Sandia National Laboratories
Compliance Monitoring
Parameter Assessment
For 2021

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WBS 4.3.1
March 2022

Prepared for the United States Department of Energy
Carlsbad Field Office

Sandia National Laboratories

WIPP:4.3.1:CO:QA-L:pkg 510062

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Executive Summary

This document reports the twentieth 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 2020).

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 impact of the February 2014 equipment fire and unrelated radiological release events at WIPP have resulted in continuing access restrictions to many parts of the WIPP underground. Many monitoring activities have been suspended or delayed and data for the geotechnical COMPs have been affected. This 2021 report identifies the affected COMPs and associated monitoring data collection issues. Although data collection 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 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

[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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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 2021 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* (DOE 2014a) describes the overall monitoring program and responsibilities for COMPs derivation and assessment. This report documents the results of the reporting year 2021 COMPs assessment (for most COMPs data, between July 1st 2020 to June 30th 2021). 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). Note that since the CRA-2014, the certified baseline has been supplemented by EPA-defined parameters identified by Zeitler (2019).

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. 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. Additionally, the DOE decided to abandon the southern end of the repository due to ground control and worker safety issues (Veal 2019). Access to Panels 3, 4, 5 and 6 was discontinued such that there will be no further data for these areas. Waste emplacement in these panels had been completed such that repository operations were not impacted by the abandonment of these areas.

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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.

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.

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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."

This section summarizes the results of the 2021 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 2020). 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 10. 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 40 drilling encounters with pressurized brine (water) in the Castile Formation. Of these encounters, 30 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 2021a, 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 2021. During this reporting period (between September 1, 2020, and August 31, 2021), 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 2021a, Section 2.6).

Of the 10 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. 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

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used in the CCA which was based on a geostatistical analysis of actual brine encounters. Results 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).

In the CRA-2014, 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 (Zeitler 2019).

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Table 2.1 Probability of Encountering a Brine Reservoir - 2021:

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)	Previous 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 2021 COMP Assessment Value - Reporting Period September 2020 to August 2021				
No new data reported in State record during the reporting period; no new report from Field Observations. 40 Total Brine Encounters 30 CCA total occurrences before 1996 0 State Record occurrences since 1996 10 Site Personnel/ Drillers Survey occurrences since 1996				
Related Performance and Compliance Elements				
Element Title	Parameter Type & ID or Model Description	Derivation Procedure	Current Compliance Baseline	Impact of Change
Probability of Encountering Brine	Parameter PBRINE FEP N2 "Brine Reservoirs"	EPA/DOE Defined Parameters outlined by Zeitler 2019.	4.00E-02 to 5.70E-01 Mean 2.63E-01 (Zeitler 2019)	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[2].

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.
8	T22S-R30E-Sec 13	Apache "13" - Federal #8H	08/19/2005	Oil Well: Encountered a severe H_2S water flow.
9	T23S-R30E-Sec 1	James Ranch Unit #108H	12/06/2009	Oil Well: Encountered salt water flow occurred at 2,894 ft.
10	T21S-R31E-Sec 35	Lost Tank "36" - State SWD #1	06/28/2013	Salt Water Disposal: Encountered H2S influx from 2,678-3,004 ft then shut in on well.

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[2] From DOE 2021a, Table 7

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:

$$D_r = (D_{100} \text{ x } 10{,}000 \text{ yrs}) \div (A_{DB} \text{ x } 100 \text{ yrs}) \quad (1)$$

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 2021) increases the rate to 151.3 boreholes per square kilometer per 10,000 years (DOE 2021a), as shown in Table 2.4. 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 - 2021:

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 2021 COMP Assessment Value - Reporting Period September 1, 2020 to August 31, 2021				
(34,964 boreholes on record for the Delaware Basin) Drilling Rate = 151.3 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 FEP H1 "Oil and Gas Exploration" FEP H4 "Oil and Gas Exploitation"	COMP/10,000 years	6.73E-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[3].

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	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
2019	24,408	105.7
2020	28,669	124.1
2021	34,964	151.3

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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
- Displacement of Deformation Features
- Subsidence

[3] From DOE 2021a, Section 2.5 and Table 6

Data needed to derive and evaluate the geotechnical COMPs are available from the most recent annual Geotechnical Analysis Report (GAR; DOE 2021b) and the annual Subsidence Monument Leveling Survey (DOE 2021c). 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 2021b) summarizes data collected from July 2019 through June 2020.

Subsidence monitoring survey reports are also prepared by the M&OC on an annual basis and present the results of leveling surveys performed in 2020 for nine vertical control loops comprising approximately 15 linear miles traversed over the ground surface of the WIPP site. Elevations are determined for 46 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 2021c) summarizes data collected between September through December of 2020.

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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 current 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 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 that support WIPP certification. In effect, these annual comparisons of actual geotechnical response with expected response serve to validate or improve models.

The 2021 GAR (DOE 2021b) reporting period is from July 1, 2019 to June 30, 2020 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, 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-related 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. Nominally these rates are of the order of $1x10^{-10}$/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 closure 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 of one order of magnitude 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 closure 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, 2020. For this reporting period, Panels 1 through 7 had been fully excavated and Panel 8 mining was almost completely mined. Figure 2.1 shows all areas mined as of June 30, 2020. At that time, CH waste had progressed to Panel 7, Room 3 and RH waste had been emplaced in Panel 7, Rooms 7 and 6. In Panel 7, Room 6, waste disposal operations had ceased. Waste was not emplaced in Rooms 6 and 4 due to anticipated roof fall over much of these rooms. Waste had been emplaced in entry drifts S-2520 and S-2180 to Room 2. During the reporting period of the GAR (ending June 30, 2020), no RH was emplaced.

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Table 2.5 Creep Closure - 2021:

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 2019 through June 2020				
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 FEP W20 "Salt Creep"	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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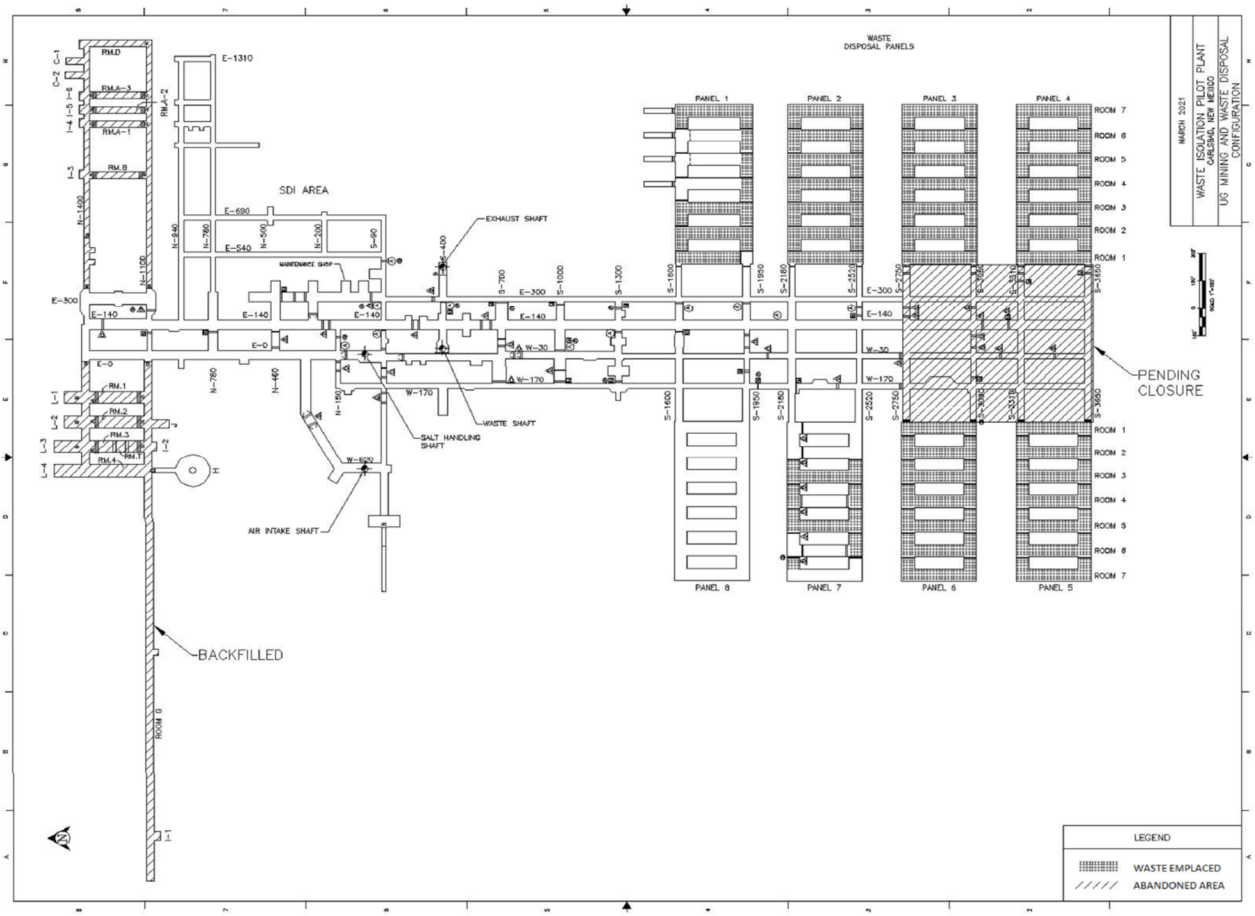

Figure 2.1. Configuration of the WIPP Underground for Geotechnical COMPs (after DOE 2021b; through June 30, 2020).

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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 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-related 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.

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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 lifetime 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. Routine ground control activities were performed during this reporting period.

