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2.0 SITE CHARACTERIZATION

1
2 The U.S. Department of Energy (DOE) uses the performance assessment (*PA*) methodology
3 described in ~~Section 6.4~~ *Chapter 6.0* to demonstrate that the Waste Isolation Pilot Plant (WIPP)
4 disposal system will meet the environmental performance standards of Title 40 of the Code of
5 Federal Regulations (CFR) Part 191 Subparts B and C. In order to effectively use *PA*, three
6 inputs are necessary: What can happen to the disposal system? What are the chances of it
7 happening? What are the consequences if it happens? The answers to these questions are derived
8 from many sources, including field studies, laboratory evaluations, experiments, and, in the case
9 of some features not amenable to direct characterization, professional judgment. The
10 information used in *PA* is described in terms of features of the disposal system that can be used
11 to describe its isolation capability, events that can affect the disposal system, and processes that
12 are reasonably expected to act on the disposal system.

13 The DOE selected the Los Medaños region and present site for the WIPP based on certain
14 defined siting criteria. The site selection process, which was focused on sites that contained
15 certain favorable features while other unfavorable features were excluded, was applied by the
16 DOE with the intent of finding the area that best met the siting criteria. The siting process is
17 discussed in this application in *CCA* Appendix GCR. ~~See Table 1-2 in Chapter 1.0 for a list of~~
18 ~~appendices that~~ *Chapters 3.0, 4.0, and 6.0 and several appendices* provide additional
19 information supporting this chapter.

20 Conceptual models of the WIPP disposal system simulate the interaction between the natural
21 environment (described in this chapter), the engineered structures (described in Chapter 3.0) and
22 the waste (described in Chapter 4.0). One starting point in developing conceptual models of the
23 WIPP disposal system is an understanding of the natural characteristics of the site and of the
24 region around the site. Site characterization and model development is an interactive process
25 that the DOE has used for many years. Basic site information leads to initial models. Initial
26 model sensitivity studies indicate the need for more detailed information. More site
27 characterization then leads to improved models. In addition, an assessment of the impacts of
28 uncertainty inherent in the parameters used to numerically simulate geological features and
29 processes has also led the DOE to conduct more in-depth investigations of the natural system.
30 These investigations generally proceeded until uncertainty was sufficiently reduced or to the
31 point where no further information could be reasonably obtained.

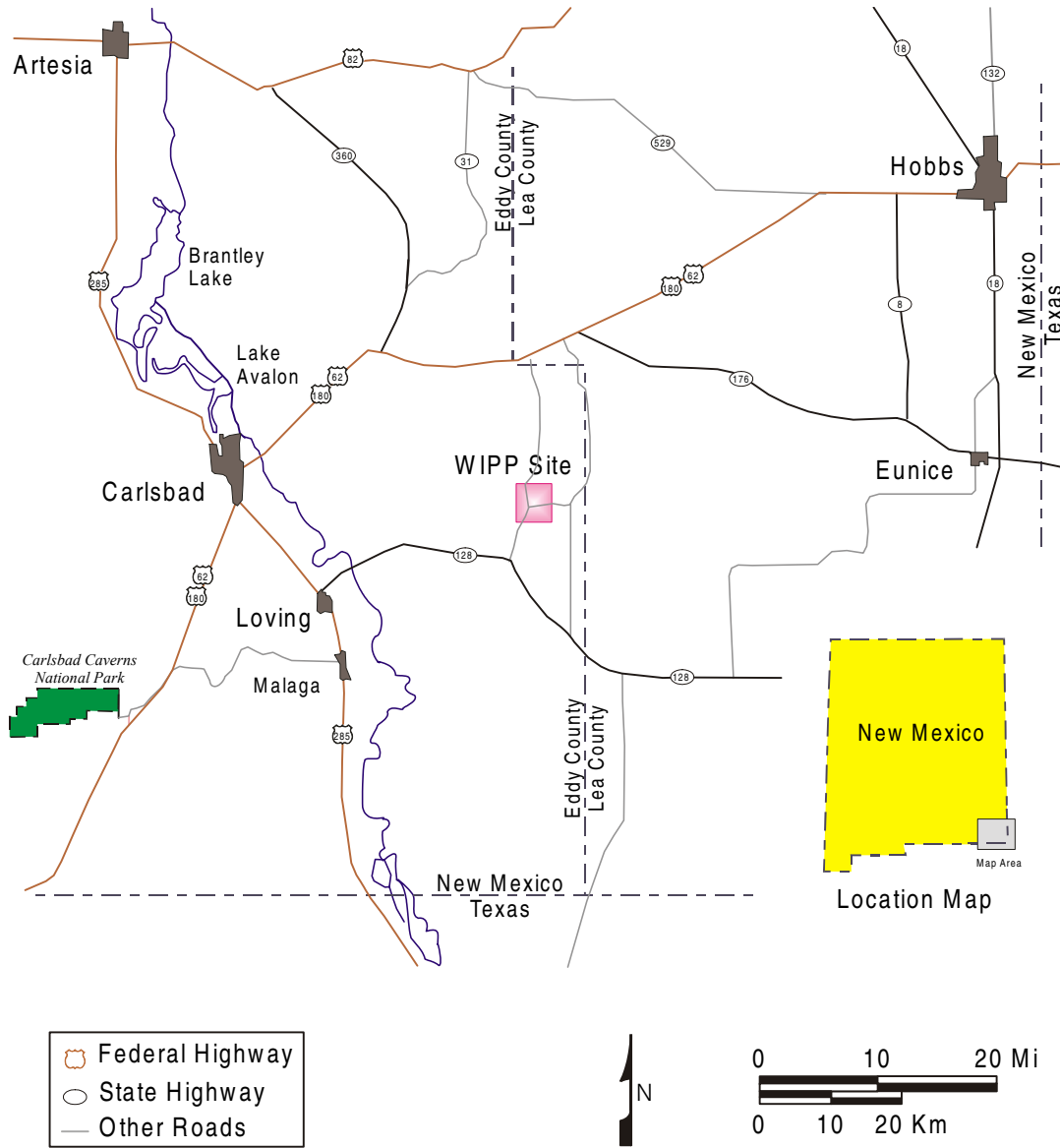
32 The discussion of conceptual models and initial and boundary conditions is in Section 6.4 and
33 Appendix *PA, Attachment MASS* (~~Sections MASS.2 and MASS.4 through MASS.18~~).
34 Conceptual models implement scenarios about the future. Scenario development is discussed in
35 Section 6.3. Scenario development requires as inputs information about the natural features,
36 events, and processes (FEPs) that can reasonably be expected to act on the disposal system.
37 While the list of possible FEPs is derived independently of the disposal system, their screening
38 (in Section 6.2 ~~Appendix SCR~~ and *Appendix PA, Attachment SCR*) is based on a ~~basic~~ *an*
39 understanding of the geology, hydrology, and climatology of the region and the site in particular.
40 The screening methodology follows U.S. Environmental Protection Agency (EPA) criteria on the
41 Scope of Performance Assessments (40 CFR § 191.32). This basic understanding is provided in
42 this chapter and its associated appendices.

1 Table 2-1 shows the tie between the list of natural FEPs that were identified and screened for the
2 WIPP and the sections of this chapter or Appendix *PA, Attachment SCR*. Those FEPs that have
3 been retained for inclusion in the modeling are shown in bold in Table 2-1. These generally
4 receive a greater level of detail in the following discussions and are supported by additional
5 discussion in Chapter 6.0, Appendix *PA, Attachments MASS and SCR*, and Appendix ~~MASS~~.
6 In addition, parameter values that have been derived for these FEPs are included in Appendix
7 ~~PAR~~ *Appendix PA, Attachment PAR*.

