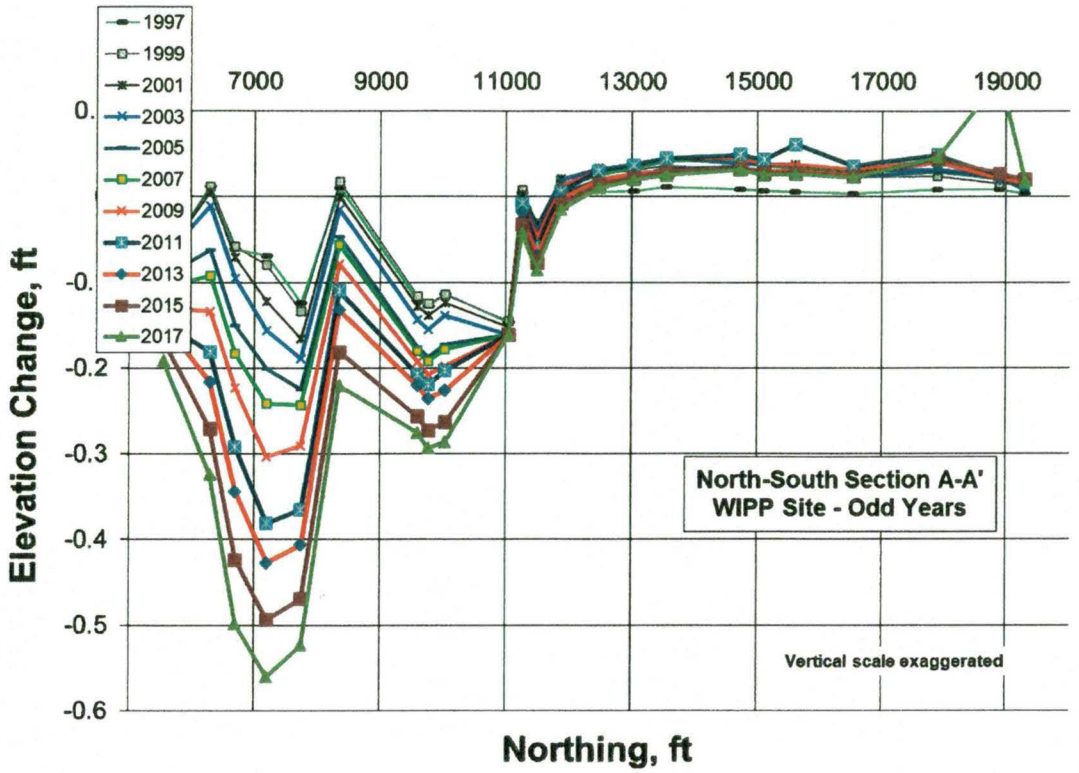


Figure 2.8. North-South subsidence profile A-A'.

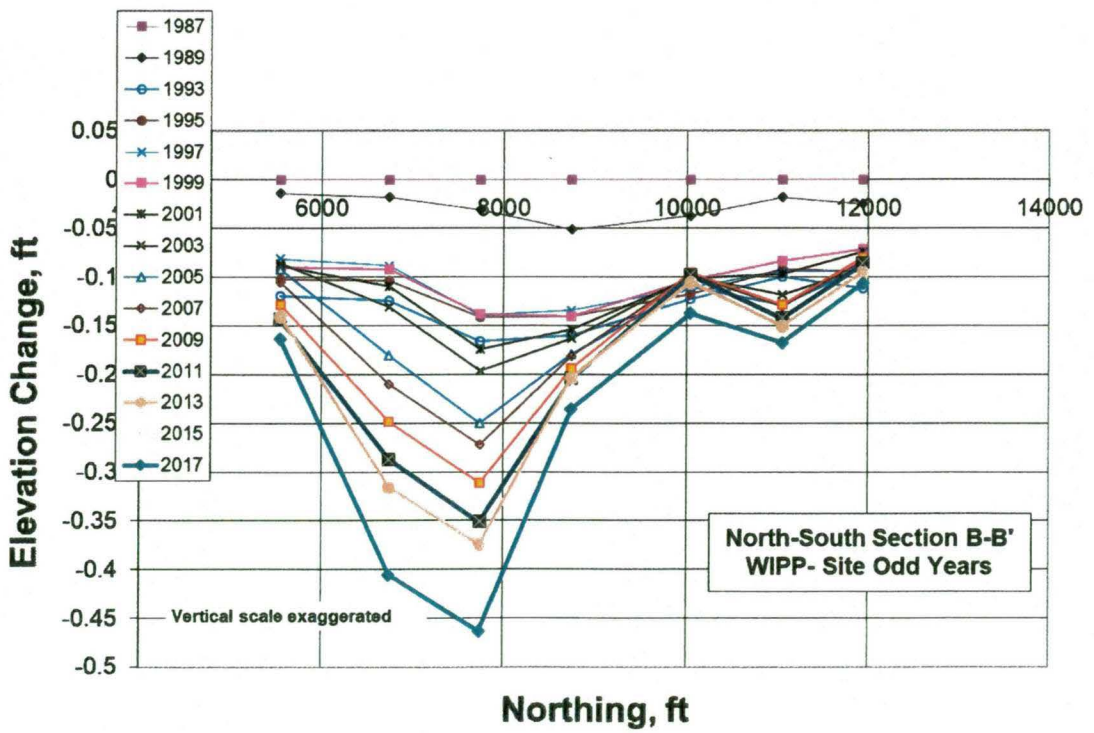


Figure 2.9. North-South subsidence profile B-B'.

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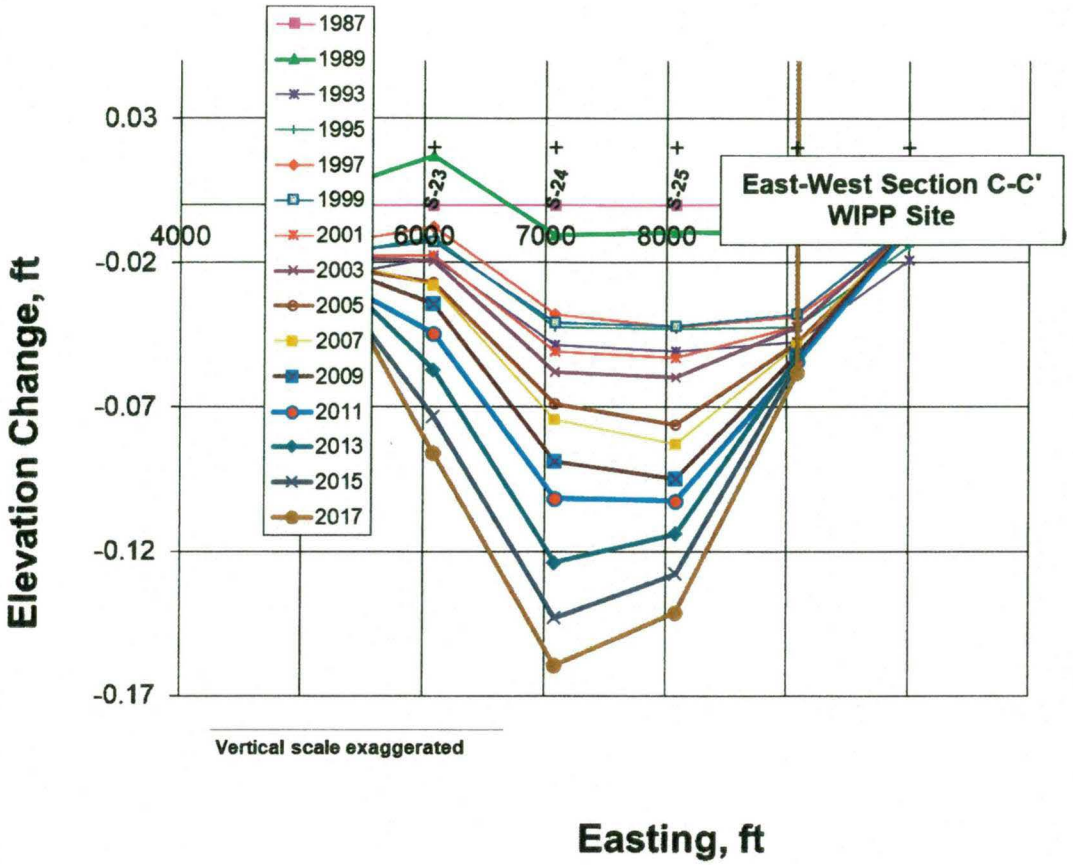


Figure 2.10. East-West subsidence profile C-C′.