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 (2019-2020) and the previous reporting period (2018-2019) are summarized in Table 2.6. Most of the measurements are for vertical closure. Based on shaft station convergence data, the current vertical displacement rates range from 0.2 to

2.4 in/yr (0.51 to 6.10 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 3.22×10^{-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 closure rates associated with the WIPP shaft stations are considered acceptable and meet the TV requiring creep closure 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[b]	Displacement Rate (in/yr)[a]		Change In Rate (%)
		2018–2019	2019-2020	
Salt Handling Shaft Station				
E0 Drift – S18 (A-E)	CP	1.3	1.9	46
E0 Drift – S18 (B-D)	CP	—	2.4	—
E0 Drift – S18 (F-H)	CP	0.8	1.1	38
E0 Drift – S30 (A-C)	CP	1.3	2.0	54
E0 Drift – S65 (A-C)	CP	0.8	1.2	50
Waste Shaft Station[c]				
S400 Drift – E35 (Vert CL)	Ext	0.3	0.3	0
S400 Drift – W30 (A-C)	CP	0.8	0.9	13
Air Intake Shaft Station[c]				
S65 Drift – W620 (Vert CL)	Ext	0.3	0.3	0
N93 Drift – W620 (Vert CL)	Ext	0.3	0.3	0
AIS North Brow (Vert CL)	Ext	0.2	0.3	50
AIS South Brow (Vert CL)	Ext	0.2	0.4	100
N20 Drift – W620 (Vert CL)	Ext	0.2	0.2	0

(a) Data are from the 2021 GAR (DOE 2021b, Volume 2, Tables 3-1 and 4-1).
(b) Instrument Type: Ext = extensometer; CP = convergence point.
(c) CL = Centerline

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Access Drifts and Waste Disposal Area

Waste emplacement has been completed in Panels 1 through 6. No access is allowed in these areas and no additional monitoring data are available. Access Drift (entries) data were only monitored for the main access drifts, Panel 7, and Panel 8 at locations where access is allowed.

Main 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.

Waste emplacement continued during the current reporting period for the GAR (July 2019 to June 2020), with waste disposal emplacement proceeding in the Panel 7 entry drift near Room 2.

Mining of Panel 8 started in September of 2013. Mining was interrupted by the two February 2014 underground events. Panel 8 was almost completely mined 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, and 7 will be at the original horizon and Panels 3, 4, 5, 6, and 8 approximately 2.4 m higher in elevation (roof at Clay G). Note that Panel 8 was originally planned to be mined on the lower horizon, but due to the interruption in mining, which resulted in significant low angle shear and roof separation, it is now being mined to the upper horizon. 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-related 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 2021b). 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 2020 COMPs data were low or near zero. For this 2021 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: 18.0 cm/yr
Maximum Horizontal Displacement Rates along Access Drifts: 0.5 cm/yr.

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Using a typical average drift dimension of 5 m and the maximum displacement rates shown above, the inferred maximum vertical creep rate is approximately 11.44×10^{-10}/s. This rate is based on the maximum displacement which is not representative of the behavior of the system. This rate is less than last year's rate of 12.56×10^{-10}/s.

Creep closures associated with the Access Drifts are acceptable and meet the TV requiring creep closure 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.

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 were initially planned to 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. Panel 8, which began mining in 2013, is almost completely excavated during this reporting period. 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 2018-2019 and 2019-2020 Reporting Periods [(a)]					
	< 0%	0 – 25%	25 – 50%	50 – 75%	75 – 100%	100 – 200%
Access Drifts						
Vertical	31	114	11	2	1	1
Horizontal	1	0	0	0	0	0
Waste Disposal Area Panel 7						
Vertical	5	10	3	3	1	2
Waste Disposal Area Panel 8						
Vertical	0	1	2	1	1	0

(a) Displacement rate change data are from the 2021 GAR (DOE 2021b, Volume 2, Tables 4-1, 5-1, and 5-2).

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Assessment of creep-related 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 2021b). Panels 1 through 6 were previously closed and are no longer accessible. Panel 5 was closed in 2011 and Panel 6 closed in 2014. No new convergence points were installed in Panel 7 and over 40 new convergence points were installed in Panel 8 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, data in the waste disposal area are from Panels 7 and 8. The maximum displacement rate corresponding to these data is provided as follows:

Maximum Vertical Displacement Rates along Waste Disposal Area: 14.7 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 5.84×10^{-10}/s. This rate is more than last year's rate of 4.73×10^{-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 have 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, 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 2018). 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 is under development for PA.

Excavation of Panel 3 raises the waste disposal panels by 2.4 m such that the roof of the disposal rooms is coincident with Clay Seam G and the floor is 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 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

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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 Marker Bed 139 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 routinely performed during this reporting period. Routine geoscience work has not been performed since the radiological release event in 2014 and the resulting significant reduction in ventilation. As such there is no new data for this COMP. Fracture maps are not provided in the 2021 GAR (DOE 2021b) for comparison to maps in the previous year's report. Similarly, the previous year's GAR did not include fracture mapping.

Table 2.8. Extent of Deformation - 2021:

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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 2019 through June 2020				
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 FEP W18 "Disturbed Rock Zone"	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)		

2.2.3 Initiation of Brittle Deformation

Table 2.9 summarizes data and TV information relating to the COMP, 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. No other issues were noted as part of this monitoring.

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Table 2.9. Initiation of Brittle Deformation - 2021:

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 2019 through June 2020				
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, 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 semi-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, and 7. Marker Bed 139 (anhydrite) is located approximately 2 m below the floor of these panels. For Panels 3, 4, 5, 6, and 8, 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 - 2021:

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 2019 through June 2020				
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)		

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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. During the reporting period, two boreholes were drilled and inspected to identify separations/fractures into the immediate roof beam (DOE 2021b, Volume 2, Section 7).

2.2.5 Subsidence

Table 2.11 summarizes data and TV information relating to the COMP, 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 2020 for 9 control loops (see Figure 2-2). Construction activities in the vicinity of two monuments precluded them from inclusion in the 2020 survey. To address EPA monitoring requirements, the most recent survey results (DOE 2021c) 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 × √mile or better was achieved in all cases. This year's measured accuracy ranged from <0.001 to 0.004 ft√mile (DOE 2021c).

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Table 2.11. Subsidence - 2021:

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 – 2021; Data acquired between September 2020 through December of 2020			
Survey data from annual WIPP Subsidence Monument Leveling are evaluated. Elevations of 60 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 W23 "Subsidence"	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-2014 Appendix 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 2014d).

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.

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Table 2.12 lists these monuments. Historically, the surveys were conducted by private 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 2021a).

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 2021c). 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 -0.028 ft (D-419) far north of the repository to -0.692 ft (S-46) directly over the waste panels.

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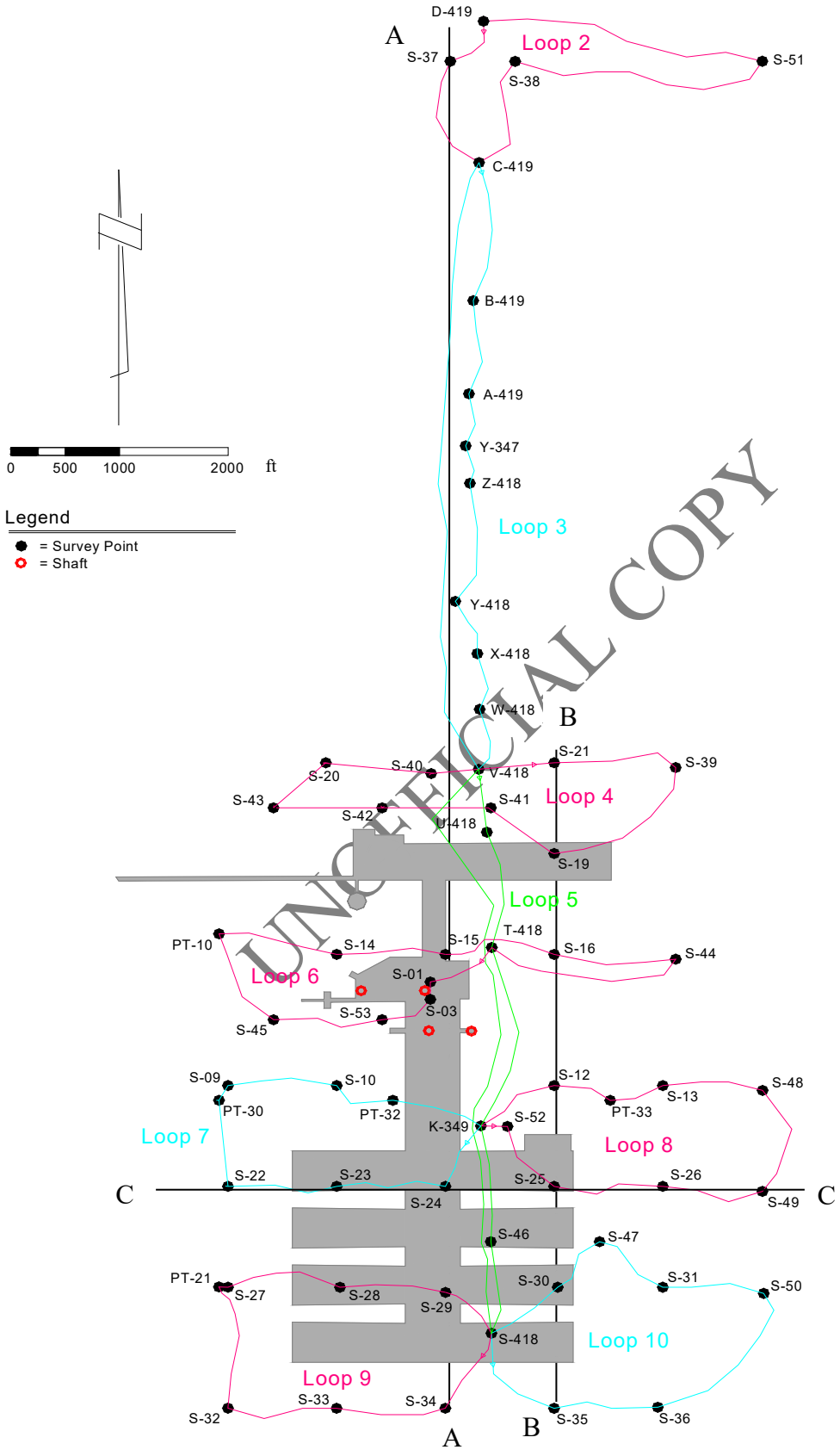
Figure 2.2. Monuments and vertical control points comprising WIPP subsidence survey loops.