8 In this chapter, the DOE describes the WIPP site geology, hydrology, climatology, air quality,
9 ecology, and cultural and natural resources. This chapter's purpose is to (1) explain
10 characteristics of the site, (2) describe background environmental quality, and (3) discuss
11 features of the site that might be important for inclusion in a quantitative *PA*. The DOE has used
12 this information to develop and screen FEPs and to develop conceptual, mathematical, and
13 computational models to evaluate the efficacy of natural and engineered barriers in meeting
14 environmental performance standards (Chapter 6.0). Results of these predictive models are used
15 by the DOE to demonstrate that the DOE has a reasonable expectation that compliance with
16 applicable regulations will be achieved. This chapter has been prepared to describe the site prior
17 to excavating the repository. Excavation of the repository and its associated effects, such as the
18 disturbed rock zone (DRZ), are discussed in Chapter 3.0.

19 The DOE located the WIPP site 42 km (26 mi) east of Carlsbad, New Mexico, in Eddy County
20 (Figure 2-1). Additional details related to the location of the WIPP site can be found in Section
21 2.1.4.2 and in Figure 3-1 (see Chapter 3.0). The latitude of the WIPP site center is 32°22' 11" N
22 and the longitude is 103°47' 30" W. The region surrounding the WIPP site has been studied for
23 many years, and exploration of both potash and hydrocarbon deposits has provided extensive
24 knowledge of the geology of the region. Two exploratory holes were drilled by the federal
25 government in 1974 at a location northeast of the present site; that location was abandoned in
26 1975 as a possible repository site after U.S. Energy Research and Development Administration
27 (ERDA)-6 borehole was drilled and unacceptable structure and pressurized brine were
28 encountered. The results of these investigations are reported in Powers et al. (1978, 2 – 6;
29 included in ~~this document as~~ *CCA* Appendix GCR). During late 1975 and early 1976, the ERDA
30 identified the current site, and an initial exploratory hole (ERDA-9) was drilled. By the time an
31 initial phase of site characterization was completed in August 1978, 47 holes had been or were
32 being drilled for various hydrologic and geologic purposes. Geophysical techniques were
33 applied to augment data collected from boreholes. Since 1978, the DOE has drilled additional
34 holes to support hydrologic studies, geologic studies, and facility design. Geophysical logs,
35 cores, basic data reports, geochemical sampling and testing, and hydrological testing and
36 analyses are reported by the DOE and its scientific advisor, Sandia National Laboratories (SNL),
37 in numerous public documents. Many of those documents form the basis for the DOE's
38 positions in this application. As necessary, specific references from these documents are cited to
39 reinforce statements being made.

40 Biological studies of the site began in 1975 to gather information for the Environmental Impact
41 Statement (*DOE 1980*). Meteorological studies began in 1976, and economic studies were
42 initiated in 1977. Baseline environmental data were initially reported in 1977 and are now
43 updated annually by the DOE.



1

2

Figure 2-1. WIPP Site Location in Southeastern New Mexico

CCA-021-2

Table 2-1. — Issues Related to the Natural Environment That Were Evaluated for the WIPP Performance Assessment Scenario Screening

Features, Events, and Processes (FEPs) —	Discussion
NATURAL FEPs	
— Stratigraphy	
— Stratigraphy	Section 2.1.3
— Brine reservoirs	Section 2.2.1.2.2
— Tectonics	
— Changes in regional stress	Section 2.1.5.1
— Regional tectonics	Section 2.1.5.1
— Regional uplift and subsidence	Section 2.1.5.1
— Structural FEPs	
— Deformation	
— Salt deformation	Section 2.1.6.1
— Diapirism	Appendix SCR, Section SCR.1.1.3.1
— Fracture development	
— Formation of fractures	Section 2.1.5
— Changes in fracture properties	Section 2.1.5
— Fault movement	
— Formation of new faults	Section 2.1.5
— Fault movement	Section 2.1.5.4
— Seismic activity	
— Seismic activity	Section 2.6
Crustal processes	
— Igneous activity	
— Volcanic activity	Section 2.1.5.4
— Magmatic activity	Appendix SCR, Section SCR.1.1.4.1.2
— Metamorphic activity	
— Metamorphism	Appendix SCR, Section SCR.1.1.4.2
Geochemical FEPs	
— Dissolution	
— Shallow dissolution	Section 2.1.6.2
— Lateral dissolution	Section 2.1.6.2
— Deep dissolution	Section 2.1.6.2
— Solution chimneys	Section 2.1.6.2
— Breccia pipes	Section 2.1.6.2
— Collapse breccias	Section 2.1.6.2
— Mineralization	
— Fracture infills	Section 2.1.3.5.2
SUBSURFACE HYDROLOGICAL FEPs	
— Groundwater characteristics	
— Saturated groundwater flow	Section 2.2.1

1

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP Performance Assessment Scenario Screening (Continued)

Features, Events, and Processes (FEPs)	Discussion
— Unsaturated groundwater flow	Section 2.2.1
— Fracture flow	Section 2.2.1
— Density effects on groundwater flow	Section 2.2.1
— Effects of preferential pathways	Section 2.2.1
— Changes in groundwater flow	
— Thermal effects on groundwater flow	Appendix SCR, Section SCR.1.2.2.3
— Saline water intrusion	Appendix SCR, Section SCR.1.2.2.1
— Freshwater intrusion	Appendix SCR, Section SCR.1.2.2.2
— Hydrological effects of seismic activity	Appendix SCR, Section SCR.1.2.2.5
— Natural gas intrusion	Appendix SCR, Section SCR.1.2.2.4
SUBSURFACE GEOCHEMICAL FEPs	
— Groundwater geochemistry	Section 2.4.2.1
— Groundwater geochemistry	
— Changes in groundwater geochemistry	
— Saline water intrusion	Appendix SCR, Section SCR.1.2.2.1
— Freshwater intrusion	Appendix SCR, Section SCR.1.2.2.2
— Changes in groundwater Eh	Appendix SCR, Section SCR.1.3.2
— Changes in groundwater pH	Appendix SCR, Section SCR.1.3.2
— Effects of dissolution	Appendix SCR, Section SCR.1.3.2
GEOMORPHOLOGICAL FEPs	
— Physiography	
— Physiography	Section 2.1.4
— Meteorite impact	
— Impact of a large meteorite	Appendix SCR, Section SCR.1.4.2
— Denudation	
— Weathering	
— Mechanical weathering	Appendix SCR, Section SCR.1.4.3.1
— Chemical weathering	Appendix SCR, Section SCR.1.4.3.1
— Erosion	
— Eolian erosion	Section 2.1.3.10
— Fluvial erosion	Section 2.2.2

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP Performance Assessment Scenario Screening (Continued)