The elevation changes of individual monuments shown in these figures are referenced to the elevations determined from the annual surveys that first incorporated the monument so, in some cases, direct temporal comparisons between pairs of monuments cannot be made. For example, only 29 monuments were included in the 1987 survey, while 50 monuments were included in the 1992 surveys and more than 60 for all surveys since 1996. Although direct comparisons cannot always be made, several observations for this reporting period are possible including:

1. The most significant total subsidence (greater than - 0.25 ft) occurs above the waste panels (Monuments S-01, S-03, S-15, S-23, S-24, S-25, S-28, S-29, S-30, S-46, S-52, S-418 and PT-32). This subsidence trend is centered over Panels 1 and 2 while the maximum subsidence of 0.560 ft is over Panel 2 (S-46). This trend is the same as last year's results.
2. Only monuments over the Experimental and Waste Panel areas show any appreciable subsidence rate with the higher rates located directly over the Waste Panels. The highest subsidence rates measured for the 2016-2017 surveys correspond to benchmarks located generally over the center of the repository (e.g., , S-24, , S-28, S-29, S-30,S-46, S-53 and S-418) with a maximum rate for this period of -1.0×10^{-2} m/yr. This rate matches but does not exceeds the TV.

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3. The effects of subsidence extend away from the repository footprint approximately 1,000 to 1,500 ft (e.g., S-37, see Figures 2.2 and 2.8).

Total subsidence and subsidence rates are small. The highest subsidence rates are seen directly above the mined panels and have increased since the mining of Panels 4 through 7. Based on the 2017 survey data, none of the monuments exceeded the 1 x 10^{-2} m/yr TV this reporting period. It should be noted that last year's rate exceeded the TV for the first time since subsidence was monitored. The TV was based on several analyses of potential subsidence over the WIPP site. The largest rate was chosen from these analyses and is derived from the total subsidence calculated over a 35-year period. The TV assumes that this rate is constant over a 35-year period whereas the monitoring data shows a gradual increase in rate over 20 years. As such, exceedance of the TV for one year does not indicate this behavior is unexpected. No action is necessary in response to this year's subsidence data.

2.3 Hydrological COMPs

As stated in previous sections, the CCA lists 10 monitoring parameters that the DOE is required to monitor and assess during the WIPP operational period (DOE 1996). Two of these parameters are considered hydrological in nature and include:

- Changes in Culebra Groundwater Composition
- Changes in Culebra Groundwater Flow

The Scientific Advisor has reviewed the data collected by the M&OC under *Waste Isolation Pilot Plant Groundwater Protection Program* (DOE 2014b), which is comprised of two components:

- Water Quality Sampling Program (WQSP)
- Water-Level Monitoring Program (WLMP)

WQSP and WLMP data are reported in the Waste Isolation Pilot Plant Annual Site Environmental Report (ASER) for 2017 (DOE 2018c). Additionally, WLMP data are reported in monthly memoranda for the M&OC to the scientific advisor.

2.3.1 Changes in Culebra Water Composition

2.3.1.1 Water Quality Sampling Program (WQSP)

Table 2.13 summarizes data and TV information relating to the COMP parameter Change in Culebra Water Composition, as well as its implementation in PA. Under the current WQSP, six wells are sampled by the M&OC, all completed to the Culebra Dolomite Member of the Rustler Formation (Figures 2.11 and 2.12). All the WQSP wells are located within the WIPP Land Withdrawal Boundary (LWB). WQSP-1, 2, and 3 are situated hydraulically up-gradient (north) of the WIPP surface facilities and WQSP-4, 5, and 6 are situated hydraulically down-gradient (south) of the WIPP surface facilities. Previously, the Dewey Lake Formation well WQSP-6A was also sampled, but beginning with sampling round 32, this well is no longer included and is therefore no longer discussed in this section.

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The Culebra is the most transmissive and laterally extensive saturated zone in the WIPP vicinity and is considered the most likely groundwater release pathway for potential future inadvertent human intrusion of the repository. The Culebra is not a source of drinking water for humans and therefore water quality degradation is not of concern. Understanding Culebra water quality is important because it is a key component in understanding the entire flow system.

Table 2.13 Change in Groundwater Composition – 2018:

COMP Title:	Groundwater Composition			
COMP Units:	mg/L (concentration data); unitless (p-value, level of marginal significance)			
Related Monitoring Data				
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value	
Ground Water Monitoring	Composition	Annual chemical analyses	Ion concentration data (i.e., sampling rounds 1-35) reported in the WIPP ASER. Expanded from the original Resource Conservation and Recovery Act (RCRA) Background Water Quality baseline (i.e., sampling rounds 1-10).	
COMP Derivation Process				
Annually evaluate ASER data and compare to previous years and baseline information				
Related Performance and Compliance Elements				
Element Title	Type & ID	Derivation Procedure	Compliance Baseline	Impact of Change
Groundwater conceptual model and brine chemistry	Indirect	Conceptual models	Indirect	Provides validation of the various PA models, potentially significant with respect to groundwater flow and transport
Monitoring Data Trigger Values				
Monitoring Parameter ID	Trigger Value	Basis		
Change in Culebra Groundwater Composition	The p-value for a major ion is less than or equal to 0.05 for three consecutive sampling rounds.	Annual comparison of major ion concentrations for a sampling round-of-interest (i.e., treatment group) against a sampling rounds 1-35 inclusive baseline (i.e., control group) with the randomization test. Hypothesis tested: If the p-value is less than or equal to 0.05, the treatment group is statistically significant compared to the control group.		

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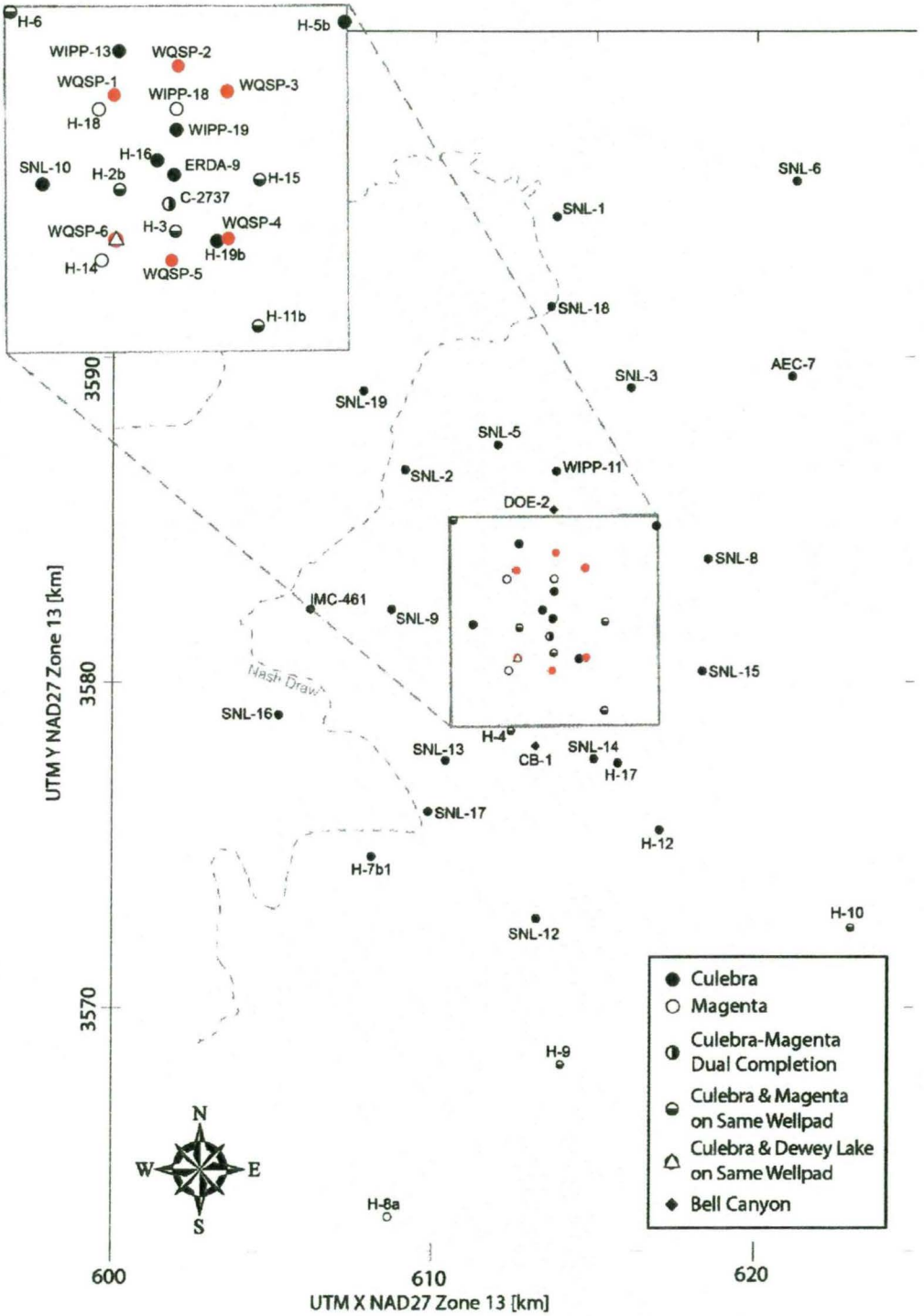


Figure 2.11 Map showing locations of WQSP wells (red) in relation to the WIPP LWB and the rest of the groundwater monitoring network.