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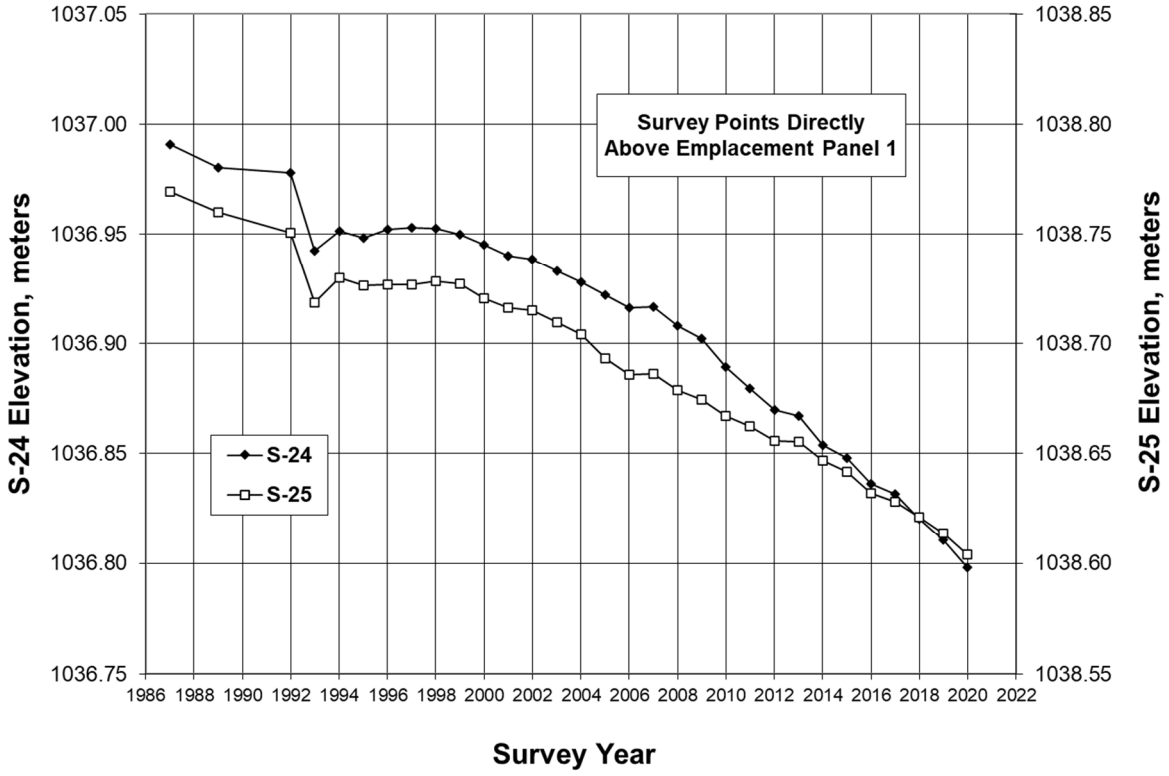

Figure 2.3. Elevations of WIPP monuments S-24 and S-25 located directly above emplacement Panel 1.

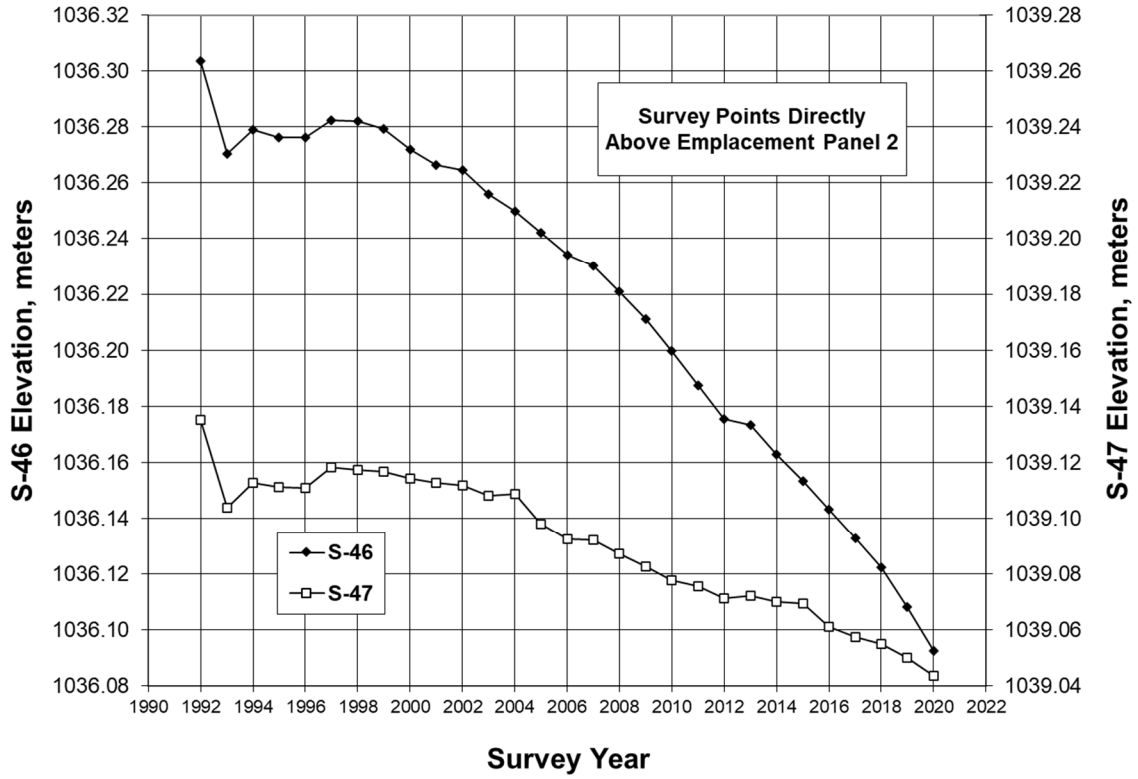

Figure 2.4. Elevations of WIPP monuments S-46 and S-47 located directly above emplacement Panel 2.

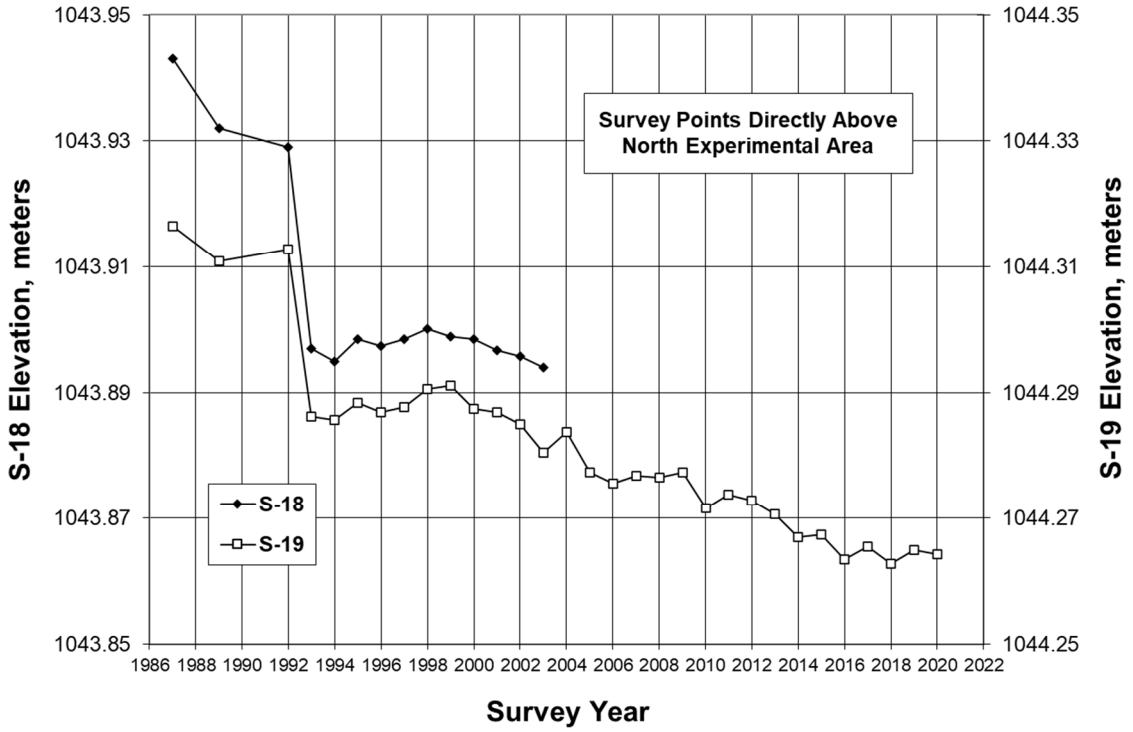

Figure 2.5. Elevations of WIPP monuments S-18 and S-19 located directly above the north experimental area.

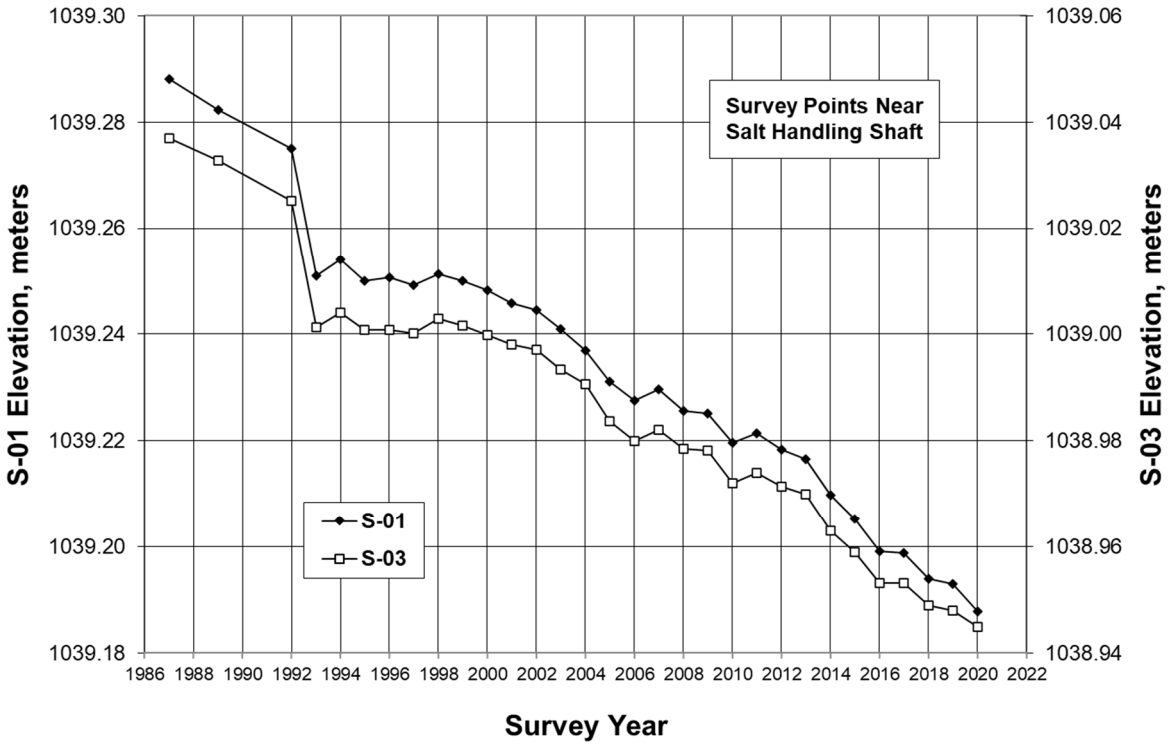

Figure 2.6. Elevations of WIPP monuments S-01 and S-03 located near the Salt Handling Shaft.