Features, Events, and Processes (FEPs)	Discussion
— Mass wasting	Appendix SCR, Section SCR.1.4.3.2
— Sedimentation	
— Eolian deposition	Appendix SCR, Section SCR.1.4.3.3
— Fluvial deposition	Appendix SCR, Section SCR.1.4.3.3
— Lacustrine deposition	Appendix SCR, Section SCR.1.4.3.3
— Mass wasting	Appendix SCR, Section SCR.1.4.3.3
— Soil development	
— Soil development	Section 2.1.3.10
SURFACE HYDROLOGICAL FEPs	
— Fluvial	
— Stream and river flow	Section 2.2.2
— Lacustrine	
— Surface water bodies	Section 2.2.2
— Groundwater recharge and discharge	
— Groundwater discharge	Section 2.2.1
— Groundwater recharge	Section 2.2.1
— Infiltration	Section 2.1.4.2
— Changes in surface hydrology	
— Changes in groundwater recharge and discharge	Section 2.2.1
— Lake formation	Section 2.2.2
— River flooding	Section 2.2.2
CLIMATIC FEPs	
— Climate	
— Precipitation (for example, rainfall)	Section 2.5.2.3
— Temperature	Section 2.5.2.2
— Climate change	
— Meteorological	
— Climate change	Section 2.5.1
— Glaciation	
— Glaciation	Section 2.5.1
— Permafrost	Appendix SCR, Section SCR.1.6.2.2
MARINE FEPs	
— Seas	
— Seas and oceans	Appendix SCR, Section SCR.1.7.1

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP Performance Assessment Scenario Screening (Continued)

Features, Events, and Processes (FEPs)	Discussion
— Estuaries	Appendix SCR, Section SCR.1.7.1
— Marine sedimentology	
— Coastal erosion	Appendix SCR, Section SCR.1.7.2
— Marine sediment transport and deposition	Appendix SCR, Section SCR.1.7.2
— Sea level changes	
— Sea level changes	Appendix SCR, Section SCR.1.7.3
ECOLOGICAL FEPs	
— Flora & fauna	
— Plants	Section 2.4.1
— Animals	Section 2.4.1
— Microbes	Appendix SCR, Section SCR.1.8.1
— Changes in flora & fauna	
— Natural ecological development	Section 2.4.1

1

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP PA Scenario Screening

<i>Features, Events, and Processes (FEPs)</i>	<i>EPA FEP No.</i>	<i>Discussion</i>
<i>NATURAL FEPs</i>		
<i>Stratigraphy</i>		
<i>Stratigraphy</i>	<i>N1</i>	<i>Section 2.1.3</i>
<i>Brine reservoirs</i>	<i>N2</i>	<i>Section 2.2.1.2.2</i>
<i>Tectonics</i>		
<i>Changes in regional stress</i>	<i>N3</i>	<i>Section 2.1.5.1</i>
<i>Regional tectonics</i>	<i>N4</i>	<i>Section 2.1.5.1</i>
<i>Regional uplift and subsidence</i>	<i>N5</i>	<i>Section 2.1.5.1</i>
<i>Structural FEPs</i>		
<i>Deformation</i>		
<i>Salt deformation</i>	<i>N6</i>	<i>Section 2.1.6.1</i>
<i>Diapirism</i>	<i>N7</i>	<i>Appendix PA, Attachment SCR</i>
<i>Fracture development</i>		
<i>Formation of fractures</i>	<i>N8</i>	<i>Section 2.1.5</i>
<i>Changes in fracture properties</i>	<i>N9</i>	<i>Section 2.1.5</i>
<i>Fault movement</i>		
<i>Formation of new faults</i>	<i>N10</i>	<i>Section 2.1.5</i>
<i>Fault movement</i>	<i>N11</i>	<i>Section 2.1.5.3</i>
<i>Seismic activity</i>		
<i>Seismic activity</i>	<i>N12</i>	<i>Section 2.6</i>
<i>Crustal processes</i>		
<i>Igneous activity</i>		

2

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP PA Scenario Screening — Continued

<i>Features, Events, and Processes (FEPs)</i>	<i>EPA FEP No.</i>	<i>Discussion</i>
<i>Volcanic activity</i>	<i>N13</i>	<i>Section 2.1.5.4</i>
<i>Magmatic activity</i>	<i>N14</i>	<i>Appendix PA, Attachment SCR</i>
<i>Metamorphic activity</i>		
<i>Metamorphism</i>	<i>N15</i>	<i>Appendix PA, Attachment SCR</i>
<i>Geochemical FEPs</i>		
<i>Dissolution</i>		
<i>Shallow dissolution</i>	<i>N16</i>	<i>Section 2.1.6.2</i>
<i>Lateral dissolution</i>	<i>N17</i>	<i>Section 2.1.6.2</i>
<i>Deep dissolution</i>	<i>N18</i>	<i>Section 2.1.6.2</i>
<i>Solution chimneys</i>	<i>N19</i>	<i>Section 2.1.6.2</i>
<i>Breccia pipes</i>	<i>N20</i>	<i>Section 2.1.6.2</i>
<i>Collapse breccias</i>	<i>N21</i>	<i>Section 2.1.6.2</i>
<i>Mineralization</i>		
<i>Fracture infills</i>	<i>N22</i>	<i>Section 2.1.3.5.2</i>
<i>SUBSURFACE HYDROLOGICAL FEPs</i>		
<i>Groundwater characteristics</i>		
<i>Saturated groundwater flow</i>	<i>N23</i>	<i>Section 2.2.1</i>
<i>Unsaturated groundwater flow</i>	<i>N24</i>	<i>Section 2.2.1</i>
<i>Fracture flow</i>	<i>N25</i>	<i>Section 2.2.1</i>
<i>Density effects on groundwater flow</i>	<i>N26</i>	<i>Section 2.2.1</i>
<i>Effects of preferential pathways</i>	<i>N27</i>	<i>Section 2.2.1</i>
<i>Changes in groundwater flow</i>		
<i>Thermal effects on groundwater flow</i>	<i>N28</i>	<i>Appendix PA, Attachment SCR</i>
<i>Saline water intrusion</i>	<i>N29</i>	<i>Appendix PA, Attachment SCR</i>
<i>Freshwater intrusion</i>	<i>N30</i>	<i>Appendix PA, Attachment SCR</i>
<i>Hydrological effects of seismic activity</i>	<i>N31</i>	<i>Appendix PA, Attachment SCR</i>
<i>Natural gas intrusion</i>	<i>N32</i>	<i>Appendix PA, Attachment SCR</i>
<i>SUBSURFACE GEOCHEMICAL FEPs</i>		
<i>Groundwater geochemistry</i>		
<i>Groundwater geochemistry</i>	<i>N33</i>	<i>Section 2.2.1.4.1.2</i>
<i>Changes in groundwater geochemistry</i>		
<i>Saline water intrusion</i>	<i>N34</i>	<i>Appendix PA, Attachment SCR</i>
<i>Freshwater intrusion</i>	<i>N35</i>	<i>Appendix PA, Attachment SCR</i>
<i>Changes in groundwater Eh</i>	<i>N36</i>	<i>Appendix PA, Attachment SCR</i>
<i>Changes in groundwater pH</i>	<i>N37</i>	<i>Appendix PA, Attachment SCR</i>

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP PA Scenario Screening — Continued