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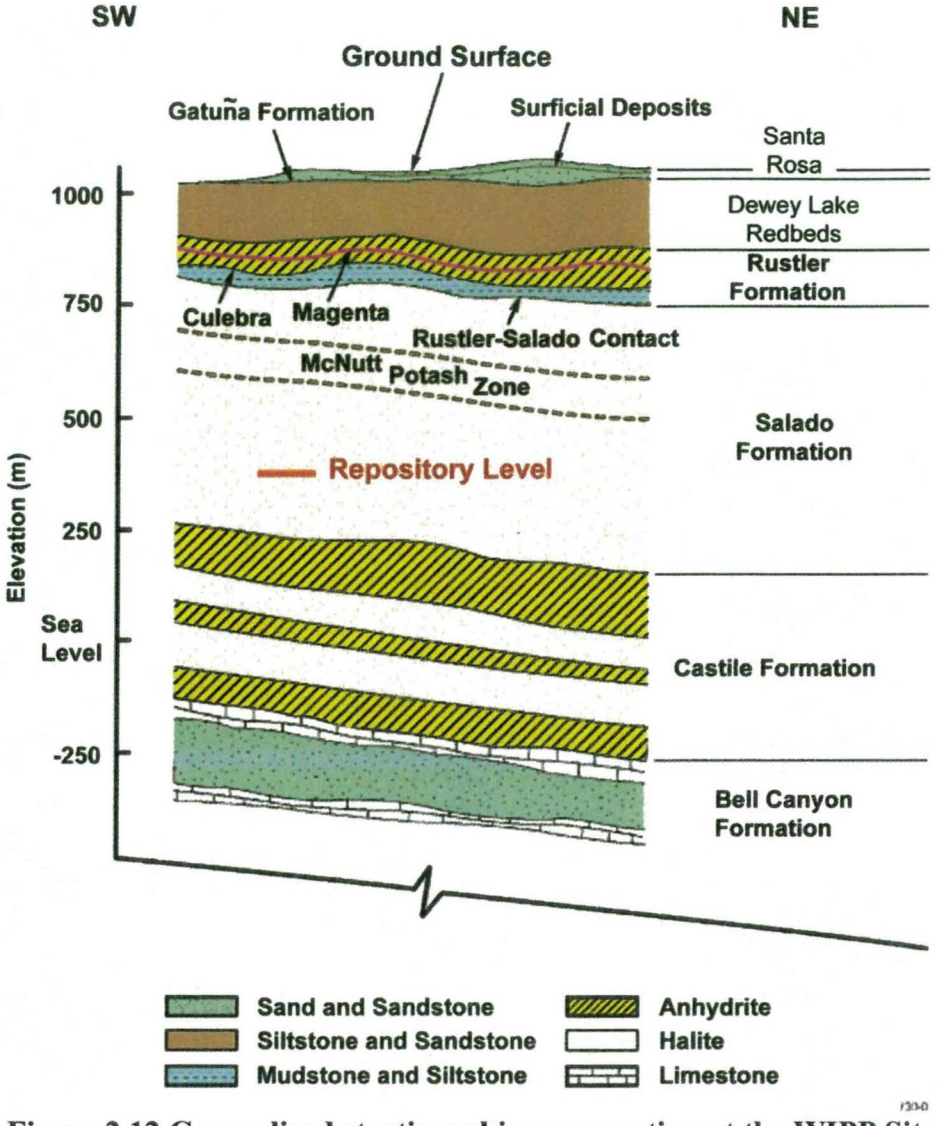


Figure 2.12 Generalized stratigraphic cross section at the WIPP Site

Solute concentrations in Culebra waters differ widely among wells across the WIPP site, a reflection of local compositional equilibrium, diffusion, and, perhaps most importantly, slow regional transport rates. The conceptual model for the Culebra was presented in the CRA-2014 (Appendix TFIELD: DOE 2014d) and is implemented in the PA hydrological models. The conceptual model consists of a confined groundwater flow system with natural-gradient solute travel times across the WIPP site on the order of thousands to tens of thousands of years. In such a system, no changes in water quality at an individual well outside the range of normal analytical uncertainty and noise are expected. Stability of major ion concentrations (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-) is consistent with and supports the Scientific Advisor's conceptual model of solute transport in the Culebra. If sustained, representative, and statistically significant changes in the concentrations of major ionic species are observed, this condition could imply that groundwater movement through the Culebra is quicker than what is predicted by the PA models. Thus, this evaluation of the water-quality data focuses on the stability of major ion concentrations.

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2.3.1.1.1 Water Quality Sampling

Currently, two water samples (a primary and a duplicate) are collected from each WQSP well once per year. Round 39 is the sixth year of annual sampling; rounds 2–33 (1996–2011) included two sampling rounds per year. Water sampling procedures are outlined in the Groundwater Protection Plan (DOE 2014e) and are summarized here.

Serial and final samples are collected using a submersible pump (each well has its own dedicated pump) set mid-formation. Serial samples are collected at regular intervals during pumping and they are analyzed in a mobile field laboratory to determine when water chemistry has stabilized. Stabilization parameters include temperature, pH, specific gravity and specific conductance. Final samples are collected in the appropriate containers for each particular analysis when water quality parameters have stabilized to within ±5% of their field parameter averages. Once collected, final samples are placed in coolers and delivered to the analytical laboratory within a day of collection.

2.3.1.1.2 Laboratory Analysis

The M&OC collects samples to be analyzed for volatiles, total organic halogens, total organic carbon, semi-volatiles, metals, and general chemistry. For this report, only the results from the metals and general chemistry analyses are discussed, as they provide the necessary information for assessment of the COMP. In the field, the general chemistry samples are not preserved, metals samples are preserved with nitric acid, and neither sample is filtered. In the lab, samples are analyzed using a variety of published, lab-standard methods. Samples are analyzed for major cations (including Na^+, Ca^{2+}, Mg^{2+} and K^+), major anions (including Cl^-, SO_4^{2-} and HCO_3^-), and other constituents not discussed here.

For sampling rounds 7 through 26, TraceAnalysis, Inc. of Lubbock, TX was responsible for analysis of the water samples submitted by the M&OC. In 2008, the analytical contract was awarded to Hall Environmental Analysis Laboratory (HEAL) of Albuquerque, NM, who began analysis with round 27.

2.3.1.1.3 Data Analysis

The results of the WQSP analyses are compared to baseline results in order to determine stability. Wagner and Thomas (2016) modified the Culebra Groundwater Composition TV due to the ongoing occurrence of false positive water-quality composition fluctuations. Compared to Wagner and Thomas (2015), the number of measurements incorporated into the water-quality baseline estimates is 250% larger. Evaluation of the Culebra Groundwater Composition TV no longer rests upon assumptions about the underlying statistical distribution of the ion concentration data. The randomization test is used to determine whether or not the treatment group (i.e., sampling round of interest) is statistically significant compared to the control group (i.e., sampling rounds 1-35). For a given sampling round, a p-value is calculated for each major constituent, for each well, totaling 42 values. If the p-value for a given constituent is less than or equal to 0.05 for three consecutive sampling rounds, a TV violation is reported. If the change appears to accurately reflect Culebra conditions, the Scientific Advisor will investigate what

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effects the changes might have on Culebra model conceptualization. The model will be revised to be consistent with the new information if appropriate.

For the purposes of this evaluation, a small number of measurements have been eliminated from the baselines for WQSP-3, 5, and 6. The reasons for eliminating these values are discussed in detail in the COMPs assessment report for data collected in the year 2000 (SNL 2001). The elimination of these values is always conservative; it reduces the "stable" range of concentrations for the affected parameters.

In addition to the comparison of species concentrations with trigger values, a charge-balance error (CBE) was also calculated for each analysis. The CBE is defined as the difference between the positive and negative charges from the ions in solution divided by the sum of the positive and negative charges. CBE is useful in evaluating analysis reliability because water must be electrically neutral. CBE is rarely zero because of inherent inaccuracy in analytical procedures, but a reliable analysis should not have a CBE exceeding ± 5 % (Freeze and Cherry 1979). A CBE in excess of ± 5 % implies either the analysis of one or more ions is inaccurate, or a major ion has been overlooked. The variation between the results of primary and duplicate sample analysis for each individual ion is also considered. In general, this variation should be < 10 %; large variability can indicate a problem with one or both analyses. Analytical results and CBE for round 39 are presented in Table 2.14.