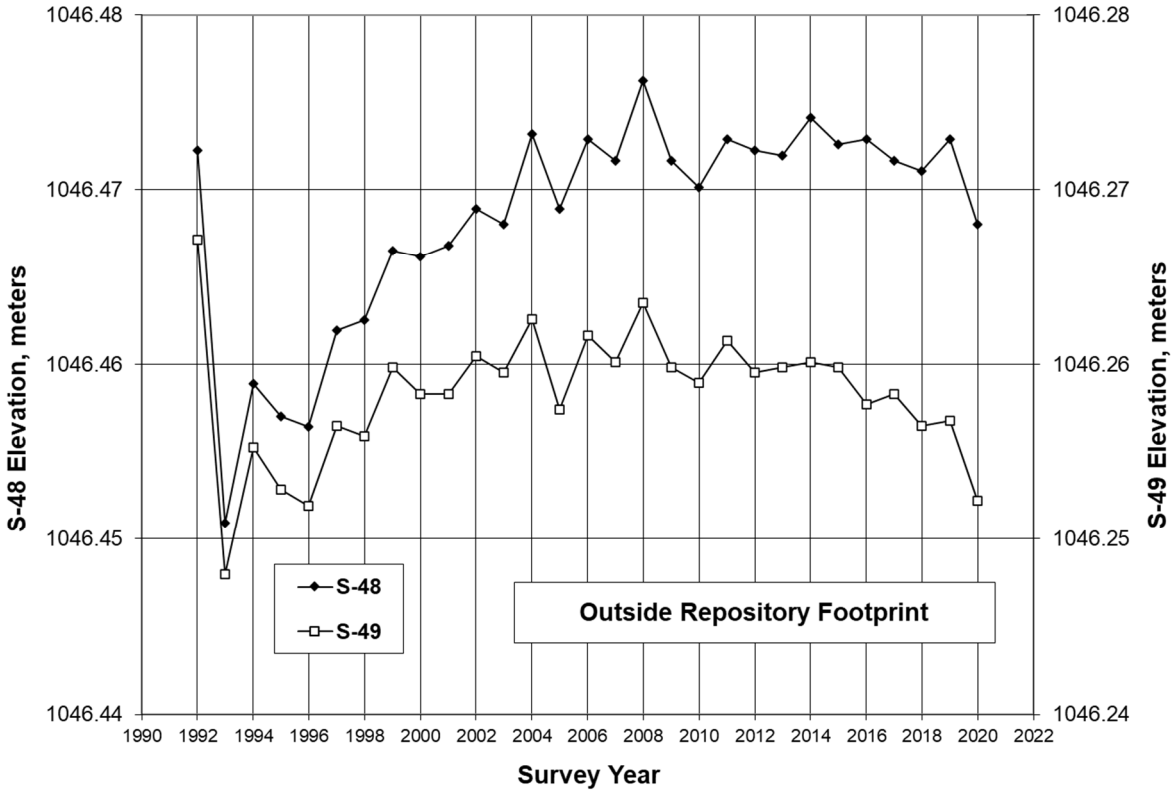

Figure 2.7. Elevations of WIPP monuments S-48 and S-49 located outside the repository footprint.

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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

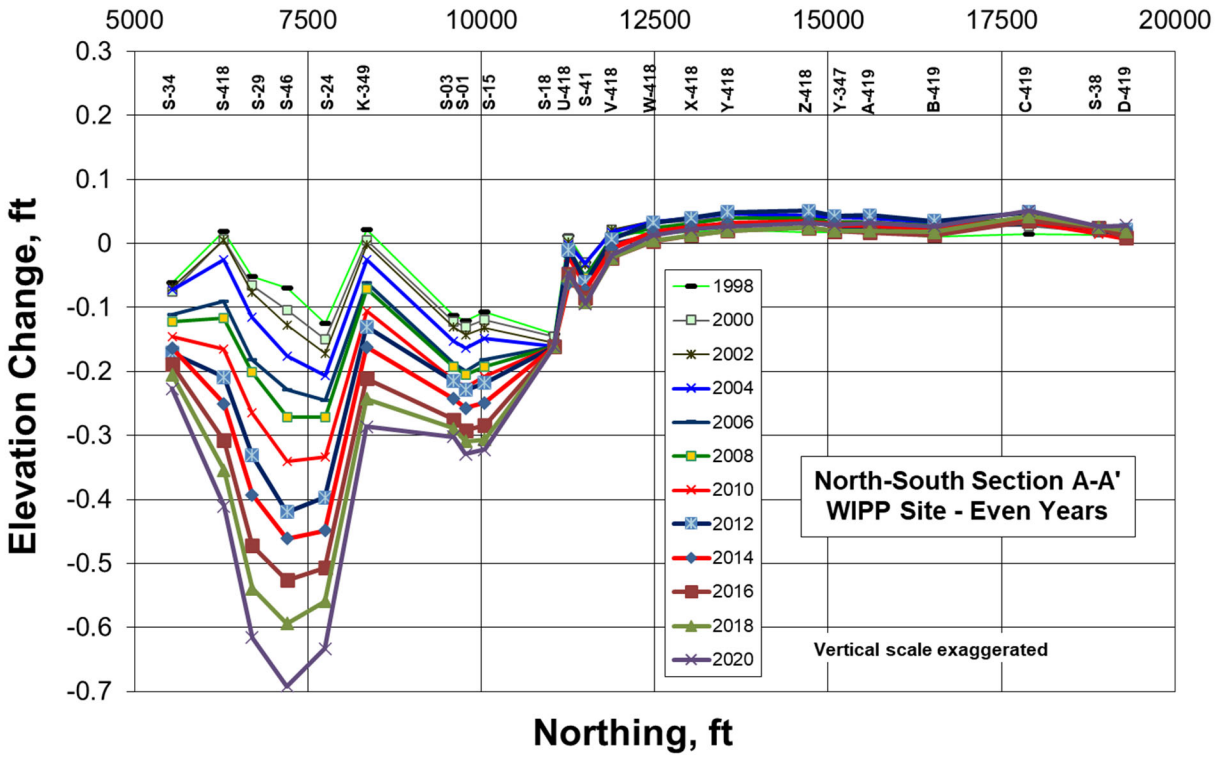

Figure 2.8. North-South subsidence profile A-A'.

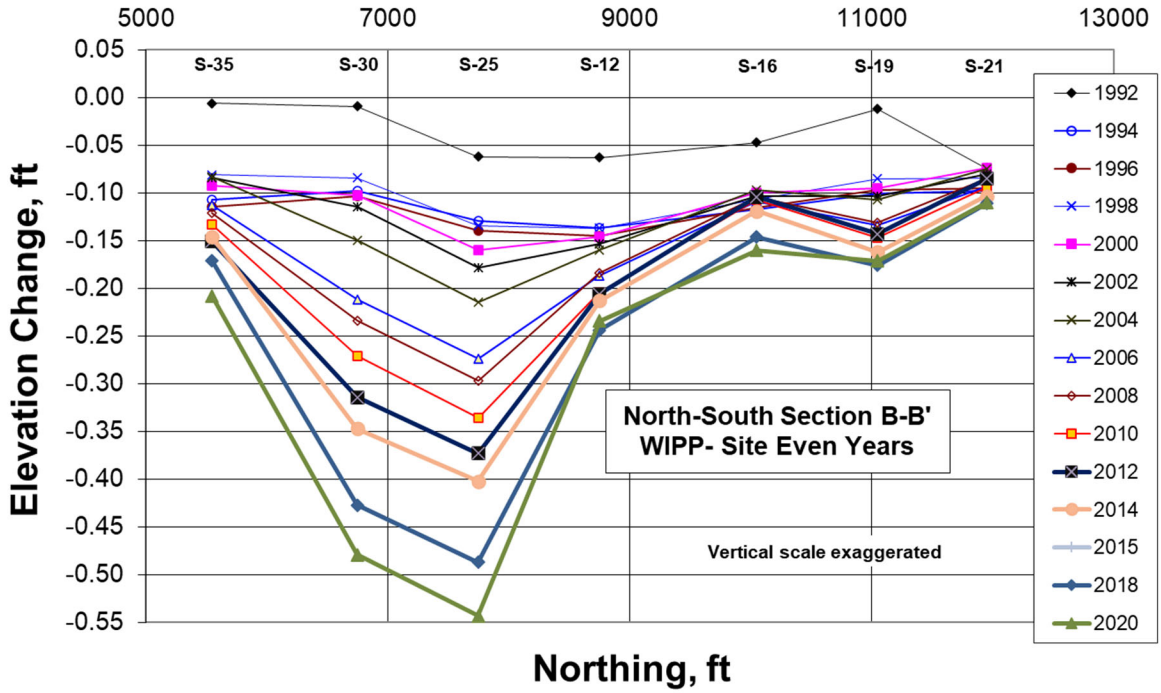

Figure 2.9. North-South subsidence profile B-B'.