<i>Features, Events, and Processes (FEPs)</i>	<i>EPA FEP No.</i>	<i>Discussion</i>
<i>Effects of dissolution</i>	<i>N38</i>	<i>Appendix PA, Attachment SCR</i>
GEOMORPHOLOGICAL FEPs		
<i>Physiography</i>		
<i>Physiography</i>	<i>N39</i>	<i>Section 2.1.4</i>
<i>Meteorite impact</i>		
<i>Impact of a large meteorite</i>	<i>N40</i>	<i>Appendix PA, Attachment SCR</i>
Denudation		
<i>Weathering</i>		
<i>Mechanical weathering</i>	<i>N41</i>	<i>Appendix PA, Attachment SCR</i>
<i>Chemical weathering</i>	<i>N42</i>	<i>Appendix PA, Attachment SCR</i>
Erosion		
<i>Eolian erosion</i>	<i>N43</i>	<i>Section 2.1.3.10</i>
<i>Fluvial erosion</i>	<i>N44</i>	<i>Section 2.1.3.6</i>
<i>Mass wasting</i>	<i>N45</i>	<i>Appendix PA, Attachment SCR</i>
Sedimentation		
<i>Eolian deposition</i>	<i>N46</i>	<i>Appendix PA, Attachment SCR</i>
<i>Fluvial deposition</i>	<i>N47</i>	<i>Appendix PA, Attachment SCR</i>
<i>Lacustrine deposition</i>	<i>N48</i>	<i>Appendix PA, Attachment SCR</i>
<i>Mass wasting (deposition)</i>	<i>N49</i>	<i>Appendix PA, Attachment SCR</i>
Soil development		
<i>Soil development</i>	<i>N50</i>	<i>Section 2.1.3.10</i>
SURFACE HYDROLOGICAL FEPs		
Fluvial		
<i>Stream and river flow</i>	<i>N51</i>	<i>Section 2.2.2</i>
Lacustrine		
<i>Surface water bodies</i>	<i>N52</i>	<i>Section 2.2.2</i>
Groundwater recharge and discharge		
<i>Groundwater discharge</i>	<i>N53</i>	<i>Section 2.2.1</i>
<i>Groundwater recharge</i>	<i>N54</i>	<i>Section 2.2.1</i>
<i>Infiltration</i>	<i>N55</i>	<i>Section 2.1.3 Section 2.2.1</i>
Changes in surface hydrology		
<i>Changes in groundwater recharge and discharge</i>	<i>N56</i>	<i>Section 2.2.1</i>
<i>Lake formation</i>	<i>N57</i>	<i>Section 2.2.2</i>
<i>River flooding</i>	<i>N58</i>	<i>Section 2.2.2</i>

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP PA Scenario Screening — Continued

<i>Features, Events, and Processes (FEPs)</i>	<i>EPA FEP No.</i>	<i>Discussion</i>
CLIMATIC FEPs		
<i>Climate</i>		
<i>Precipitation (for example, rainfall)</i>	<i>N59</i>	<i>Section 2.5.2.3</i>
<i>Temperature</i>	<i>N60</i>	<i>Section 2.5.2.2</i>
<i>Climate change</i>		
<i>Meteorological</i>		
<i>Climate change</i>	<i>N61</i>	<i>Section 2.5</i>
<i>Glaciation</i>		
<i>Glaciation</i>	<i>N62</i>	<i>Section 2.5.1</i>
<i>Permafrost</i>	<i>N63</i>	<i>Appendix PA, Attachment SCR</i>
MARINE FEPs		
<i>Seas</i>		
<i>Seas and oceans</i>	<i>N64</i>	<i>Appendix PA, Attachment SCR</i>
<i>Estuaries</i>	<i>N65</i>	<i>Appendix PA, Attachment SCR</i>
<i>Marine sedimentology</i>		
<i>Coastal erosion</i>	<i>N66</i>	<i>Appendix PA, Attachment SCR</i>
<i>Marine sediment transport and deposition</i>	<i>N67</i>	<i>Appendix PA, Attachment SCR</i>
<i>Sea level changes</i>		
<i>Sea level changes</i>	<i>N68</i>	<i>Appendix PA, Attachment SCR</i>
ECOLOGICAL FEPs		
<i>Flora and fauna</i>		
<i>Plants</i>	<i>N69</i>	<i>Section 2.4.1</i>
<i>Animals</i>	<i>N70</i>	<i>Section 2.4.1</i>
<i>Microbes</i>	<i>N71</i>	<i>Appendix PA, Attachment SCR</i>
<i>Changes in flora and fauna</i>		
<i>Natural ecological development</i>	<i>N72</i>	<i>Section 2.4.1</i>

1 ***NOTE: Additional information for FEPs N1-N72 is located in Appendix PA, Attachment SCR.**

2 The DOE located the WIPP disposal horizon within a rock salt deposit known as the Salado
3 Formation (hereafter referred to as the Salado) at a depth of 650 m (2,150 ft) below the ground
4 surface. The Salado is regionally extensive, includes continuous beds of salt without
5 complicated structure, is deep with little potential for dissolution in the immediate vicinity of the
6 WIPP, and is near enough to the surface to make access reasonable. Particular site selection
7 criteria narrowed the choices when the present site was located during 1975 and 1976, as is
8 discussed in **CCA** Appendix GCR (2-10 to 2-27) and summarized by Weart (1983).

1 2.1 Geology

2 The DOE and its predecessor agencies determined at the outset of the geological disposal
 3 program that the geological characteristics of the disposal system are extremely important
 4 because the natural barriers provided by the geological units have a significant impact on the
 5 performance of the disposal system. Among the DOE's site selection criteria was the intent to
 6 maximize the beneficial impacts of the geology. This was accomplished when the DOE selected
 7 (1) a host formation that behaves plastically, thereby creeping closed to encapsulate buried
 8 waste, (2) a location where the effects of dissolution are minimal and predictable, (3) an area
 9 where deformation of the rocks is low, (4) an area where excavation is relatively easy, (5) an
 10 area where future resource development is predictable and minimal, and (6) a repository host
 11 rock that is relatively uncomplicated lithologically and structurally. Therefore, a thorough and
 12 accurate description of the WIPP facility's natural environmental setting is considered crucial by
 13 the DOE for a demonstration of compliance with the disposal standards and is an EPA
 14 certification ~~criteria~~ **criteria** in 40 CFR § 191.14(a). The DOE is providing the detail necessary
 15 to assess the achievable degree of waste isolation. In this chapter, the DOE addresses
 16 environmental factors and long-term environmental changes that are important for assessing the
 17 waste isolation potential of the disposal system. The first of these environmental factors is
 18 geology.

19 Geological data have been collected from the WIPP site and surrounding area to evaluate the
 20 site's suitability as a radioactive waste repository. These data have been collected principally by
 21 the DOE, the DOE's predecessor agencies, the United States Geological Survey (USGS), the
 22 New Mexico Bureau of Mines and Mineral Resources (NMBMMR), and private organizations
 23 engaged in natural resource exploration and extraction. The DOE has analyzed the data and has
 24 determined that the data support the DOE's position that the WIPP site is suitable for the long-
 25 term isolation of radioactive waste.

26 Many issues have been discussed, investigated, and resolved in order for the DOE to conclude
 27 that the site is suitable. The DOE discusses these issues in the following sections. Most of the
 28 data collected have been reported or summarized in **CCA** Appendices GCR, SUM, HYDRO, and
 29 FAC. These appendices represent the majority of the site characterization results for the WIPP
 30 site which ended in 1988. A number of more focused geological and hydrological studies
 31 continued after this date. These latter studies, ~~many of which were only recently concluded,~~
 32 provided detailed information needed to construct the conceptual models for disposal system
 33 performance that are discussed in Section 6.4. An example of these studies is the H-19 multiwell
 34 tracer test that was completed in early 1996. Results of this test ~~were~~ **were** have been incorporated
 35 into the discussions in this chapter and into the conceptual models described in Section 6.4.6.
 36 Model parameters derived from the ~~results~~ **data** are displayed in Appendix ~~PAR~~ **PA, Attachment**
 37 **PAR**. A discussion of the ~~test results~~ **data** is included in **CCA** Appendix MASS; (Section
 38 MASS.15) and **Appendix PA, Attachment MASS**.