2.3.1.2 Results

WQSP results for sampling round 39 conducted in 2017 are reported in the 2017 ASER (DOE 2018c). The reported major ion concentrations are listed in Table 2.14. Sampling round 39 was conducted between March and May with analyses performed by HEAL. In the following subsections, anomalous values given in Table 2.14 (identified with either bolded or italicized fonts) are discussed.

2.3.1.2.1 WQSP-1

All ion concentrations resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses were within the tolerated ± 5 % range. All primary and duplicate samples were within 10% of each other.

2.3.1.2.2 WQSP-2

All ion concentrations resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses were within the tolerated ± 5 % range. All primary and duplicate samples were within 10% of each other.

2.3.1.2.3 WQSP-3

All ion concentrations resulted in a p-value greater than 0.05. The CBE for the primary analysis was within the tolerated ± 5 % range. The CBE for the duplicate analysis exceeded the acceptable range. With the exceptions of chloride and bicarbonate, the primary and duplicate

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Table 2.14 Round 39 major ion concentrations and charge-balance errors, with p-value defined for each major ion for each well.

Well	Round 38	Ca^{2+} (mg/L)	Cl^- (mg/L)	HCO_3^- (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	SO_4^{2-} (mg/L)	CBE (%)
WQSP-1	primary	1,760	39,800	50.4	480	1,130	21,200	4,700	-4.5%
	duplicate	1,760	36,500	50.6	482	1,130	21,900	4,680	0.8%
	diff %	0.0%	8.7%	-0.2%	-0.4%	0.0%	-3.2%	0.4%	
	p-value	0.631	0.701	0.945	0.174	0.998	0.232	0.498	
	TV violated?	No	No	No	No	No	No	No	
WQSP-2	primary	1,640	33,900	48.2	460	1,080	21,600	5,140	2.6%
	duplicate	1,660	34,000	48.2	475	1,100	21,000	5,280	1.3%
	diff %	-1.2%	-0.3%	0.0%	-3.2%	-1.8%	2.8%	-2.7%	
	p-value	0.162	0.362	0.749	0.270	0.446	0.296	0.137	
	TV violated?	No	No	No	No	No	No	No	
WQSP-3	primary	1,490	128,000	43.4	1,420	2,300	74,500	7,920	-3.2%
	duplicate	1,520	161,000	35.7	1,510	2,380	76,800	8,050	**-12.7%**
	diff %	-2.0%	*-22.8%*	*19.4%*	-6.1%	-3.4%	-3.0%	-1.6%	
	p-value	0.632	0.305	0.084	0.202	0.631	0.944	0.897	
	TV violated?	No	No	No	No	No	No	No	
WQSP-4	primary	1,700	58,500	48.0	737	1,250	35,400	6,950	-1.4%
	duplicate	1,480	54,000	37.8	747	1,090	36,800	7,300	3.1%
	diff %	*13.8%*	8.0%	*23.7%*	-1.3%	*13.7%*	-3.9%	-4.9%	
	p-value	0.948	0.309	0.097	0.231	0.740	0.304	0.870	
	TV violated?	No	No	No	No	No	No	No	
WQSP-5	primary	1,090	14,400	48.4	338	608	11,200	4,570	**8.9%**
	duplicate	1,100	14,500	48.2	330	592	10,900	4,620	**7.3%**
	diff %	-0.9%	-0.7%	0.3%	2.4%	2.7%	2.7%	-1.1%	
	p-value	0.348	0.086	0.681	0.596	**0.000**	**0.014**	0.103	
	TV violated?	No	No	No	No	No	No	No	
WQSP-6	primary	669	5,520	53.4	153	212	4,280	4,870	-3.4%
	duplicate	686	4,720	48.2	153	216	4,840	4,340	**8.6%**
	diff %	-2.5%	*15.6%*	*10.4%*	0.0%	-1.9%	*-12.3%*	*11.5%*	
	p-value	0.716	0.177	0.126	0.223	0.954	0.369	0.489	
	TV violated?	No	No	No	No	No	No	No	

Bold = analyses returning a charge-balance error ≥5% or a p-value ≤0.05
Italics = sample and duplicate analyses differ by >10%

samples were within 10 % of each other. The duplicate analysis values for chloride and bicarbonate are suspect and likely caused by the multiple dilutions required for chloride analysis. The samples for the primary analysis were recollected to ensure that the dilutions for chloride analysis were accurate.

2.3.1.2.4 WQSP-4

All ion concentrations resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses were within the tolerated ± 5 % range. The original duplicate analysis was suspect, and samples were recollected and reanalyzed. This resulted in > 10 % difference in calcium, magnesium, and bicarbonate between the primary and secondary samples. Chloride, potassium, sodium, and sulfate were within 10 % of each other.

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2.3.1.2.5 WQSP-5

Magnesium ion concentrations resulted in a p-value less than 0.05. This constitutes a TV violation because the p-value for magnesium in WQSP-5 has been less than 0.05 for three consecutive sampling rounds. Sodium ion concentrations resulted in a p-value less than 0.05. This does not constitute a second TV violation because the round 38 p-value for sodium is 0.085 (i.e. the p-value is not less than 0.05 for three consecutive rounds). All other ion concentrations resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses both exceeded the tolerated ± 5 % range. All primary and duplicate samples were within 10% of each other.

2.3.1.2.6 WQSP-6

All ion concentrations resulted in a p-value greater than 0.05. The CBE for the primary analysis was within the tolerated ± 5 % range. The CBE for the duplicate analysis exceeded the acceptable range. The original primary analysis was suspect, and samples were recollected and reanalyzed. This resulted in > 10 % difference in chloride, bicarbonate, sodium, and sulfate concentrates between the primary and duplicate samples. Calcium, potassium, and magnesium concentrations were within 10 % of each other.

2.3.1.3 Assessment of Culebra Water Quality Data

A common method of assessing water-quality stability is through the use of Piper diagrams, which illustrate the relative proportions of three cation and three anion concentrations (four cations are treated by combining sodium and potassium together). By plotting the ion ratios for every round (including outliers thrown out in the calculation of confidence intervals presented in Table 2.13), we can visually assess water quality trends. Piper diagrams of Culebra water chemistry (Figure 2.13) over the course of the WQSP (now 15+ years) show that the groundwater is quite stable, with results for each well continually plotting within relatively small envelopes.

As shown in Table 2.14, CBEs were calculated for the primary and duplicate samples for WQSP 1-6. Four of the twelve CBEs fell outside the tolerated ± 5 % range. Two of the deviations occurred in wells that had one sample re-collected due to original analyses being suspect. The other deviations occurred in WQSP-5 samples. As mentioned in a previous COMPs report (SNL 2012), it is believed that the majority of analytical problems can be linked to the high salinity (i.e., TDS) observed in Culebra brines. The sensitive analytical equipment used in environmental labs requires that samples be diluted up to 10,000 times in order for samples to be within the calibration range of the instrument. Dilution of the samples introduces error, which can cause results to be less precise. Sandia National Laboratories will contact the M&OC and Hall Environmental Analysis Laboratory to review the laboratory-based protocols for analyzing the WQSP water samples. If future analyses reveal similar CBE trends, SNL may need to investigate the possibility of evaluating additional constituents or the occurrence of ion complexation as part of the CBE calculation.