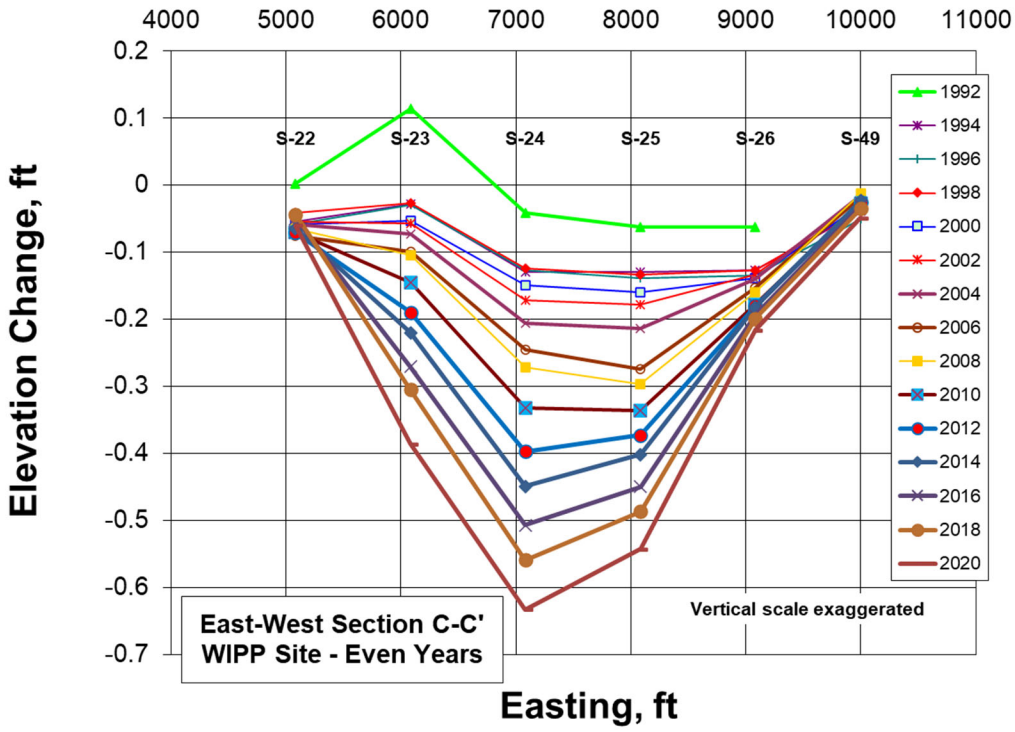

Figure 2.10. East-West subsidence profile C-C′.

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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-14, S-15, S-23, S-24, S-25, S-28, S-29, S-30, S-46, S-52, S-418 and PT-32). The maximum subsidence of 0.692 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 2019-2020 surveys correspond to benchmarks located generally over the center of the repository (e.g., , S-24, , S-28, S-29, S-30, S-46, and S-418) with a maximum rate for this period of -1.6 x 10^{-2} m/yr. This rate exceeds the TV.
3. The effects of subsidence extend away from the repository footprint approximately 1,000 to 1,500 ft (e.g., S-38, 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 8. Based on the 2020 survey data and comparing to the 2019 survey data, a few of the monuments exceeded the 1 x 10^{-2} m/yr TV this reporting period, which has occurred a few times 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 show a gradual increase in rate over 20 years. Considering the WIPP subsidence data over a 20-year period, subsidence rates are below the TV for all monuments. As such, exceedance of the TV in a few monuments over a few years 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 (Managing and Operating Contractor) under *Waste Isolation Pilot Plant Groundwater Protection Program* (DOE 2014e), 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 2020 (DOE 2021d) and Hall Environmental Reports (Bowman 2022). Additionally, WLMP data are reported in monthly memoranda from the M&OC to the scientific advisor.

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2.3.1 Changes in Culebra Water Composition

2.3.1.1 Water Quality Sampling Program (WQSP)

Table 2.13 summarizes the data and Trigger Values (TV) relating to the COMP parameter Change in Culebra Water Composition, as well as its implementation in Performance Assessment (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.

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 – 2020:

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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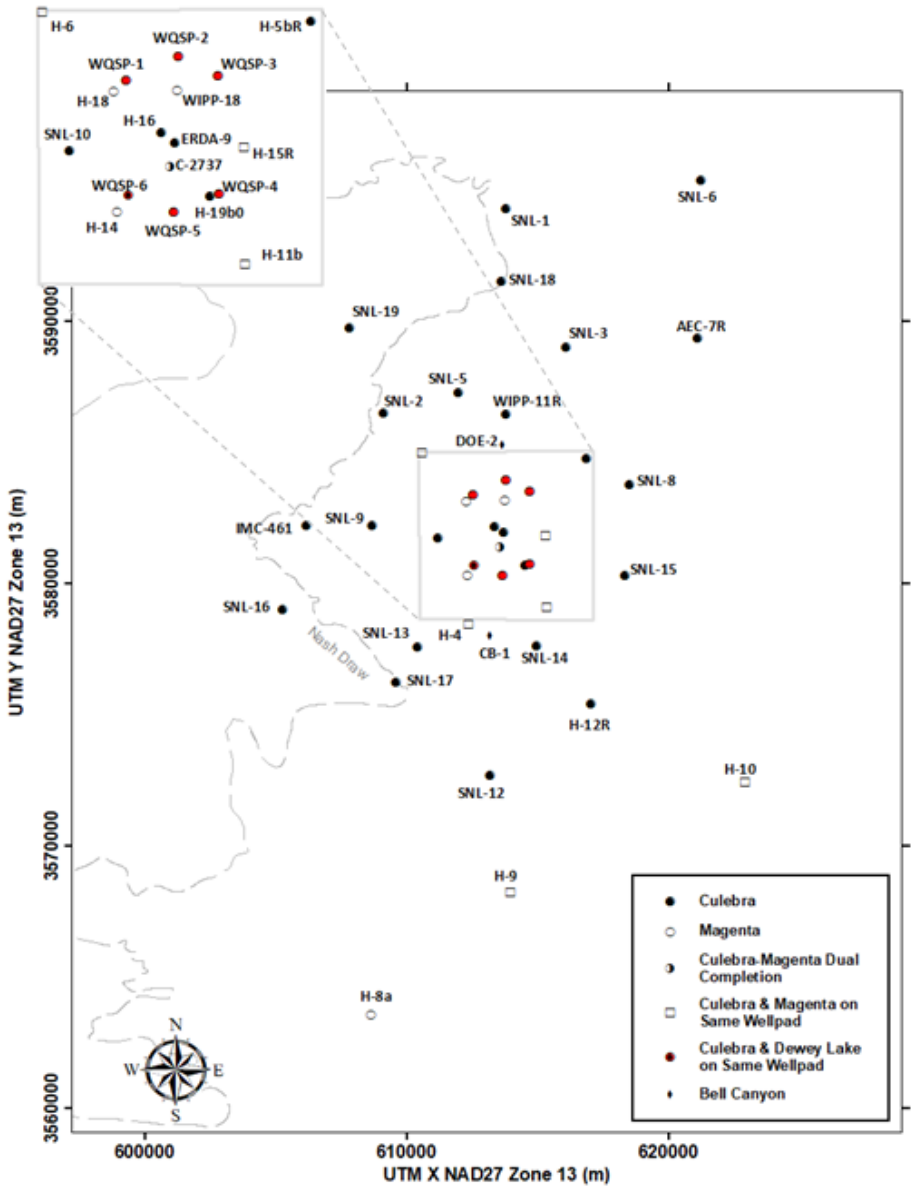

Figure 2.11 Map showing the locations of WQSP wells (red) in relation to the WIPP LWB and the rest of the groundwater monitoring network.

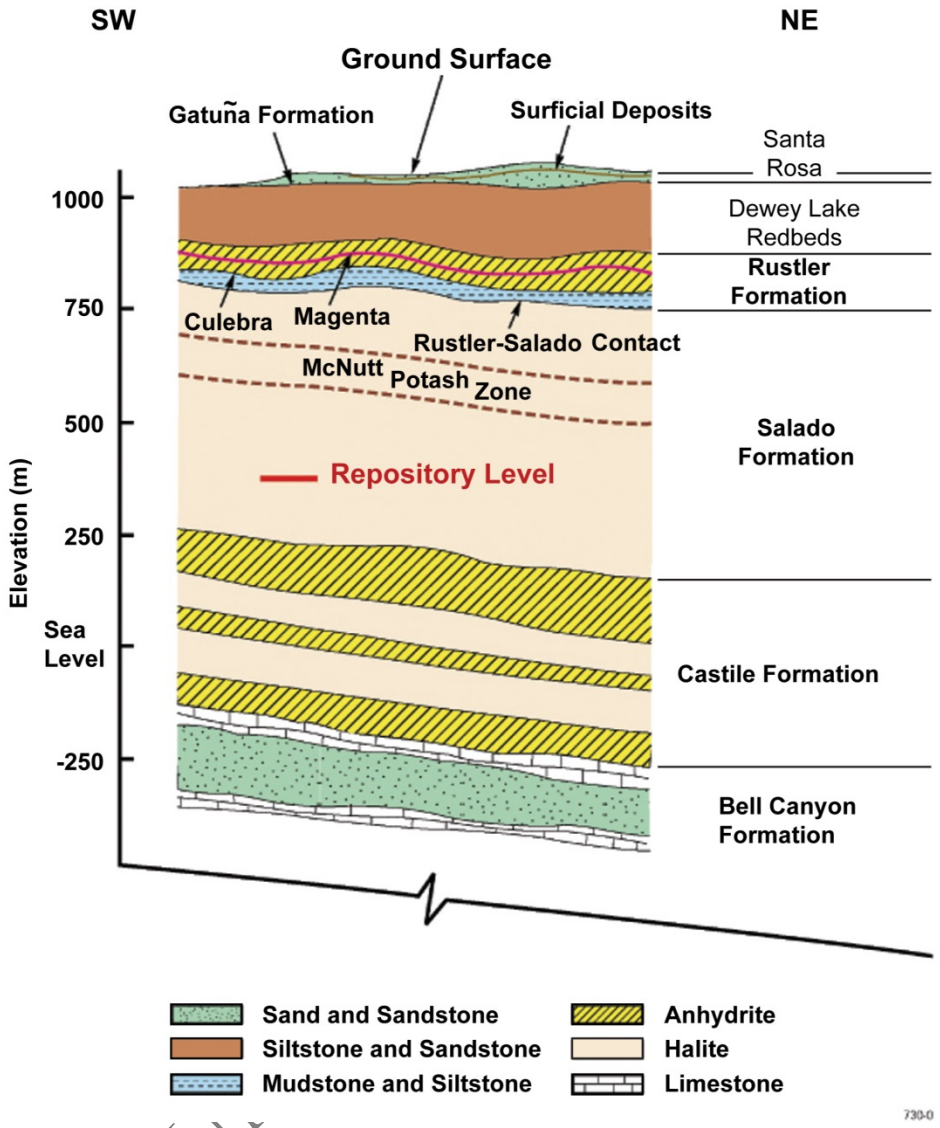

Figure 2.12 Generalized stratigraphic cross section at the WIPP Site

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.

