

1	<b>Table of Contents</b>	
2	2.0 SITE CHARACTERIZATION.....	2-1
3	2.1 Geology.....	2-11
4	2.1.1 Data Sources.....	2-12
5	2.1.2 Geologic History.....	2-14
6	2.1.3 Stratigraphy and Lithology in the Vicinity of the WIPP Site .....	2-17
7	2.1.3.1 General Stratigraphy and Lithology below the Bell Canyon ....	2-21
8	2.1.3.2 The Bell Canyon Formation.....	2-22
9	2.1.3.3 The Castile Formation.....	2-24
10	2.1.3.4 The Salado.....	2-28
11	2.1.3.5 The Rustler.....	2-36
12	2.1.3.6 The Dewey Lake <del>Redbeds</del> Formation.....	2-50
13	2.1.3.7 The Santa Rosa.....	2-53
14	2.1.3.8 The Gatuña Formation.....	2-53
15	2.1.3.9 Mescalero Caliche.....	2-55
16	2.1.3.10 Surficial Sediments.....	2-57
17	2.1.3.11 Summary .....	2-58
18	2.1.4 Physiography and Geomorphology.....	2-58
19	2.1.4.1 Regional Physiography and Geomorphology.....	2-59
20	2.1.4.2 Site Physiography and Geomorphology.....	2-59
21	2.1.5 Tectonic Setting and Site Structural Features .....	2-63
22	2.1.5.1 Tectonics .....	2-63
23	2.1.5.2 Loading and Unloading.....	2-66
24	2.1.5.3 Faulting.....	2-69
25	2.1.5.4 Igneous Activity .....	2-69
26	2.1.6 Nontectonic Processes and Features .....	2-71
27	2.1.6.1 Evaporite Deformation.....	2-71
28	2.1.6.2 Evaporite Dissolution.....	2-76
29	2.2 Surface Water and Groundwater Hydrology .....	2-81
30	2.2.1 Groundwater Hydrology .....	2-83
31	2.2.1.1 Conceptual Models of Groundwater Flow .....	2-89
32	2.2.1.2 Units Below the Salado.....	2-91
33	2.2.1.3 Hydrology of the Salado.....	2-95
34	2.2.1.4 Units Above the Salado.....	2-99
35	2.2.1.5 Hydrology of Other Groundwater Zones of	
36	Regional Importance .....	2-123
37	2.2.2 Surface-Water Hydrology .....	2-128
38	2.3 Resources.....	2-134
39	2.3.1 Extractable Resources .....	2-135
40	2.3.1.1 Potash Resources at the WIPP Site .....	2-135
41	2.3.1.2 Hydrocarbon Resources at the WIPP Site.....	2-136
42	2.3.1.3 Other Resources .....	2-140
43	2.3.2 Cultural and Economic Resources .....	2-140
44	2.3.2.1 Demographics.....	2-140
45	2.3.2.2 Land Use.....	2-143
46	2.3.2.3 History and Archaeology.....	2-144

1 2.4 Background Environmental Conditions..... 2-147  
2 2.4.1 Terrestrial and Aquatic Ecology ..... 2-148  
3 2.4.1.1 Vegetation ..... 2-149  
4 2.4.1.2 Mammals ..... 2-150  
5 2.4.1.3 Reptiles and Amphibians..... 2-150  
6 2.4.1.4 Birds ..... 2-150  
7 2.4.1.5 Arthropods..... 2-151  
8 2.4.1.6 Aquatic Ecology ..... 2-151  
9 2.4.1.7 Endangered Species..... 2-151  
10 2.4.2 Water Quality ..... 2-152  
11 2.4.2.1 Groundwater Quality ..... 2-152  
12 2.4.2.2 Surface Water Quality..... 2-154  
13 2.4.3 Air Quality ..... 2-154  
14 2.4.4 Environmental Radioactivity ..... 2-155  
15 2.4.4.1 Atmospheric Radiation Baseline ..... 2-155  
16 2.4.4.2 Ambient Radiation Baseline..... 2-156  
17 2.4.4.3 Terrestrial Baseline..... 2-156  
18 2.4.4.4 Hydrologic Radioactivity ..... 2-156  
19 2.4.4.5 Biotic Baseline ..... 2-159  
20 2.5 Climate and Meteorological Conditions ..... 2-159  
21 2.5.1 Historic Climatic Conditions..... 2-160  
22 2.5.2 Recent Climatic Conditions ..... 2-162  
23 2.5.2.1 General Climatic Conditions ..... 2-162  
24 2.5.2.2 Temperature Summary ..... 2-163  
25 2.5.2.3 Precipitation Summary ..... 2-163  
26 2.5.2.4 Wind Speed and Wind Direction Summary ..... 2-163  
27 2.6 Seismology..... 2-164  
28 2.6.1 Seismic History ..... 2-180  
29 2.6.2 Seismic Risk..... 2-182  
30 2.6.2.1 Acceleration Attenuation..... 2-182  
31 2.6.2.2 Seismic Source Zones ..... 2-183  
32 2.6.2.3 Source Zone Recurrence Formulas and Maximum  
33 Magnitudes..... 2-183  
34 2.6.2.4 Design Basis Earthquake..... 2-186  
35 REFERENCES ..... 2-188