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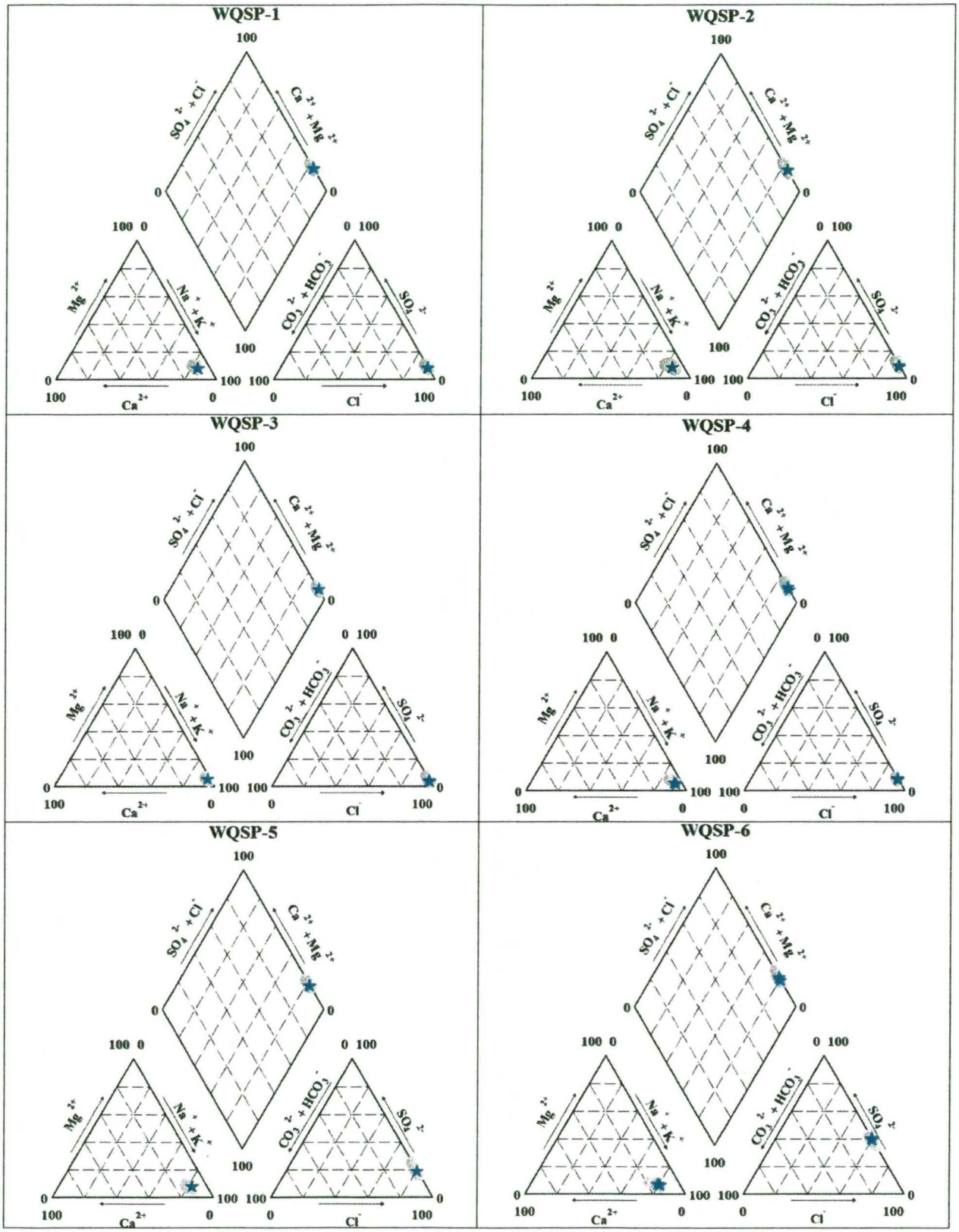


Figure 2.13 Piper diagrams of all data collected from WQSP-1 through WQSP-6. The plots show both historical data (grey) and results from Round 39 (blue).

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2.3.2 Changes in Groundwater Flow (Water Level)

Table 2.15 summarizes data and TV information relating to the COMP parameter Change in Groundwater Flow, as well as its implementation in PA. Assessment of the COMP for the Culebra involves comparisons of two sets of modeling results. The baseline model results are derived from the ensemble of models used in PA for CRA-2014 (e.g., Hart et al., 2009; DOE 2014d), while annual model results are adjusted to best-fit freshwater heads observed in 2017 (DOE 2018b).

The Dewey Lake, Magenta, and Bell Canyon are not currently monitored as COMPs, do not have PA flow models, and therefore do not have TVs. The water-level measurements in these units do, however, provide information used in the development of the conceptual model of overall site hydrology.

2.3.2.1 Water Level Monitoring Program (WLMP)

In 2017, the M&OC made monthly water-level measurements in all the WIPP non-shallow subsurface water (SSW) monitoring network wells (see Figure 2.14 and Table 2.16), or quarterly in any redundant wells (i.e., six of the seven H-19b wells). As of September 2017, the WIPP monitoring network consisted 65 monitoring wells (including one dual-completion Magenta/Culebra well, see Table 2.16). There were 49 wells with completions in the Culebra Member of the Rustler Formation (hereafter referred to as Culebra), 13 with completions to the Magenta Member of the Rustler Formation (hereafter referred to as Magenta), two with completion to the Bell Canyon Formation, and one to the Dewey Lake Formation.

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Table 2.15 Changes in Groundwater Flow – 2018:

COMP Title:	Changes in Culebra Groundwater Flow
COMP Units:	Inferred from water-level data

Related Monitoring Data

Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value
Groundwater Monitoring	Head and Topography	Monthly water-level measurements, annual pressure-density surveys.	Indirect

COMP Derivation Procedure - Data acquired between December 2014 and December of 2015

Annual assessment from ASER data.

Related PA Elements

Element Title	Type & ID	Derivation Procedure	Compliance Baseline	Impact of Change
Groundwater conceptual model, Transmissivity fields	T-Fields	Computer codes are used along with groundwater data to generate transmissivity fields for the Culebra on a regional scale. A summary of the conceptualization, implementation and calibration of the Culebra T-fields is given in Kuhlman (2010b).	Attachment T-FIELDS to Appendix PA.	Validates assumptions used in T-Field modeling and the groundwater basin model.

Monitoring Data Trigger Values

Monitoring Parameter ID	Trigger Value	Basis
Change in Culebra Groundwater Flow	PA Compliance Baseline	Model-predicted travel time in the Culebra is compared to the distribution found in PA, for an ensemble-average model with best-fit boundary conditions to the current year's observed freshwater heads. The travel time from the center of the WIPP panels to the WIPP LWA boundary must fall within the distribution found using 100 model runs used in the baseline PA.

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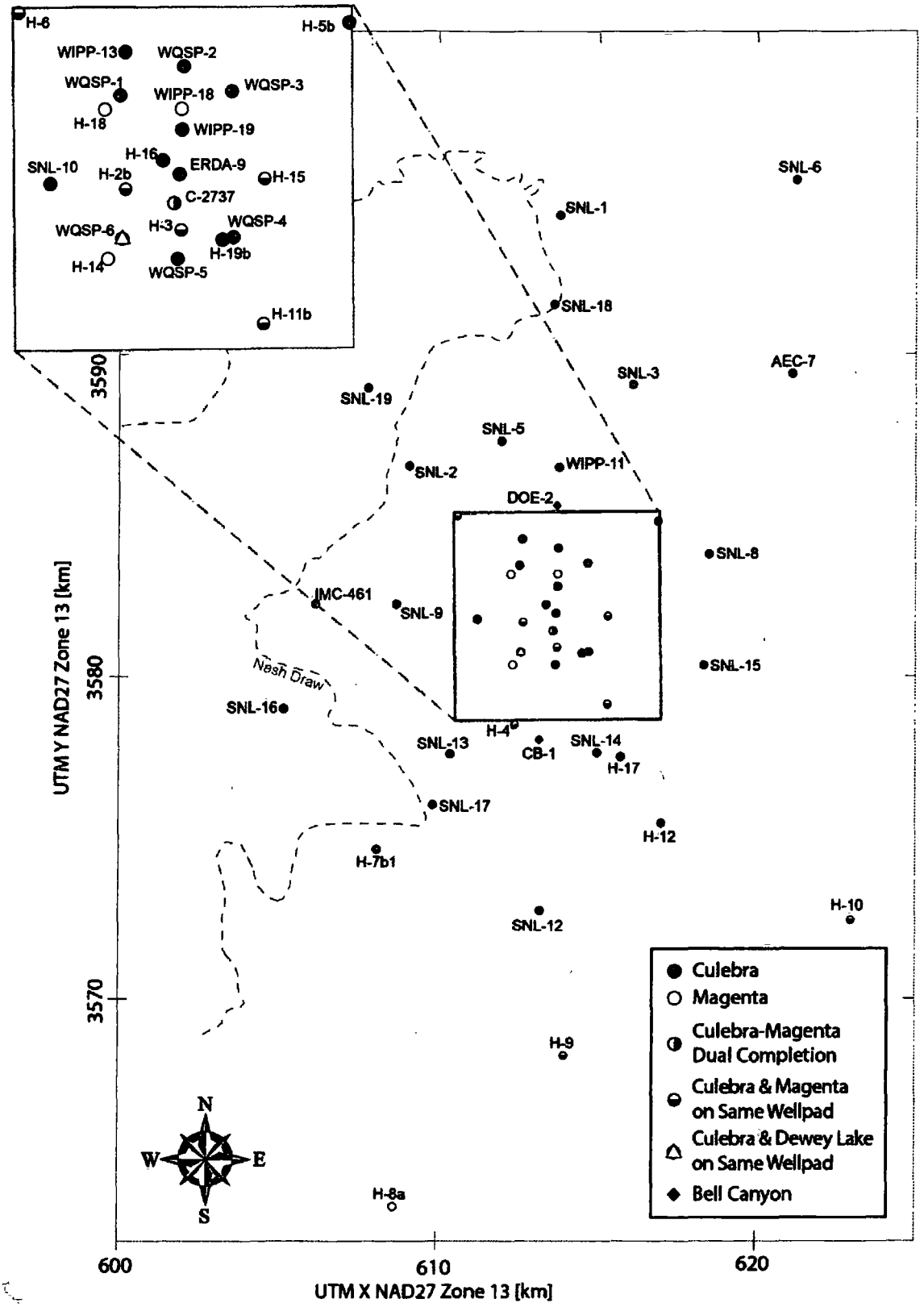