39 ***Geological field studies designed to collect data pertinent to the WIPP PA continue. The***
 40 ***Culebra Dolomite Member and Magenta Dolomite Members are the two carbonates in the***
 41 ***Rustler Formation, the youngest evaporite-bearing formation in the Delaware Basin.***
 42 ***Geologic data related to the Culebra and Magenta remain of particular interest, as these***
 43 ***members are the most significant transmissive units at the WIPP site.***

1 *The EPA's December 19, 1996 letter (A-93-02, Docket II-I-01) made a request to the DOE for*
2 *recent studies that had provided detailed information used in developing conceptual models*
3 *for disposal system performance. In a response letter to EPA dated February 26, 1997 (Docket*
4 *A-93-02, Item II-I-10), the DOE cited Holt (1997) for detailed information on the recent*
5 *enhancement of the conceptual model for transport in the Culebra. Holt (1997) discusses*
6 *interpretation and conceptual insights obtained from field and laboratory tracer tests and core*
7 *studies that support the double-porosity conceptual model of the Culebra, in which Culebra*
8 *porosity is divided into advective and diffusive components.*

9 *Geological data provide the basis for a different approach to estimating the transmissivity field*
10 *for modeling fluid flow and transport in the Culebra (Beauheim 2002). Geological data*
11 *correlate strongly with Culebra transmissivity (Holt and Yarbrough 2002), and they are*
12 *available from many more locations, such as industry (oil, gas, potash) drillholes, than are*
13 *transmissivity data. With this correlation, Culebra properties can be inferred over a wide area,*
14 *leading to an improved computational model of the spatial distribution of Culebra*
15 *transmissivity. Initial results from this computational model of the spatial distribution of*
16 *Culebra transmissivity have been incorporated in the PA; they are discussed in more detail in*
17 *Section 2.2.1.4.1.2, and are incorporated in Appendix PA, Attachment TFIELD. Additional*
18 *data in support of this modeling are being collected through field activities, including drilling*
19 *and testing of new wells, to improve understanding of the Culebra and to assess the causes(s)*
20 *of rising water levels (see Section 2.2.1.4.1.2).*

21 **2.1.1 Data Sources**

22 The geology of southeastern New Mexico has been of great interest for more than a century. The
23 Guadalupe Mountains have become a common visiting and research point for geologists because
24 of the spectacular exposures of Permian-age reef rocks and related facies (see Shumard 1858,
25 Crandall 1929, Newell et al. 1953, and Dunham 1972 in the [CCA](#) bibliography). Because of
26 intense interest in both hydrocarbon and potash resources in the region, a large volume of data
27 exists as background information for the WIPP site, though some data are proprietary. Finally,
28 there is the geological information developed directly and indirectly by studies sponsored by the
29 DOE for the WIPP project; it ranges from raw data to interpretive reports.

30 Elements of the geology of southeastern New Mexico have been discussed or described in
31 professional journals or technical documents from many different sources. These types of
32 articles are an important source of information, and where there is consistency among the
33 technical community, the information in these articles is referenced when subject material is
34 relevant. Implicit rules of professional conduct for research and reporting have been assumed, as
35 have journal and editorial review. Elements of the geology presented in such sources have been
36 deemed critical to the WIPP and have been the subject of specific DOE-sponsored WIPP studies.

37 The geological data that the DOE has developed explicitly for the WIPP project have been
38 produced over a ~~25~~20-year period by different organizations and contractors using applicable
39 national standards (Quality Assurance Program history is described in Section 5.1.2). During a
40 rulemaking in 1988 related to the underground injection of hazardous wastes, the EPA addressed
41 the use of older geological data in making a long-term demonstration of repository performance.
42 In response to comments on a proposed rule regarding the permitting of underground injection

1 wells, the EPA concluded that “[e]xcluding historical data or information which might have been
2 gathered off-site by methods not consistent with certain prescribed procedures may be
3 counterproductive.” The EPA further stated that such data should be used as long as their
4 limitations are accounted for. In the final rule, the EPA stipulated “that only measurements
5 pertaining to the waste or that result from testing performed to gather data for the petition
6 demonstration comply with prescribed procedures.” Further, the EPA stated that “the concerns
7 about the accuracy of geologic data are addressed more appropriately by requiring that the
8 demonstration identify and account for the limits on data quality rather than by excluding data
9 from consideration” (EPA 1988).

10 As site characterization activities progressed, the DOE, along with independent review groups
11 such as the National Academy of Sciences (NAS), the Environmental Evaluation Group (EEG),
12 and the state of New Mexico acting through the Governor’s Radioactive Waste Consultation
13 Task Force, identified natural FEPs that required additional detailed investigation. Because
14 these investigations, in many cases, were to gather data that would either be used in developing
15 conceptual models or in the prediction of disposal system performance, the quality assurance
16 (QA) standards applied to these investigations were more stringent, thereby ensuring accuracy
17 and repeatability to the extent possible for geologic investigations.

18 Geological data from site characterization have been developed by the DOE through a variety of
19 WIPP-sponsored studies using drilling, mapping or other direct observation, geophysical
20 techniques, and laboratory work. Most of the techniques and statistics of data acquisition will be
21 incorporated by specific discussion. The processes used in deriving modeling parameters from
22 field and laboratory data are discussed in records packages which support the conceptual models
23 in Section 6.4 and the parameters in Appendix ~~PAR PA, Attachment PAR~~. Pointers to these
24 records packages are provided principally in Appendix ~~PAR PA, Attachment PAR~~. Records
25 packages are stored in the Sandia WIPP Central Files (SWCF) in Albuquerque ~~Records Center~~
26 ~~in Carlsbad~~. Access to review of these records packages can be obtained by contacting the
27 person designated in Table 1-10. Borehole investigations are a major source of geological data
28 for the WIPP and surrounding area. Borehole studies provide raw data (for example, depth
29 measurements, amount of core, geophysical logs) that support point data and interpreted data
30 sets. These data sets are used in developing other analysis tools such as structure maps for
31 selected stratigraphic horizons or isopachs (thicknesses) of selected stratigraphic intervals.

32 The borehole data sets that ~~were~~*was* used specifically for obtaining ~~Waste Isolation Pilot Plant~~
33 ~~(WIPP)~~ geologic information *is* included as reference information in ~~CCA~~ Appendix BH. This
34 ~~appendix provides some summary information and is a pointer for data reports that contain more~~
35 ~~detailed results.~~—A map of some borehole locations in the data set is provided in Figure 2-2.

36 *Figure 2-3 shows Culebra monitoring wells within the site boundary as of December 2002,*
37 *including well C-2737, which was drilled and completed in 2001 (Powers 2002c). Figure 2-4*
38 *shows Culebra monitoring wells outside the WIPP site as of December 2002; plugged and*
39 *abandoned wells formerly monitored are not included in this figure. Figure 2-5 shows the*
40 *locations of wells configured to monitor the Magenta, including well C-2737. Other*
41 *hydrostratigraphic units are monitored in wells shown in Figure 2-6, including well C-2811,*
42 *which was drilled and completed in 2001 to monitor a shallow saturated zone developed since*
43 *the WIPP surface structures were constructed (Powers and Stensrud 2003). Other holes are*
44 not shown because they were not of sufficient depth, were not cored, or were not drilled for

1 purposes of site characterization. A more comprehensive drillhole database of the entire
2 Delaware Basin is addressed in Section 2.3.1.2 and is presented in *Appendix DATA Appendix*
3 ~~DEL~~ (Figure ~~DEL-4~~). This database includes all drillholes used in evaluating human intrusion
4 rates for the WIPP *PA*.