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 42, conducted in 2020, is the ninth 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.

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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

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.

Table 2.14 Round 42 major ion concentrations and charge-balance errors, with p-value defined for each major ion for each well.

Well	Round 41	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	1660	36600	50.3	500	1120	21000	4140	-0.82%
	duplicate	1650	36500	50.4	503	1110	21200	4580	-0.76%
	diff %	-0.60%	-0.27%	0.20%	0.60%	-0.90%	0.95%	*10.09%*	
	p-value	0.390	0.718	0.954	0.280	0.796	0.333	0.057	
	TV violated?	No	No	No	No	No	No	No	
WQSP-2	primary	1450	34500	47.6	481	1020	21000	5250	-0.05%
	duplicate	1460	35600	47.5	478	1020	20500	5290	-2.50%
	diff %	0.69%	3.14%	-0.21%	-0.63%	0.00%	-2.41%	0.76%	
	p-value	0.306	0.444	0.554	0.350	0.613	0.463	0.189	
	TV violated?	No	No	No	No	No	No	No	
WQSP-3	primary	1560	134000	33.5	1550	2430	82700	7640	-0.31%
	duplicate	1490	129000	33.3	1510	2410	81600	7490	0.86%
	diff %	-4.59%	-3.80%	-0.60%	-2.61%	-0.83%	-1.34%	-1.98%	
	p-value	0.501	0.657	0.583	0.316	0.307	0.327	0.597	
	TV violated?	No	No	No	No	No	No	No	
WQSP-4	primary	1620	59900	40.0	739	1190	35800	6980	-2.25%
	duplicate	1620	57900	40.3	752	1190	36400	6960	0.07%
	diff %	0.00%	-3.40%	0.75%	1.74%	0.00%	1.66%	-0.29%	
	p-value	0.627	0.710	0.399	0.238	0.967	0.302	0.897	
	TV violated?	No	No	No	No	No	No	No	
WQSP-5	primary	1100	14000	46.6	310	530	9800	4800	3.61%
	duplicate	1100	15000	46.6	310	530	9900	4500	1.85%
	diff %	0.00%	6.90%	0.00%	0.00%	0.00%	1.02%	-6.45%	
	p-value	0.297	0.101	0.669	0.371	**0.018**	0.531	0.135	
	TV violated?	No	No	No	No	Yes	No	No	
WQSP-6	primary	650	5000	51.2	150	200	4600	4600	3.09%
	duplicate	630	5300	51.3	140	190	4600	4700	0.51%
	diff %	-3.13%	5.83%	0.20%	-6.90%	-5.13%	0.00%	2.15%	
	p-value	0.125	0.210	0.079	0.106	0.079	0.308	0.634	
	TV violated?	No	No	No	No	No	No	No	

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 42 are presented in Table 2.14.

2.3.1.2 Results

WQSP results for sampling round 42 are reported in the 2020 ASER (DOE 2021d) (for Ca^{2+}, Cl^{-}, K^{+}, and Mg^{2+}) and the Hall Environmental Reports (Bowman 2022) (for HCO_3^{-}, Na^{+}, and SO_4^{2-}). The reported major ion concentrations are listed in Table 2.14. Sampling round 42 was conducted between March and May 2020 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 in WQSP-2 water samples resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses were both within the tolerated ± 5% range. The primary and duplicate sample chemistries were within 10% of each other except for the Sulfate ion which had a duplicate value of 10.09% higher than the primary value.

2.3.1.2.2 WQSP-2

All ion concentrations in WQSP-2 water samples resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses were both within the tolerated ± 5% range. The primary and duplicate sample chemistries were within 10% of each other.

2.3.1.2.3 WQSP-3

All ion concentrations in WQSP-3 water samples resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses were both within the tolerated ± 5% range. The primary and duplicate sample chemistries were within 10% of each other.

2.3.1.2.4 WQSP-4

All ion concentrations in WQSP-4 water samples resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses were both within the tolerated ± 5% range. The primary and duplicate sample chemistries were within 10% of each other.

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2.3.1.2.5 WQSP-5

Magnesium concentrations for the WQSP-5 water samples 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 four consecutive sampling rounds. The CBE for both the primary and duplicate analyses were within the tolerated ± 5% range. The primary and duplicate sample chemistries were within 10% of each other.

2.3.1.2.6 WQSP-6

All ion concentrations in WQSP-6 water samples resulted in a p-value greater than 0.05. The CBE for the primary and duplicate analyses were both within the tolerated ± 5% range. The primary and duplicate sample chemistries 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. None of the twelve CBEs fell outside the tolerated ± 5% range. 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. The number of CBEs outside of tolerance was improved this year with a decrease from 6 to 0 between 2018-2020. Sandia National Laboratories will continue to monitor the CBE trend and contact the M&OC and HEAL to review the laboratory-based protocols if the number of out of tolerance CBEs greatly increases. If future analyses reveal a trend of out of compliance CBEs, SNL may investigate the possibility of evaluating additional constituents or the occurrence of ion complexation as part of the CBE calculation.

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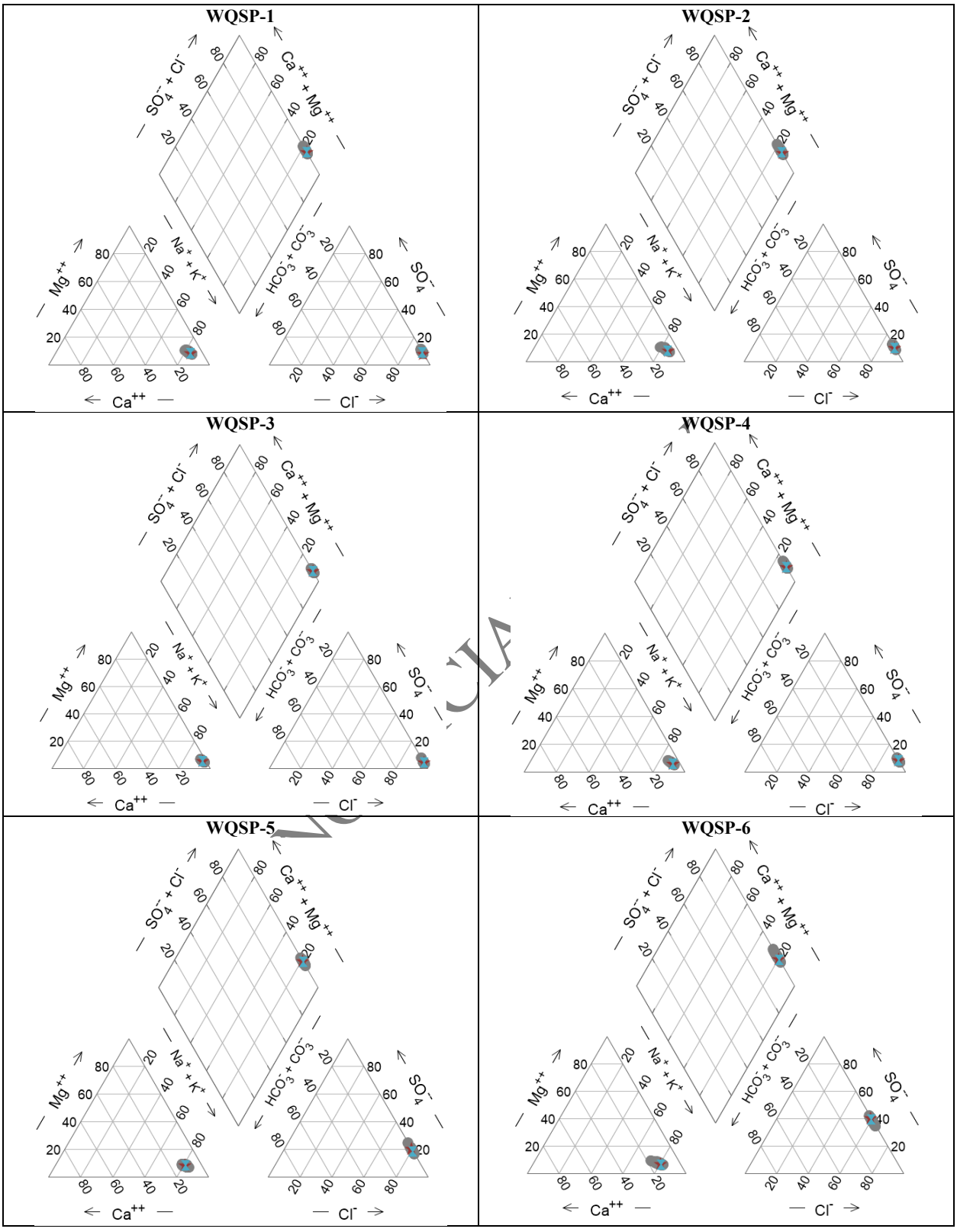

Figure 2.13 Piper diagrams of all data collected from WQSP-1 through WQSP-6. The plots show both historical data (gray) and results from Round 42 (red star and blue hourglass for duplicate).

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 2014a), while annual model results are adjusted to best-fit freshwater heads observed in 2019 (DOE 2021d).