Figure 2.14 Map of the WIPP area showing well pad locations discussed in this section (See Table 2.16 for listing of wells at each well pad)

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Table 2.16 March 2016 Non-SSW[1] WIPP Groundwater Monitoring Network

Well	Pad[1]	Completion[2]
AEC-7R	AEC-7	CUL
C-2737	C-2737	CUL/MAG DUAL
CB-1	CB-1	BC
DOE-2	DOE-2	BC
ERDA-9	ERDA-9	CUL
H-2b1	H-2b	MAG
H-2b2		CUL
H-3b1	H-3	MAG
H-3b2		CUL
H-4bR	H-4	CUL
H-4c		MAG
H-5b	H-5b	CUL
H-6bR	H-6	CUL
H-6c		MAG
H-7b1	H-7b1	CUL
H-8a	H-8a	MAG
H-9c	H-9	MAG
H-9bR		CUL
H-10a	H-10	MAG
H-10cR		CUL
H-11b2	H-11b	MAG
H-11b4R		CUL
H-12R	H-12	CUL
H-14	H-14	MAG
H-15R	H-15	CUL
H-15		MAG
H-16	H-16	CUL
H-17	H-17	CUL
H-18	H-18	MAG
H-19b0	H-19b	CUL REDUN
H-19b2		CUL REDUN
H-19b3		CUL REDUN
H-19b4		CUL REDUN
H-19b5		CUL REDUN
H-19b6		CUL REDUN
H-19b7		CUL REDUN
IMC-461	IMC-461	CUL
SNL-1	SNL-1	CUL
SNL-2	SNL-2	CUL
SNL-3	SNL-3	CUL
SNL-5	SNL-5	CUL
SNL-6	SNL-6	CUL
SNL-8	SNL8	CUL
SNL-9	SNL-9	CUL
SNL-10	SNL-10	CUL
SNL-12	SNL-12	CUL
SNL-13	SNL-13	CUL
SNL-14	SNL-14	CUL
SNL-15	SNL-15	CUL
SNL-16	SNL-16	CUL
SNL-17	SNL-17	CUL
SNL-18	SNL-18	CUL
SNL-19	SNL-19	CUL
WIPP-11	WIPP-11	CUL
WIPP-13	WIPP-13	CUL
WIPP-18	WIPP-18	MAG
WIPP-19	WIPP-19	CUL
WQSP-1	WQSP-1	CUL
WQSP-2	WQSP-2	CUL
WQSP-3	WQSP-3	CUL
WQSP-4	WQSP-4	CUL
WQSP-5	WQSP-5	CUL
WQSP-6	WQSP-6	CUL
WQSP-6A		DL

[1]Pad names used in Figure 2.14
[2]Well completion codes are as follows:
BC: Bell Canyon formation
CUL: Culebra Member of the Rustler Formation
MAG: Magenta Member of the Rustler Formation
DL: Dewey Lake formation
DUAL: dual-completion well
REDUN: redundant well (quarterly water levels)

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2.3.2.2 Culebra Groundwater Flow Results and Assessment

Assessment of Culebra data involves the interpretation of freshwater head data in the context of the hydrogeologic knowledge about the WIPP area. If heads change significantly in wells, this may be due to an underlying change in Culebra flow patterns. At the request of the New Mexico Environment Department (NMED), the Scientific Advisor uses the ensemble-average of the 100 calibrated Culebra groundwater flow model runs developed for PA to create the baseline transmissivity (T) field. This ensemble-average T field is used to produce the freshwater head potentiometric surface map each year for the ASER. Each year the boundary conditions of the ensemble-averaged model are adjusted to best fit the observed freshwater head values from that year. The ensemble-averaged T field and the adjusted boundary conditions are used as inputs to the MODFLOW model (Harbaugh et al. 2000) that computes the heads which are then contoured and presented in the ASER.

The Culebra PA model is a single-layer groundwater flow model that incorporates information about aquifer parameters (e.g., transmissivity, storativity, and anisotropy) and is based upon a peer-reviewed conceptual model of Culebra geology (Section 8.2 of EPA 2010a). The model is calibrated to both steady-state freshwater heads and transient pumping test drawdown data. The contour map shown in Figure 2.16 shows the area immediately around the WIPP LWA boundary, and indicates that flow is generally from north to south, which is consistent with previous results, and that the gradient is steepest across the area including the WIPP surface facilities, caused by a region of low Culebra T.

The contour map is created according to SNL specific procedure SP 9-9, and the results of following the procedure along with detailed narrative descriptions are given in the analysis report *Analysis Report for Preparation of 2017 Culebra Potentiometric Surface Contour Map* (Hayes 2018). This material is summarized in the 2017 ASER, Section 6.2.5 (DOE 2018c).

2.3.2.3 Culebra Freshwater-Head Results and Assessment

Table 2.17 shows the March 2016 freshwater heads reported in the 2016 ASER and used in the development of the Culebra contour map given in the 2017 ASER (DOE 2018c). The particle track shown as a blue arrow in Figure 2.16 begins where the Culebra intersects the WIPP waste-handling shaft and continues to the WIPP LWA boundary, as required by NMED. The travel time for this particle in the boundary-calibrated ensemble-average flow field (5,248 years) is compared to the distribution of 100 travel times computed for the CRA-2014 PA. The ensemble-average travel time also falls inside the predicted CRA-2009 Performance Assessment Baseline Calculation (PABC) range (see red points in Figure 2.15). The estimated flow velocity is higher than in previous years due to the steeper gradient caused by commercial water pumping. Since the flow model has the ensemble hydraulic conductivity and anisotropy fields as inputs, the freshwater head contours and particle track take into account the variability of aquifer conditions across the site that are consistent with the calibration data used to derive the T-fields.

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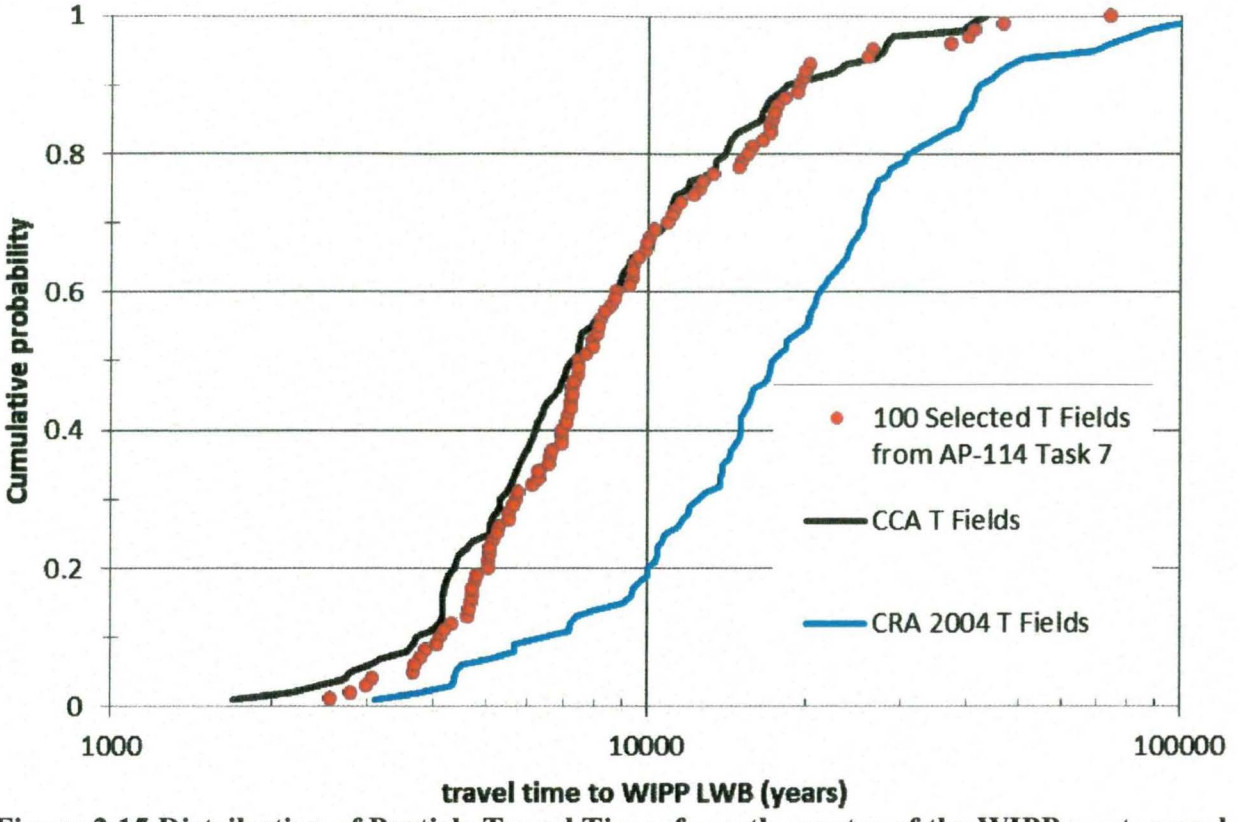


Figure 2.15 Distribution of Particle Travel Times from the center of the WIPP waste panels to WIPP LWB for CCA (black line), CRA-2004 (blue line), and CRA-2009 PABC (red points). Figure from Hart et al. (2009).