5 **2.1.2 Geologic History**

6 In this section, the DOE summarizes the more important points of the area's geologic history
7 within about 320 km (200 mi) of the WIPP site, with emphasis on more recent or nearby events.
8 Figure 2-37 shows the major elements of the area's geological history from the end of the
9 Precambrian Period.

10 The geologic time scale that the DOE uses for WIPP is based on the compilation by Palmer
11 (1983, *pp.* 503 – 504) for *The Decade of North American Geology* (DNAG). There are several
12 compiled sources of chronologic data related to different reference sections or methods (see, for
13 example, Harland et al. 1989 and Salvador 1985 in the bibliography). Although most of these
14 sources show generally similar ages for chronostratigraphic boundaries, there is no consensus on
15 either reference boundaries or most-representative ages. The DNAG scale is accepted by the
16 DOE as a standard that is useful and sufficient for WIPP purposes, as no known critical
17 performance assessment parameters require more accurate or precise dates.

18 The geologic history in this region can be conveniently subdivided into three general phases:

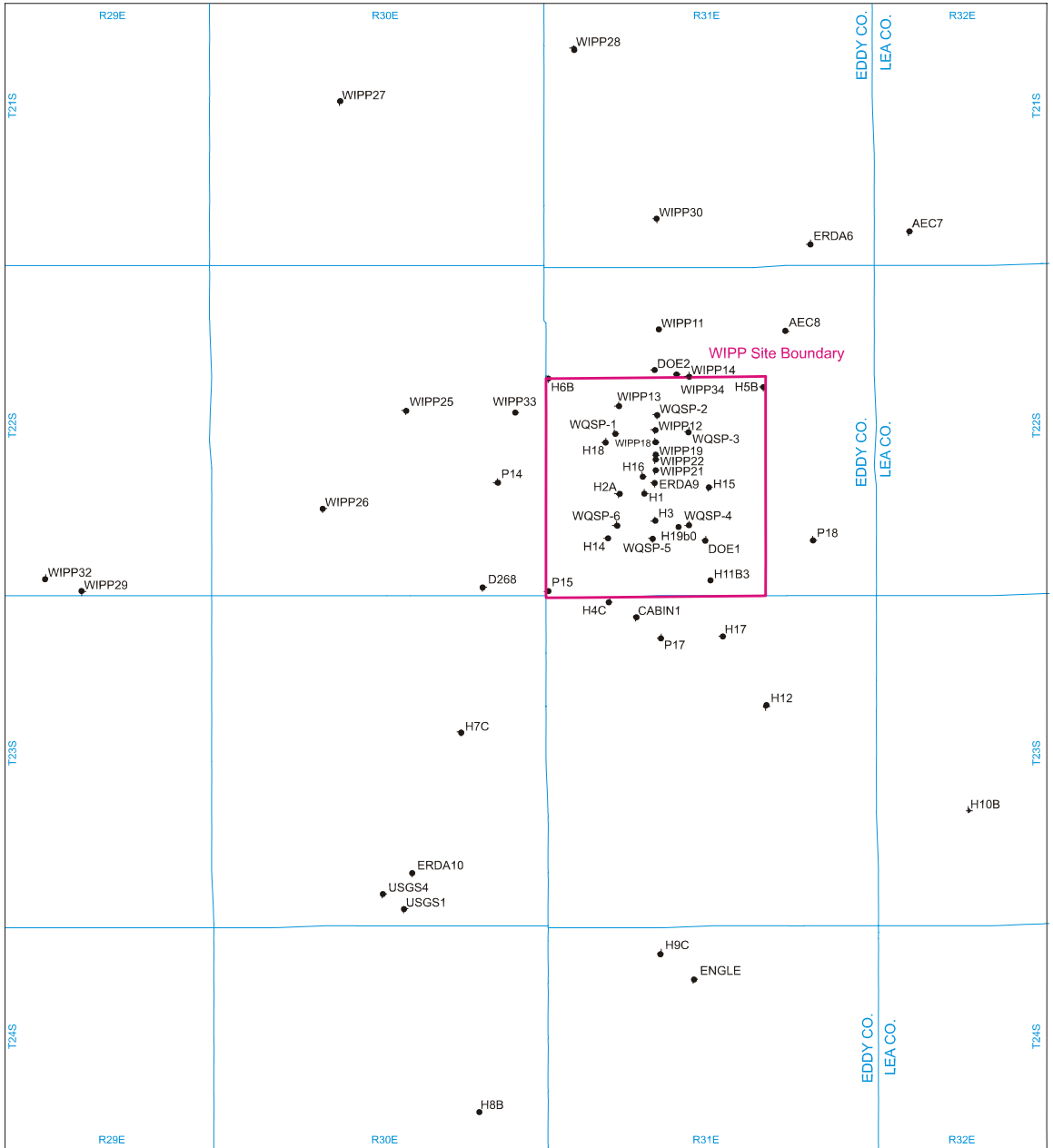
- 19 • A Precambrian Period, represented by metamorphic and igneous rocks ranging in age
20 from about 1.5 to 1.1 billion years;
- 21 • A period from about 1.1 to 0.6 billion years ago, from which no rocks are preserved.
22 Erosion may have been the dominant process during much of this period; *and*
- 23 • An interval from 0.6 billion years ago to the present represented by a more complex set
24 of mainly sedimentary rocks and shorter periods of erosion and dissolution.

25 This latter phase is the main subject of the DOE's detailed discussion in this text.

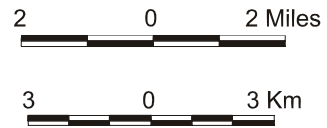
26 Only a few boreholes in the WIPP region have bored deep enough to penetrate Precambrian
27 crystalline rocks, and, therefore, relatively little petrological information is available. Foster
28 (1974, Figure 3) extrapolated the elevation of the Precambrian surface under the area of WIPP as
29 being between 4.42 km (14,500 ft) and 4.57 km (15,000 ft) below sea level; the site surface at
30 WIPP is about 1,036 m (3,400 ft) above sea level. Keesey (1976, Vol. II, Exhibit No. 2)
31 projected a depth of about 5,545 m (18,200 ft) from the surface to the top of Precambrian rocks
32 in the vicinity of the WIPP. The depth projection is based on the geology of the nearby borehole
33 in Section 15, T22S, R31E.