**List of Figures**

37 Figure 2-1. WIPP Site Location in Southeastern New Mexico ..... 2-3  
38 Figure 2-2. WIPP Site and Vicinity Borehole Location Map (partial)..... 2-15  
39 **Figure 2-3. Locations of Culebra Monitoring Wells Inside the WIPP Site Boundary**... 2-16  
40 **Figure 2-4. Locations of Culebra Monitoring Wells Located Outside the WIPP Site**  
41 **Boundary** ..... 2-16  
42 **Figure 2-5. Locations of Magenta Monitoring Wells** ..... 2-17

1	<b>Figure 2-6.</b>	<b><i>Locations of Monitoring Wells Completed to Hydrostratigraphic Units</i></b>	
2		<b><i>Other Than the Culebra and Magenta Dolomite Members (See also</i></b>	
3		<b><i>Figure 2-39).</i></b>	2-18
4	Figure 2- <del>3</del> 7.	Major Geologic Events - Southeast New Mexico Region	2-19
5	<b>Figure 2-8.</b>	<b><i>Partial Site Geologic Column</i></b>	2-20
6	Figure 2- <del>5</del> 9.	Schematic Cross-Section from Delaware Basin (southeast) through	
7		Marginal Reef Rocks to Back-Reef Facies (based on King, P.B., 1948)	2-23
8	Figure 2- <del>6</del> 10.	Structure Contour Map of Top of Bell Canyon	2-25
9	Figure 2- <del>7</del> 11.	Generalized Stratigraphic Cross Section above Bell Canyon Formation at	
10		WIPP Site	2-26
11	Figure 2- <del>8</del> 12.	Salado Stratigraphy <i>in the Vicinity of the WIPP Disposal Zone</i>	2-30
12	<b>Figure 2-13.</b>	<b><i>Dissolution Margin for the Upper Salado</i></b>	2-34
13	<del>Figure 2-9.</del>	<del>Rustler Stratigraphy (From Appendix FAC, Figure 3-2)</del>	2-37
14	<b>Figure 2-14.</b>	<b><i>Rustler Stratigraphy</i></b>	2-38
15	<del>Figure 2-10.</del>	<del>Halite Margins in the Rustler</del>	2-40
16	<b>Figure 2-15.</b>	<b><i>Halite Margins for the Rustler Formation Members</i></b>	2-41
17	Figure 2- <del>11</del> 16.	Isopach Map of the Entire Rustler	2-43
18	Figure 2- <del>12</del> 17.	Percentage of Natural Fractures in the Culebra Filled with Gypsum	2-46
19	Figure 2- <del>13</del> 18.	Log Character of the Rustler Emphasizing Mudstone-Halite Lateral	
20		Relationships	2-49
21	Figure 2- <del>14</del> 19.	Isopach of the Dewey Lake	2-52
22	Figure 2- <del>15</del> 20.	Isopach of the Santa Rosa	2-54
23	Figure 2- <del>16</del> 21.	Isopach of the Gatuña	2-56
24	Figure 2- <del>17</del> 22.	Physiographic Provinces and Sections	2-60
25	Figure 2- <del>23</del> 25.	<b><i>Topographic Map of the Area Around the WIPP Site</i></b>	2-61
26	<del>Figure 2-18.</del>	<del>Topographic Map of the Area Around the WIPP Site</del>	2-62
27	Figure 2- <del>19</del> 24.	Structural Provinces of the Permian Basin Region	2-64
28	Figure 2- <del>20</del> 25.	Loading and Unloading History Estimated to the Base of the Culebra	2-67
29	Figure 2- <del>21</del> 26.	Regional Structures	2-70
30	Figure 2- <del>22</del> 27.	Igneous Dike in the Vicinity of the WIPP Site	2-72
31	<b>Figure 2-28.</b>	<b><i>Elevations of the Top of the Culebra Dolomite Member</i></b>	2-75
32	Figure 2- <del>23</del> 29.	Isopach from the Base of MB 103 to the Top of the Salado	2-79
33	<del>Figure 2-24.</del>	<del>Structure Contour Map of Culebra Dolomite Base</del>	2-82
34	<del>Figure 2-25.</del>	<del>Drainage Pattern in the Vicinity of the WIPP Facility</del>	2-84
35	Figure 2- <del>26</del> 30.	Schematic West-East Cross Section through the North Delaware Basin	2-86
36	Figure 2- <del>27</del> 31.	Schematic North-South Cross Section through the North Delaware Basin	2-87
37	Figure 2- <del>28</del> 32.	Recent Occurrences of Pressurized Brine in the Castile	2-94
38	Figure 2- <del>29</del> 33.	Outline of the Groundwater Basin Model Domain on a Topographic Map	2-100
39	Figure 2- <del>30</del> 34.	Transmissivities of the Culebra	2-106
40	<b>Figure 2-35.</b>	<b><i>Correlation Between Culebra Transmissivity (log T (m<sup>2</sup>/s)) and</i></b>	
41		<b><i>Overburden Thickness for Different Geologic Environments (after Holt</i></b>	
42		<b><i>and Yarbrough 2002)</i></b>	2-108
43	<b>Figure 2-36.</b>	<b><i>Water-level Trends in Nash Draw Wells and at P-14 (see Figure 2-2 for</i></b>	
44		<b><i>well locations)</i></b>	2-111
45	<del>Figure 2-31.</del>	<del>Hydraulic Heads in the Culebra</del>	2-113
46	<b>Figure 2-37.</b>	<b><i>Hydraulic Heads in the Culebra</i></b>	2-114