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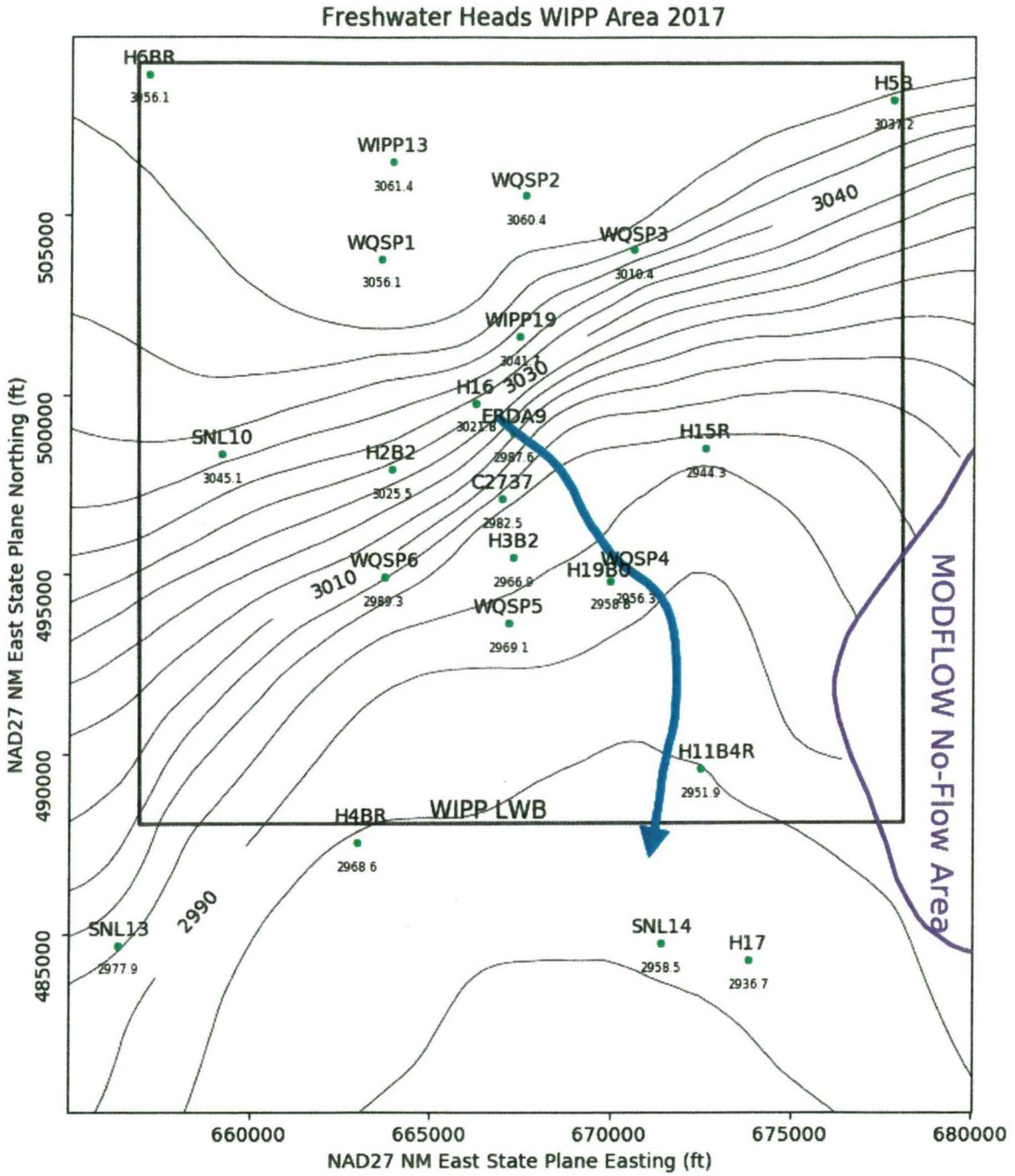


Figure 2.16 September 2017 modeled Culebra potentiometric surface of the immediate WIPP vicinity (DOE 2018) generated using ensemble average distributed aquifer parameters from the SNL Culebra flow model used in CRA-2014 PA (DOE, 2014d).

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Table 2.17 Summary of September 2017 Culebra freshwater heads

Well ID[1]	Measurement Date	Adjusted Freshwater Head (m AMSL)	Specific Gravity
C-2737[(b)]	09/18/17	908.08	1.023
ERDA-9[(b)]	9/18/17	910.61	1.073
H-02b2[(b)]	9/18/17	922.18	1.011
H-03b2[(b)]	9/18/17	904.32	1.013
H-04bR[(b)]	09/18/17	904.83	1.023
H-05b	09/14/17	925.74	1.082
H-06bR	09/15/17	931.51	1.038
H-07b1	09/15/17	913.07	1.008
H-09bR	09/14/17	905.31	1.004
H-11b4R[(b)]	09/14/17	899.75	1.078
H-12R	09/14/17	896.86	1.110
H-15R[(b)]	09/18/17	897.43	1.119
H-16(b)	09/19/17	921.03	1.035
H-17(b)	09/14/17	895.12	1.133
H-19b0[(b)]	09/18/17	901.83	1.066
IMC-461	09/13/17	926.39	1.002
SNL-01	09/13/17	937.06	1.031
SNL-02	09/13/17	934.92	1.009
SNL-03	09/15/17	935.04	1.028
SNL-05	09/13/17	935.33	1.010
SNL-08	09/14/17	919.15	1.096
SNL-09	09/15/17	928.60	1.018
SNL-10	09/15/17	928.14	1.010
SNL-12[(b)]	09/14/17	904.53	1.006
SNL-13[(b)]	09/15/17	907.66	1.025
SNL-14[(b)]	09/14/17	901.75	1.045
SNL-16	09/13/17	917.13	1.015
SNL-17	09/15/17	912.46	1.008
SNL-18	09/13/17	935.85	1.010
SNL-19	09/13/17	935.12	1.006
WIPP-11	09/15/17	932.86	1.038
WIPP-13	09/15/17	933.10	1.035
WIPP-19	09/15/17	927.12	1.052
WQSP-1	09/18/17	931.51	1.049
WQSP-2	09/15/17	932.81	1.048
WQSP-3	09/15/17	917.58	1.144
WQSP-4[(b)]	09/18/17	901.08	4.076
WQSP-5[(b)]	09/18/17	904.99	1.028
WQSP-6[(b)]	09/18/17	911.15	1.016

[1]SNL-06 and SNL-15 are not listed because they are currently not representative of undisturbed conditions in the Culebra; water levels in these wells are predicted to continue to rise for the foreseeable future.

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2.3.2.4 Interpretation/Summary of the 2017 Culebra Data

As mentioned previously, change in Culebra groundwater flow would be manifested as a change in gradient and/or flow velocity, which would be observed through changes in freshwater head measured in observation wells. In general, the freshwater potentiometric gradient of the Culebra is, and has been, from north to south with low flow velocities across the WIPP modeling domain (Hart et al., 2009). The basis of the assessment of the groundwater flow COMP is the computed travel time and potentiometric surface map of the Culebra (Figure 6.4, DOE 2018c). The map was generated using the Culebra flow model developed by the Scientific Advisor for performance assessment associated with CRA-2014 PA and Culebra Heads from September 2017 and is consistent with the historical general north to south gradient.

The ensemble-averaged model predicted travel time for a particle of 5,248 years currently falls within the range modeled for PA, although it is near the lower bound of the distribution because of the smoothness of the average field compared to the stochastically generated individual fields used in PA. The travel time indicates that the current observed freshwater heads are consistent with the model used in PA, and therefore they do not violate the TV.

2.3.2.5 Results and Assessment of Data from Other Units

Assessment of water-level changes from other hydrologic units present in the WIPP vicinity (Table 2.18) is important for confirming the conceptual model of overall site hydrology. Water-level measurements for the Magenta Member of the Rustler Formation provide information about confinement of and connectivity to the underlying Culebra Member.