34 Precambrian rocks of several types crop out in the following locations: the Sacramento
35 Mountains northwest of WIPP; around the Sierra Diablo and Baylor Mountains near Van Horn,
36 Texas; west of the Guadalupe Mountains at Pump Station Hills; and in the Franklin Mountains

37



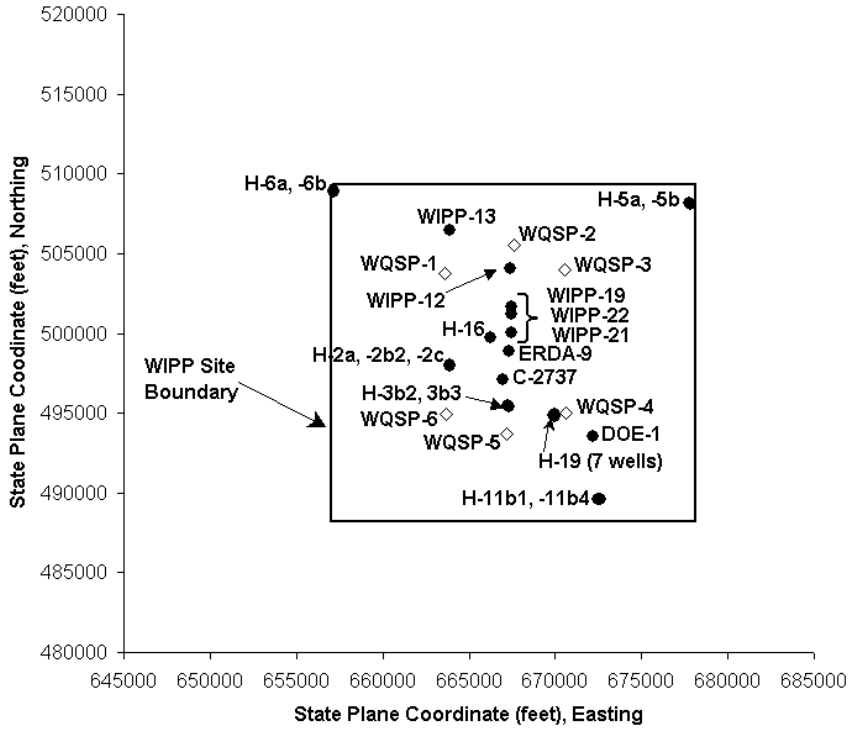
● Borehole Location



CCA-022-2

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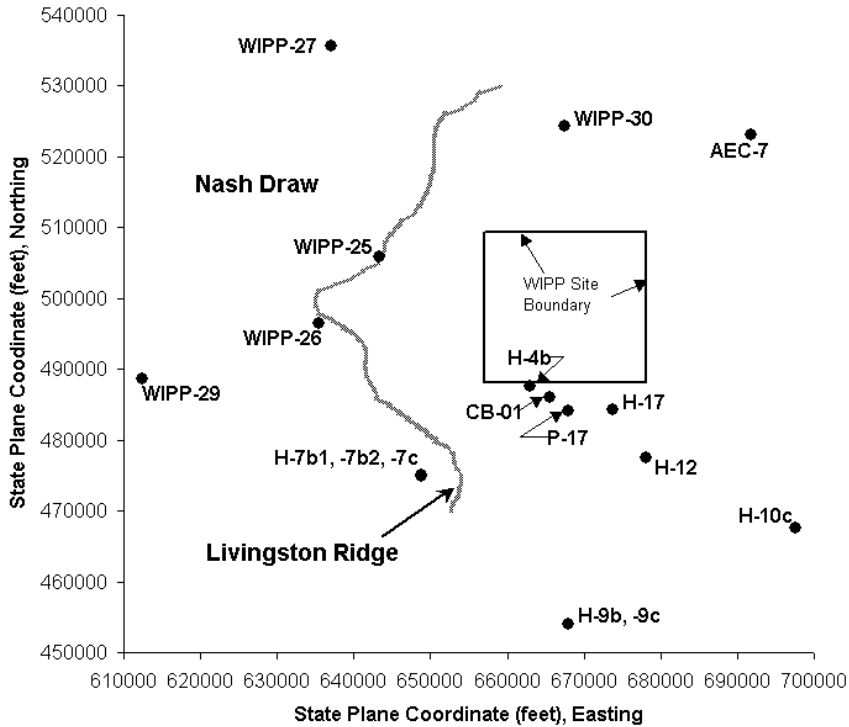
Figure 2-2. WIPP Site and Vicinity Borehole Location Map (partial)



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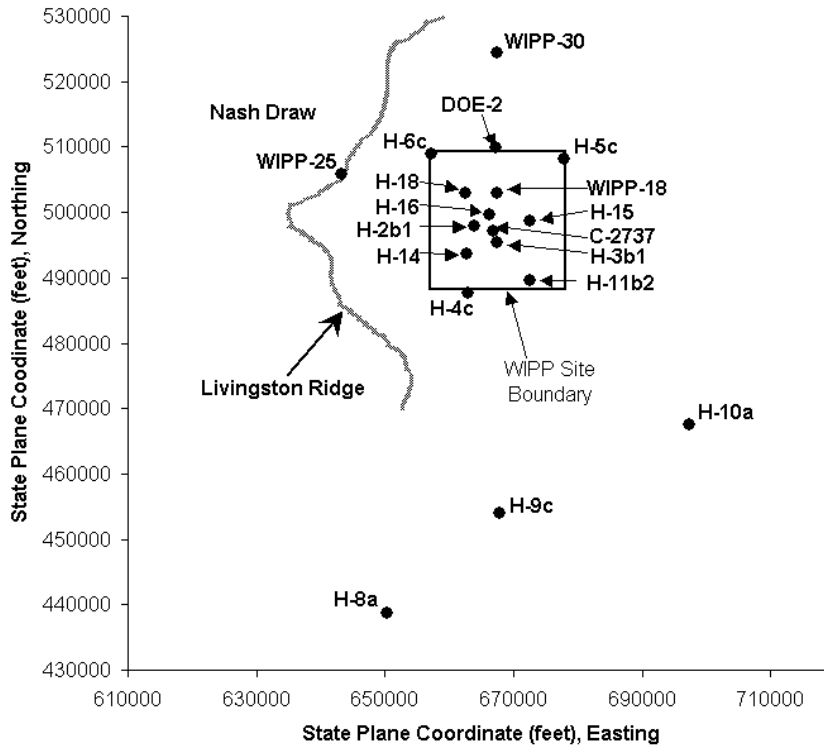
Figure 2-3. Locations of Culebra Monitoring Wells Inside the WIPP Site Boundary



3

4

Figure 2-4. Locations of Culebra Monitoring Wells Located Outside the WIPP Site Boundary



1

2

Figure 2-5. Locations of Magenta Monitoring Wells

3

near El Paso, Texas. East of the WIPP, a relatively large number of boreholes on the Central Basin Platform have penetrated the top of the Precambrian (Foster 1974, Figure 3). As summarized by Foster (1974, 10), Precambrian rocks in the area considered similar to those in the vicinity of the site range in age from about 1.14 to 1.35 billion years.

7

For about 500 million years (1.1 to 0.6 billion years ago), there is no certain rock record in the region around the WIPP. The most likely rock record for this period may be the Van Horn sandstone (McGowan and Groat 1971), but there is no conclusive evidence that it represents part of this time period (CCA Appendix GCR, Section 3.3.1). The region is generally thought to have been subject to erosion for much of the period until the Bliss sandstone began to accumulate during the Cambrian.

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There is additional geologic history information contained in the EPA Technical Support Document for Section 194.14: Content of Compliance Certification Application, Section IV (Docket A-93-02, Item V-B-3).