1 Figure 2-32~~38~~. Hydraulic Heads in the Magenta (1980s) ..... 2-118  
2 Figure 2-33. Interpreted Water Table Surface ..... 2-122  
3 **Figure 2-39. Site Map of WIPP Surface Structures Area Showing Location of Wells**  
4 **(e.g., C-2505) and Piezometers (e.g., PZ-1) (after INTERA 1997)** ..... 2-124  
5 **Figure 2-40. Santa Rosa Potentiometric Surface Map** ..... 2-125  
6 Figure 2-34~~41~~. Brine Aquifer in the Nash Draw (Redrawn from CCA Appendix  
7 HYDRO, Figure 14)..... 2-127  
8 Figure 2-35. Measured Water Levels of the Unnamed Lower Member and Rustler-  
9 Salado Contact Zone ..... 2-129  
10 **Figure 2-42. Measured Water Levels of the Los Medaños and Rustler-Salado**  
11 **Contact Zone (1980s)** ..... 2-130  
12 Figure 2-36~~43~~. Location of Reservoirs and Gauging Stations in the Pecos River Drainage  
13 Area ..... 2-132  
14 Figure 2-37~~44~~. Known Potash Leases Within the Delaware Basin ..... 2-137  
15 Figure 2-38~~45~~. Extent of Economically Mineable Reserves Inside the Site Boundary  
16 (Based on NMBMMR Report) ..... 2-138  
17 Figure 2-39~~46~~. Delaware Basin Boundary ..... 2-141  
18 **Figure 2-47. Distribution of Existing Petroleum Industry Boreholes Within Two**  
19 **Miles of the WIPP Site** ..... 2-142  
20 Figure 2-40. Hydrochemical Zones of the Culebra ..... 2-153  
21 Figure 2-41. Monthly Precipitation for the WIPP Site from 1990 through 1994 ..... 2-165  
22 **Figure 2-48. Monthly Precipitation for the WIPP Site from 1990-2002.** ..... 2-166  
23 Figure 2-42. 1991 Annual Windrose WIPP Site ..... 2-167  
24 Figure 2-43. 1992 Annual Windrose WIPP Site ..... 2-168  
25 Figure 2-44. 1993 Annual Windrose WIPP Site ..... 2-169  
26 Figure 2-45. 1994 Annual Windrose WIPP Site ..... 2-170  
27 **Figure 2-49. 1995 Annual Wind Rose at 10-m (33-ft.) Height at WIPP Site** ..... 2-171  
28 **Figure 2-50. 1996 Annual Wind Rose at 10-m (33-ft.) Height at WIPP Site** ..... 2-172  
29 **Figure 2-51. 1997 Annual Wind Rose at 10-m (33-ft.) Height at WIPP Site** ..... 2-173  
30 **Figure 2-52. 1998 Annual Wind Rose at 10-m (33-ft.) Height at WIPP Site** ..... 2-174  
31 **Figure 2-53. 1999 Annual Wind Rose at 10-m (33-ft.) Height at WIPP Site** ..... 2-175  
32 **Figure 2-54. 2000 Annual Wind Rose at 10-m (33-ft.) Height at WIPP Site** ..... 2-176  
33 **Figure 2-55. 2001 Annual Wind Rose at 10-m (33-ft.) Height at WIPP Site** ..... 2-177  
34 **Figure 2-56. 2002 Annual Wind Rose at 10-m (33-ft.) Height at WIPP Site** ..... 2-178  
35 Figure 2-46. 1994 Annual Wind Rose Carlsbad, NM ..... 2-179  
36 Figure 2-47~~57~~. Regional Earthquake Epicenters Occurring between 1961 and 2002 ..... 2-181  
37 Figure 2-48~~58~~. Seismic Source Zones ..... 2-184  
38 Figure 2-49~~59~~. Alternate Source Geometries ..... 2-185  
39 Figure 2-50~~60~~. Total WIPP Facility Risk Curve Extrema ..... 2-187