February 2017 was chosen as the period for reporting water level data from non-Culebra units to make a consistent year to year comparison. Water-level changes in the Magenta ranged from -0.069 to 1.83 m, with five wells experiencing water-level changes $\geq$ 0.61 m (2.0 ft). Water level rises in Magenta wells C-2737, H-03b, H-11b2, and WIPP-18 have occurred gradually over the past year. Well H-15 experienced a decrease in water level throughout the year. Continuous pressure measurements in the wells confirm that the changes in water levels in these wells are gradual and not the result of a transient process. A comparison between 2016 and 2017 water levels in well H-10a was not performed because well H-10a was inaccessible in February 2016. However, both the January 2016 and March 2016 water measurements (948.89 m AMSL and 948.79 m AMSL respectively) show $\geq$ 0.61 m change in water-level in when compared with February 2017.

The water level in WQSP-6a is stable. This well is completed to the middle of the Dewey Lake Formation (Table 2.18). Water-levels in the Bell Canyon well CB-1 decreased for the first time since 2008. Water levels had been rising in CB-1 after swabbing activities cleaned out foreign water from the well suggesting that the water level is stabilizing (Table 2.18). Water levels in DOE-2, the other Bell Canyon well, are stable.

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Table 2.18 Summary of 2012-2016 water-level changes in non-Culebra units

Well	Feb 2012 Water Level Elevation (m AMSL)	Feb 2013 Water Level Elevation (m AMSL)	Feb 2014 Water Level Elevation (m AMSL)	Feb 2015 Water Level Elevation (m AMSL)	Feb 2016 Water Level Elevation (m AMSL)	Feb 2017 Water Level Elevation (m AMSL)	2017-2016 Water Level Change (m)
	Magenta Wells						
C-2737	958.42	958.54	958.70	958.95	959.78	**961.11**	**1.33**
H-02b1	955.81	957.71	958.05	958.46	958.61	958.87	0.26
H-03b1	959.15	959.33	959.45	959.72	960.59	**961.84**	**1.25**
H-04c	959.02	959.38	959.55	959.86	959.82	959.77	-0.05
H-06c	936.09	936.33	936.20	936.36	936.32	936.34	0.02
H-08a	922.53	923.29	923.20	923.32	923.30	923.28	-0.02
H-09c	956.14	955.84	956.18	955.73	955.78	955.62	-0.16
H-10a	948.73	948.73	948.64	948.91	*NA*	*948.66*	*NA*
H-11b2	956.94	957.14	957.24	957.48	958.15	**959.05**	**0.90**
H-14	956.57	956.98	957.15	957.41	957.54	957.63	0.09
H-15	958.63	959.42	960.32	961.41	967.80	**967.11**	**-0.69**
H-18	961.68	962.13	962.42	962.87	962.99	963.30	0.31
WIPP-18	960.20	960.45	960.65	960.89	962.35	**964.18**	**1.83**
	Dewey Lake Well						
WQSP-6A	974.24	974.24	974.16	974.20	973.99	974.07	0.08
	Bell Canyon Wells						
CB-1	920.11	921.68	922.93	924.96	925.64	925.21	-0.43
DOE-2	934.90	935.04	935.19	935.37	935.50	935.54	0.04

Bold = absolute changes in water level ≥ 0.61 m (2.0 ft)
NA = well not accessible for water level measurement in February

2.4 Waste Activity

Table 2.19 summarizes data and TV information relating to the COMP parameter Waste Activity, and its implementation in PA. The reporting period for the waste activity COMP started at first waste receipt and ended on June 30, 2017. . Waste emplacement paused in February 2014 due to an equipment fire and unrelated release. After recovery activities were completed, the WIPP resumed CH waste emplacement in April of 2017, during this year's waste activities COMP reporting period. No Remote Handled (RH) waste was emplaced over this period. A comparison of the tracked actinides and the total expected repository inventory used in the CRA-2014 is detailed in Table 2.19. No other activity-related assessment has been made at this time.

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There are no TVs for CH activity, only RH. The TV for RH is the regulatory limit of 5.1 million Curies. The total curies of RH waste for the period ending June 30, 2018 is 2.41 x 10^4 Curies, well below the TV. There are no recognized reportable issues associated with this COMP. No changes to the monitoring program are recommended at this time. A detailed waste inventory assessment has been provided in the CRA-2014 (DOE 2014d).

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Table 2.19. Waste Activity - 2018:

COMP Title:	**Waste Activity**		
COMP Units:	Curies		
Related Monitoring Data			
Monitoring Program	Monitoring Parameter ID	Characteristics (e.g., number, observation)	Compliance Baseline Value
Waste Data System (WDS; formerly the WWIS), BIR	Radionuclide activity per container and volume	Curies , volume	TRU waste inventory for the 2014 Compliance Recertification Application(Van Soest 2012)
COMP Assessment Process - Reporting Period July 1, 2017 to June 30, 2018			
Total curie content of emplaced CH-TRU and RH-TRU waste. *[Total radionuclide inventories reported by the WDS]*			
Year 2018 COMP Assessment Value			
No waste was emplaced during this reporting period. No new data is available for this COMP. A comparison of emplaced and PA waste parameters is found in Table 2.20.			

Element Title	Type and ID	Derivation Procedure	Compliance Baseline	Impact of Change
Radionuclide inventories	Parameter	Product of waste stream content and volume scaled up to the Land Withdrawal Act limits. (U.S. Congress 1992)	Table 6-1 of Van Soest 2012	May affect direct brine releases for those radionuclides that become inventory-limited during a PA simulation.
Activity of waste intersected for cuttings and cavings releases.	Parameter	Function of waste stream volumes and activities	Van Soest 2012	Cuttings are a significant contributor to releases. An increase in activity of intersected waste is potentially significant.
WIPP-scale average activity for spallings releases	Parameter	Average of all CH-TRU waste only.	Van Soest 2012	Spallings are a significant contributor to releases. An increase in average activity of intersected waste is potentially significant.

Monitoring Data Trigger Values		
Monitoring Parameter ID	Trigger Value	Basis
Waste emplacement records	None	Administrative controls address waste limits. TV Derivation Report, Revision 2 (Wagner and Thomas 2016)
Total emplaced RH-TRU waste activity	5.1 million curies	LWA emplacement limit reached. Administrative controls address these limits.

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Table 2.20. Comparison of tracked radionuclide inventory to the CRA-2014 Inventory (from NWP 2018 and Van Soest 2012).

Radionuclide (CCA Table 4-10)	Non-Decayed Total Activity as of June 30, 2017	Non-Decayed CH Inventory as of June 30, 2018	Non-Decayed RH Inventory as of June 30, 2018	Non-Decayed Total Activity as of June 30, 2018	CRA-2014Total Inventory at Closure (2033)
^{241}Am	2.590E+05	2.602E+05	6.208E+02	2.608E+05	7.05E+05
^{137}Cs	1.445E+04	1.468E+01	1.444E+04	1.445E+04	2.35E+05
^{238}Pu	4.837E+05	4.844E+05	7.289E+02	4.851E+05	6.05E+05
^{239}Pu	3.353E+05	3.360E+05	3.839E+02	3.364E+05	5.74E+05
^{240}Pu	8.306E+04	8.307E+04	2.802E+02	8.335E+04	1.75E+05
^{242}Pu	2.763E+01	2.744E+01	3.821E-01	2.782E+01	8.10E+03
^{90}Sr	7.615E+03	2.388E+01	7.599E+03	7.623E+03	2.09E+05
^{233}U	6.931E+00	6.558E+00	3.848E-01	6.942E+00	1.39E+02
^{234}U	8.785E+01	8.695E+01	1.140E-01	8.810E+01	3.44E+02
^{238}U	1.762E+01	1.761E+01	3.915E-02	1.765E+01	6.48E+01
Total	**1.183E+06**	**1.164E+06**	**2.405E+04**	**1.188E+06**	**3.64E+06**

3 COMPs Assessment Conclusion

The operational period monitoring program designed to meet the Assurance Requirements of 40 CFR § 191.14 and the terms of WIPP certification was initiated in 1999. This monitoring program is useful to further validate the assumptions and conceptual models that are used to predict WIPP performance and identify conditions that could potentially cause radioactive release above the limits established in 40 CFR § 191.13. Since releases above these limits cannot occur during the operational period of WIPP, the monitoring program looks at other potential performance indicators of the disposal system and compares these data to PA performance expectations. Specifically, 10 monitoring parameters are assessed and compared to PA expectations and assumptions. The CRA-2014 (DOE 2014d) contains the results of the most recent PA submitted to the EPA for compliance purposes. The CRA-2014 has been approved by the EPA and has become the latest compliance baseline. The results of this year's COMP assessment conclude that there are no COMPs data or results that indicate a reportable event or condition adverse to predicted performance.

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