14

15

16

2.1.3 Stratigraphy and Lithology in the Vicinity of the WIPP Site

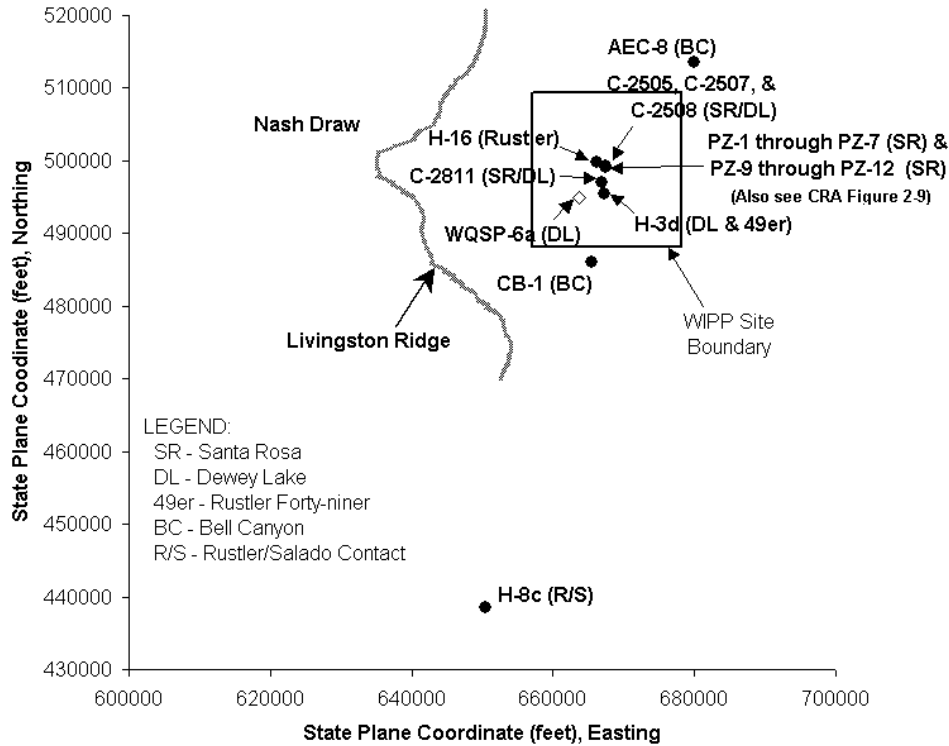
17

The conceptual model of the disposal system uses information about the geometry of the various rock layers as a model input as described in Section 6.4.2.1. This means that stratigraphic information (thickness and lateral extent) provided in the following sections are important inputs.

18

19

20



1
 2 **Figure 2-6. Locations of Monitoring Wells Completed to Hydrostratigraphic Units Other**
 3 **Than the Culebra and Magenta Dolomite Members (See also Figure 2-39).**

4 In addition, less important features such as the lithology and the presence *of* geochemically
 5 significant minerals are provided to support screening arguments in Appendix *PA, Attachment*
 6 SCR. Consequently, this discussion has focused on the general properties of the various rock
 7 units as determined from field studies. Specific parameters used in the modeling described in
 8 Sections 6.4.5 and 6.4.6 are summarized in Appendix PAR (Tables PAR-25 to PAR-32 and
 9 PAR-34 to PAR-36) *Appendix PA, Attachment PAR*. Stratigraphy-related parameters are input
 10 as constants. Stratigraphic thicknesses of units considered in modeling are compiled in
 11 Appendix *PA, Attachment PAR*, Table PAR-5749.


12 This section describes the stratigraphy and lithology of the Paleozoic and younger rocks
 13 underlying the WIPP site and vicinity (Figure 2-48), emphasizing the units nearer the surface.
 14 After briefly describing pre-Permian rocks, the section provides detailed information on the
 15 Permian (Guadalupian) Bell Canyon Formation (hereafter referred to as the Bell Canyon)—the
 16 upper unit of the Delaware Mountain Group—because this is the uppermost transmissive
 17 formation below the evaporites. The principal stratigraphic data are the chronologic sequence,
 18 age, and extent of rock units, including some of the nearby relevant facies changes. For deeper
 19 rocks, characteristics such as thickness and depth are summarized from published sources, and
 20 for shallower rocks, they are mainly based on data sets presented in *CCA* Appendix BH (above
 21 the Bell Canyon). The lithologies of upper formations and some formation members are
 22 described. A comprehensive discussion of stratigraphy in the WIPP area is presented in this
 23 application in *CCA* Appendix GCR. Detailed referencing to original investigations by the USGS
 24 and others is included.

E R A	PERIOD	EPOCH	YEARS		MAJOR GEOLOGIC EVENTS - SOUTHEAST NEW MEXICO REGION	
			DURATION	BEFORE PRESENT		
C E N O Z O I C	Quaternary	Holocene	10,000	1,600,000	Eolian and erosion/solution activity. Development of present landscape.	
		Pleistocene	1,590,000		Continued deposition of Gatuña sediments.	
	Tertiary	Pliocene	3,700,000		66,400,000	Deposition of Gatuña sediments. Formation of caliche caprock. Regional uplift and east-southeastward tilting; Basin-Range uplift of Sacramento and Guadalupe-Delaware Mountains.
		Miocene	18,400,000			Erosion dominant. No Early to Mid-Tertiary rocks present.
		Oligocene	12,900,000			Laramide revolution. Uplift of Rocky Mountains. Mild tectonism and igneous activity to west and north.
		Eocene	21,200,000			
		Paleocene	8,600,000			
M E S O Z O I C	Cretaceous		77,600,000	144,000,000	Submergence. Intermittent shallow seas. Thin limestone and clastics deposited.	
	Jurassic		64,000,000	208,000,000	Emergent conditions. Erosion, formation of rolling terrain.	
	Triassic		37,000,000	245,000,000	Deposition of fluvial clastics. Erosion. Broad flood plain develops.	
P A L E O Z O I C	Permian		41,000,000	286,000,000	Deposition of evaporite sequence followed by continental redbeds. Sedimentation continuous in Delaware, Midland, Val Verde basins and shelf areas.	
	Pennsylvanian		34,000,000	320,000,000	Massive deposition of clastics. Shelf, margin, basin pattern of deposition develops.	
	Mississippian		40,000,000	360,000,000	Regional tectonic activity accelerates, folding up Central Basin platform. Matador arch, ancestral Rockies. Regional erosion. Deep, broad basins to east and west of platform develop.	
	Devonian		48,000,000	408,000,000	Renewed submergence. Shallow sea retreats from New Mexico; erosion. Mild epeirogenic movements. Tobosa basin subsiding. Pedernal landmass and Texas Peninsula emergent until Middle Mississippian.	
	Silurian		30,000,000	438,000,000		
	Ordovician		67,000,000	505,000,000	Marathon-Quachita geosyncline, to south, begins subsiding. Deepening of Tobosa basin area; shelf deposition of clastics, derived partly from ancestral Central Basin platform and carbonates.	
	Cambrian		65,000,000	570,000,000	Clastic sedimentation - Bliss sandstone.	
	PRECAMBRIAN					Erosion to a nearly level plain. Mountain building, igneous activity, metamorphism, erosional cycles.

Figure 2-37. Major Geologic Events - Southeast New Mexico Region

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SYSTEM/ Series		Group	Formation	Members	
QUATER- NARY	Holocene		surficial deposits		
TERTIARY	Pleisto- cene		Mescalero caliche		
	Pliocene		Gatuña		
	Miocene				
TRIASSIC		Dockum			
			Dewey Lake		
PERMIAN	Ochoan		Rustler	<i>Forty-niner</i> <i>Magenta Dolomite</i> <i>Tamarisk</i> <i>Culebra Dolomite</i> <i>Los Medaños</i>	
			Salado	<i>upper</i> <i>Vaca Triste Sandstone</i> <i>McNutt potash zone</i> <i>lower</i>	
			Castile		
	Guadalupian		Delaware Mountain	Bell Canyon	
				Cherry Canyon	
		Brushy Canyon			

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Figure 2-8. Partial Site Geologic Column