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 2020, the M&OC made monthly water-level measurements in all the WIPP non-perched anthropogenic water (PAW) 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 December 2020, the WIPP monitoring network consisted 59 monitoring wells (including one dual-completion Magenta/Culebra well, see Table 2.16). There were 43 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 Data and TV information for Changes in Groundwater Flow– 2020:

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 2019 and December of 2020				
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 (2010).	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 LWB must fall within the distribution found using 100 model runs used in the baseline PA.		

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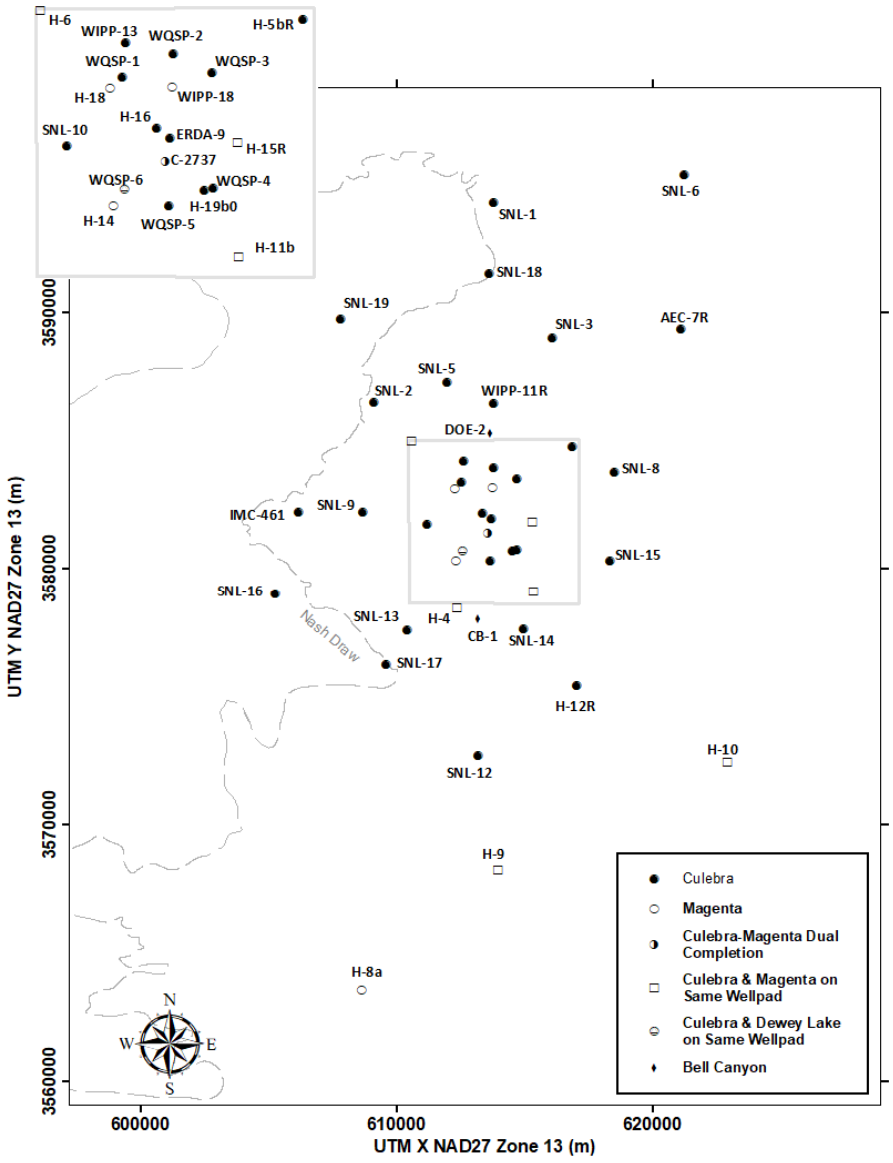

Figure 2.14 Map of the WIPP area showing well pad locations discussed in this section (See Table 2.16 for listing of wells at each well pad). Well H-5bR had not yet been included in the monitoring program as of 2020.

Table 2.16 August 2020 Non-PAW[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-3b1	H-3	MAG
H-4bR	H-4	CUL
H-4c		MAG
H-6bR	H-6	CUL
H-6c		MAG
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-18	H-18	MAG
H-19b0	H-19b	CUL
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-11R	WIPP-11	CUL
WIPP-13	WIPP-13	CUL
WIPP-18	WIPP-18	MAG
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 2010). The model is calibrated to both steady-state freshwater heads and transient pumping test drawdown data. The contour map shown in Figure 2.15 shows the area immediately around the WIPP LWB, 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 the 2020 Culebra Potentiometric Surface Contour Map* (Hayes 2021). This material is summarized in the 2020 ASER, Section 6.2.5 (DOE 2021d).

2.3.2.3 Culebra Freshwater-Head Results and Assessment

Table 2.17 shows the December 2020 freshwater heads reported and used in the development of the Culebra contour map given in the 2020 ASER (DOE 2021d). The particle track shown as a blue arrow in Figure 2.15 begins where the Culebra intersects the WIPP waste-handling shaft and continues to the WIPP LWB, as required by NMED. The travel time for this particle in the boundary-calibrated ensemble-average flow field (5934 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 2.16). The estimated flow velocity of 0.69 m/yr is lower than the 2019 reported velocity of 0.73 m/yr, but similar to the 2018 reported flow velocity of 0.68 m/yr. 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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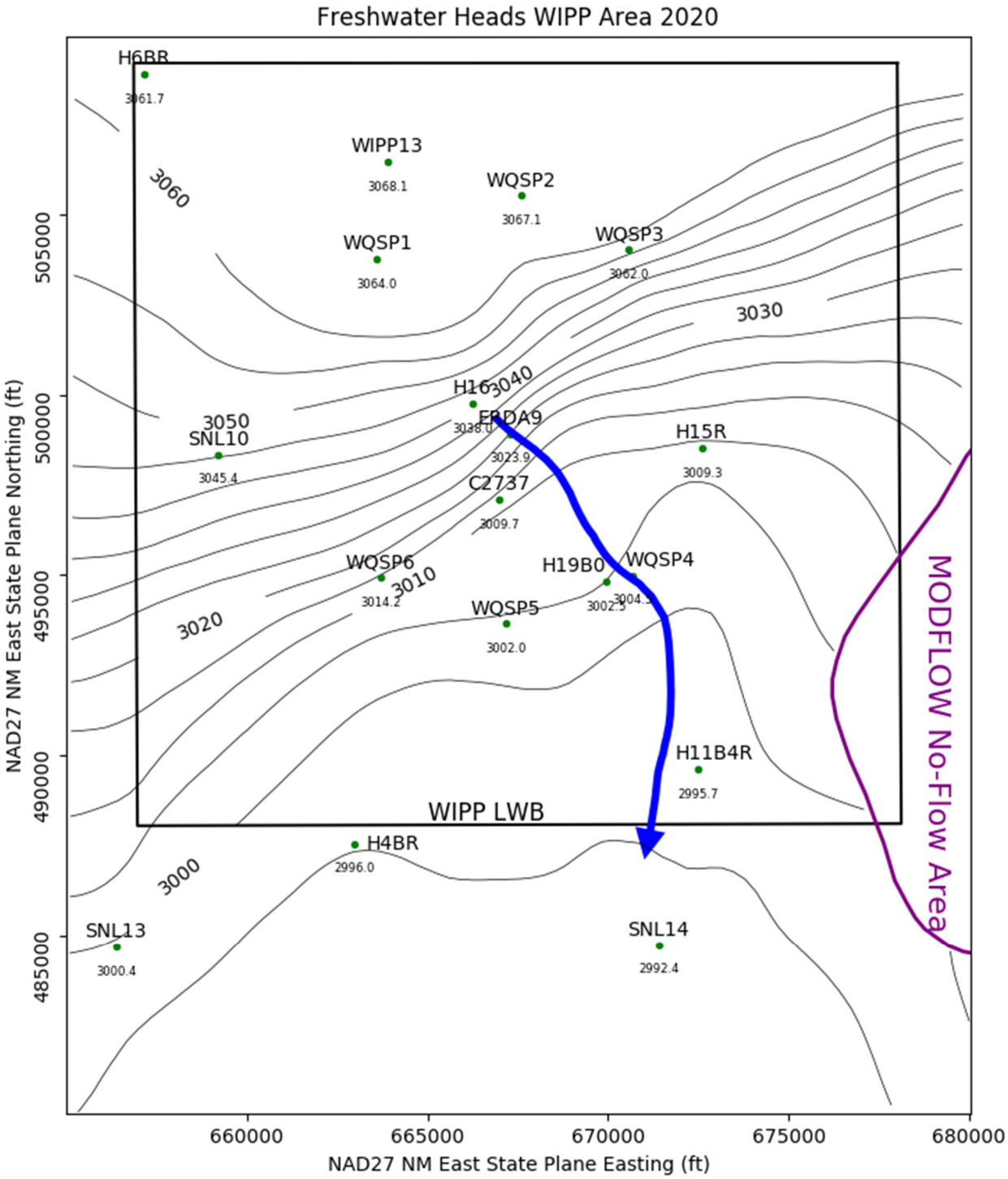

Figure 2.15 December 2020 modeled Culebra potentiometric surface of the immediate WIPP vicinity (DOE 2021d) generated using ensemble average distributed aquifer parameters from the SNL Culebra flow model used in CRA-2014 PA (DOE 2014d).

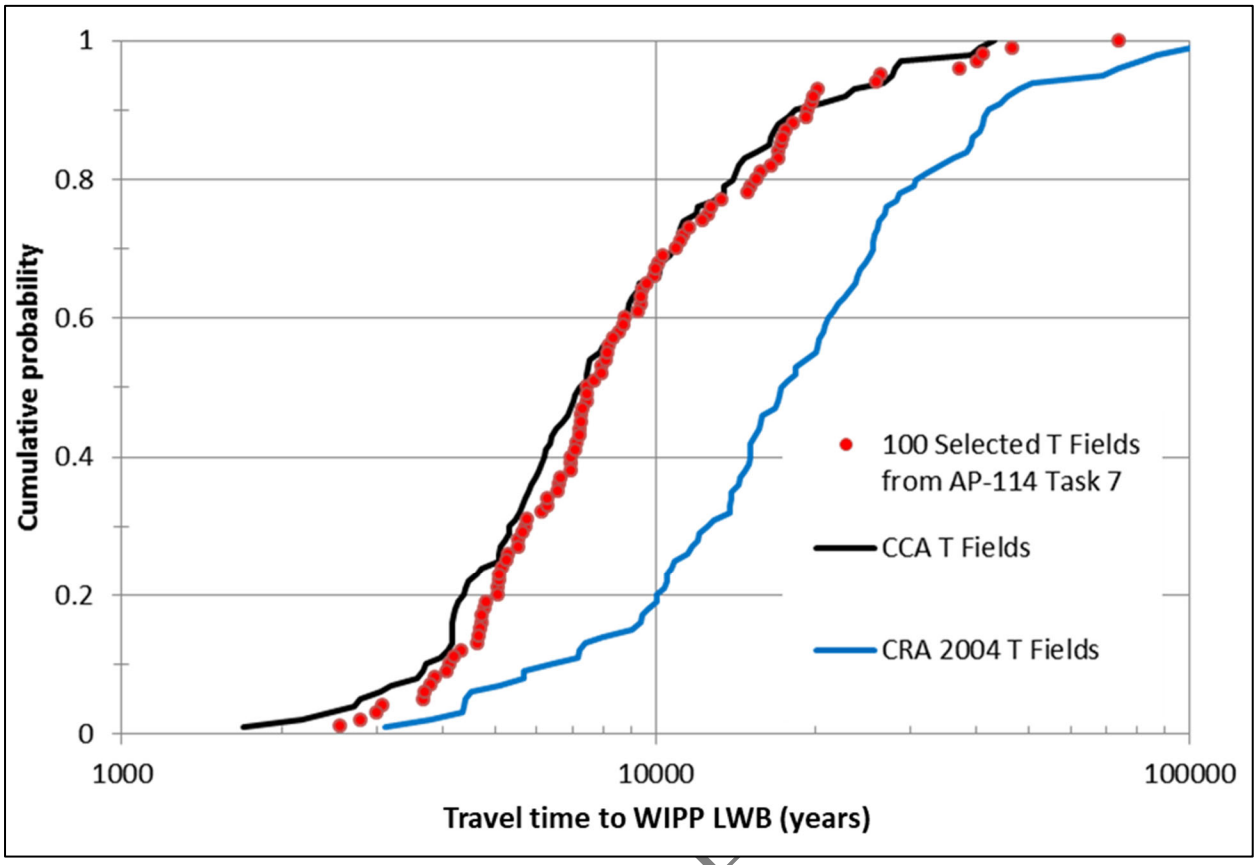

Figure 2.16 Distribution of Particle Travel Times from the center of the WIPP waste panels to WIPP LWB for CCA (black line), CRA-2004 (blue line), and CRA-2009 PABC (red points). Figure from Hart et al. (2009).

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Table 2.17 Summary of December 2020 Culebra freshwater heads

Well ID[1]	Measurement Date	Adjusted Freshwater Head (ft AMSL)	Specific Gravity
AEC-7R	12/7/2020	3058.79	1.065
C-2737	12/9/2020	3009.67	1.024
ERDA-9	12/9/2020	3023.90	1.073
H-4bR	12/8/2020	2995.98	1.020
H-6bR	12/8/2020	3061.76	1.039
H-9bR	12/7/2020	2970.72	1.005
H-10cR[†]	12/7/2020	3019.92	1.087
H-11b4R	12/8/2020	2995.66	1.078
H-12R	12/7/2020	3004.26	1.104
H-15R	12/9/2020	3009.33	1.125
H-16	12/9/2020	3038.02	1.032

Table 2.17 Summary of December 2020 Culebra freshwater heads (continued)

Well ID[1]	Measurement Date	Adjusted Freshwater Head (ft AMSL)	Specific Gravity
H-19b0	12/8/2020	3002.46	1.066
IMC-461	12/8/2020	3032.45	1.000
SNL-1	12/8/2020	3073.45	1.033
SNL-2	12/8/2020	3060.79	1.010
SNL-3	12/8/2020	3070.98	1.029
SNL-5	12/8/2020	3062.35	1.007
SNL-8	12/7/2020	3051.76	1.091
SNL-9	12/8/2020	3045.40	1.018
SNL-10	12/8/2020	3045.93	1.011
SNL-12	12/7/2020	2989.31	1.010
SNL-13	12/7/2020	3000.38	1.024
SNL-14	12/8/2020	2992.35	1.047
SNL-16	12/7/2020	3006.26	1.017
SNL-17	12/7/2020	3000.77	1.014
SNL-18	12/8/2020	3064.53	1.011
SNL-19	12/8/2020	3060.94	1.006
WIPP-11R	12/8/2020	3072.23	1.036
WIPP-13	12/8/2020	3068.14	1.035
WQSP-1	12/9/2020	3063.99	1.041
WQSP-2	12/9/2020	3067.12	1.033
WQSP-3	12/9/2020	3062.04	1.141
WQSP-4	12/9/2020	3004.50	1.078
WQSP-5	12/8/2020	3002.03	1.029
WQSP-6	12/8/2020	3014.21	1.016

[1]SNL-6 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. Well H-5bR is not listed as it was in development during December sampling.

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2.3.2.4 Interpretation/Summary of the 2020 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 2021d). 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 August 2019 and is consistent with the historical general north to south gradient.

The ensemble-averaged model predicted travel time for a particle of 5,934 years currently falls within the range modeled for 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.

Table 2.18 Summary of 2015-2020 water-level changes in non-Culebra units

Well	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)	Feb 2018 Water Level Elevation (m AMSL)	Feb 2019 Water Level Elevation (m AMSL)	Feb 2020 Water Level Elevation (m AMSL)	2020-2019 Water Level Change (m)
	Magenta Wells							
C-2737	958.7	958.95	959.78	961.11	961.65	962.03	961.89	-0.14
H-2b1	958.05	958.46	958.61	958.87	959.32	959.93	960.27	0.34
H-3b1	959.45	959.72	960.59	961.84	962.36	962.69	962.47	-0.22
H-4c	959.55	959.86	959.82	959.77	959.71	959.8	959.55	-0.25
H-6c	936.2	936.36	936.32	936.34	936.12	936.07	935.84	-0.23
H-8a	923.2	923.32	923.3	923.28	923.1	922.98	922.88	-0.10
H-9c	956.18	955.73	955.78	955.62	955.71	956.09	957.87	**1.78**
H-10a	948.64	948.91	NA	948.66	948.54	948.1	947.78	-0.32
H-11b2	957.24	957.48	958.15	959.05	959.41	959.62	959.30	-0.32
H-14	957.15	957.41	957.54	957.63	957.6	957.76	957.78	0.02
H-15	960.32	961.41	967.8	967.11	966.26	965.67	964.67	-1.00
H-18	962.42	962.87	962.99	963.3	963.47	963.72	963.80	0.08
WIPP-18	960.65	960.89	962.35	964.18	964.69	964.86	964.53	-0.33
	Dewey Lake Well							
WQSP-6A	974.16	974.2	973.99	974.07	973.99	974.01	973.91	-0.10
	Bell Canyon Wells							
CB-1	922.93	924.96	925.64	925.21	926.33	927.86	929.14	**1.28**
DOE-2	935.19	935.37	935.5	935.54	935.47	935.68	935.85	0.17

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

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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 2020 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 -0.70 to 1.92 m, with two wells experiencing water-level changes ≥ 0.61 m (2.0 ft). Continuous pressure measurements in the wells confirm that the changes in water level in wells

H-9c and H-15 are gradual and not the result of a transient process. Water levels in wells H-2b1, H-18, and WIPP-18 have gradually been increasing for more than 5 years.

Water-levels in the Bell Canyon well CB-1 decreased by 0.48 m contrary to the rising trend seen in CB-1 since swabbing activities cleaned out foreign water from the well in 2008 suggesting that the water level may have stabilized (Table 2.18). Water levels in DOE-2, the other Bell Canyon well, are increasing slightly.

2.4 Waste Activity

Table 2.19 summarizes data and TV information relating to the COMP, 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, 2021. 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. 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.

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, 2021 is 2.4×10^4 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 - 2021:

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, 2020 to June 30, 2021			
Total curie content of emplaced CH-TRU and RH-TRU waste. *[Total radionuclide inventories reported by the WDS]*			
Year 2021 COMP Assessment Value			
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 FEP W2 "Waste Activity"	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 FEP W84 "Cuttings" FEP W85 "Cavings"	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 FEP W86 "Spallings"	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 2021b and Van Soest 2012).

Radionuclide (CCA Table 4-10)	Non-Decayed Total Activity as of June 30, 2020 (curies)	Non-Decayed CH Inventory as of June 30, 2021 (curies)	Non-Decayed RH Inventory as of June 30, 2021 (curies)	Non-Decayed Total Activity as of June 30, 2021 (curies)	CRA-2014Total Inventory at Closure (2033) (curies)
^{241}Am	2.673E+05	2.756E+05	6.717E+02	2.712E+05	7.05E+05
^{137}Cs	1.448E+04	2.180E+01	1.447E+04	1.448E+04	2.35E+05
^{238}Pu	4.951E+05	5.031E+05	7.996E+02	5.038E+05	6.01E+05
^{239}Pu	3.388E+05	3.439E+05	4.151E+02	3.443E+05	5.74E+05
^{240}Pu	8.397E+04	8.503E+04	2.909E+02	8.531E+04	1.75E+05
^{242}Pu	2.846E+01	2.855E+01	3.826E-01	2.893E+01	8.09E+03
^{90}Sr	7.715E+03	1.107E+02	7.609E+03	7.725E+03	2.09E+05
^{233}U	7.253E+00	7.257E+00	3.848E-01	7.671E+00	1.39E+02
^{234}U	9.013E+01	9.023E+01	1.212E-01	9.137E+01	2.42E+02
^{238}U	1.823E+01	1.848E+01	3.922E-02	1.852E+01	6.48E+01
Total	**1.214E+06**	**1.208E+06**	**2.425E+04**	**1.227E+06**	**2.51E+06**

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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 that has been reviewed and certified. Therefore, the CRA-2014 represents 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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