40 **List of Tables**

41 ~~Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the~~  
42 ~~WIPP Performance Assessment Scenario Screening~~ ..... 2-4  
43 **Table 2-1. Issues Related to the Natural Environment That Were Evaluated for**  
44 **the WIPP PA Scenario Screening** ..... 2-7

1	Table 2-2.	Chemical Formulas, Distributions, and Relative Abundances of Minerals	
2		in the Castile, Salado, and Rustler Formations .....	2-31
3	Table 2-3.	Culebra Thickness Data Sets .....	2-47
4	Table 2-4.	Hydrologic Characteristics of the Rustler at the WIPP and in Nash Draw ....	2-88
5	<b>Table 2-5.</b>	<b><i>Depth Intervals of the Injection Zones of Six Salt-Water Injection Wells</i></b>	
6		<b><i>Located Near Well H-9 (after SNL 2003a)</i></b> .....	2-93
7	Table 2-56.	WIPP Salado and Castile Brine Compositions .....	2-96
8	<b>Table 2-7.</b>	<b><i>Estimates of Culebra Transmissivity Model Coefficients</i></b> .....	2-108
9	<b>Table 2-8.</b>	<b><i>Ninety-Five Percent Confidence Intervals for Culebra Water-Quality</i></b>	
10		<b><i>Baseline</i></b> .....	2-110
11	<b>Table 2-9.</b>	<b><i>Ninety-Five Percent Confidence Intervals for Dewey Lake Water-</i></b>	
12		<b><i>Quality Baseline</i></b> .....	2-120
13	Table 2-6 <b>10.</b>	Capacities of Reservoirs in the Pecos River Drainage.....	2-133
14	Table 2-7 <b>11.</b>	Current Estimates of Potash Resources at the WIPP Site.....	2-136
15	Table 2-8 <b>12.</b>	In-Place Oil within Study Area.....	2-139
16	Table 2-9 <b>13.</b>	In-Place Gas within Study Area.....	2-139
17	<del>Table 2-10.</del>	<del>Ranges of Mean Values Measured for Radioactive Isotopes In Soils at</del>	
18		<del>WIPP Site, 5 Miles from WIPP, and beyond 5 Miles from WIPP .....</del>	<del>2-157</del>
19	<del>Table 2-11.</del>	<del>Mean Values Measured for Radionuclides in Water Wells around the</del>	
20		<del>WIPP Site.....</del>	<del>2-159</del>
21	<del>Table 2-12.</del>	<del>Annual Average, Maximum, and Minimum Temperatures.....</del>	<del>2-163</del>
22	<b>Table 2-14.</b>	<b><i>Annual Average, Maximum, and Minimum Temperatures</i></b> .....	2-164
23			

1

*This page intentionally left blank*

## 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.

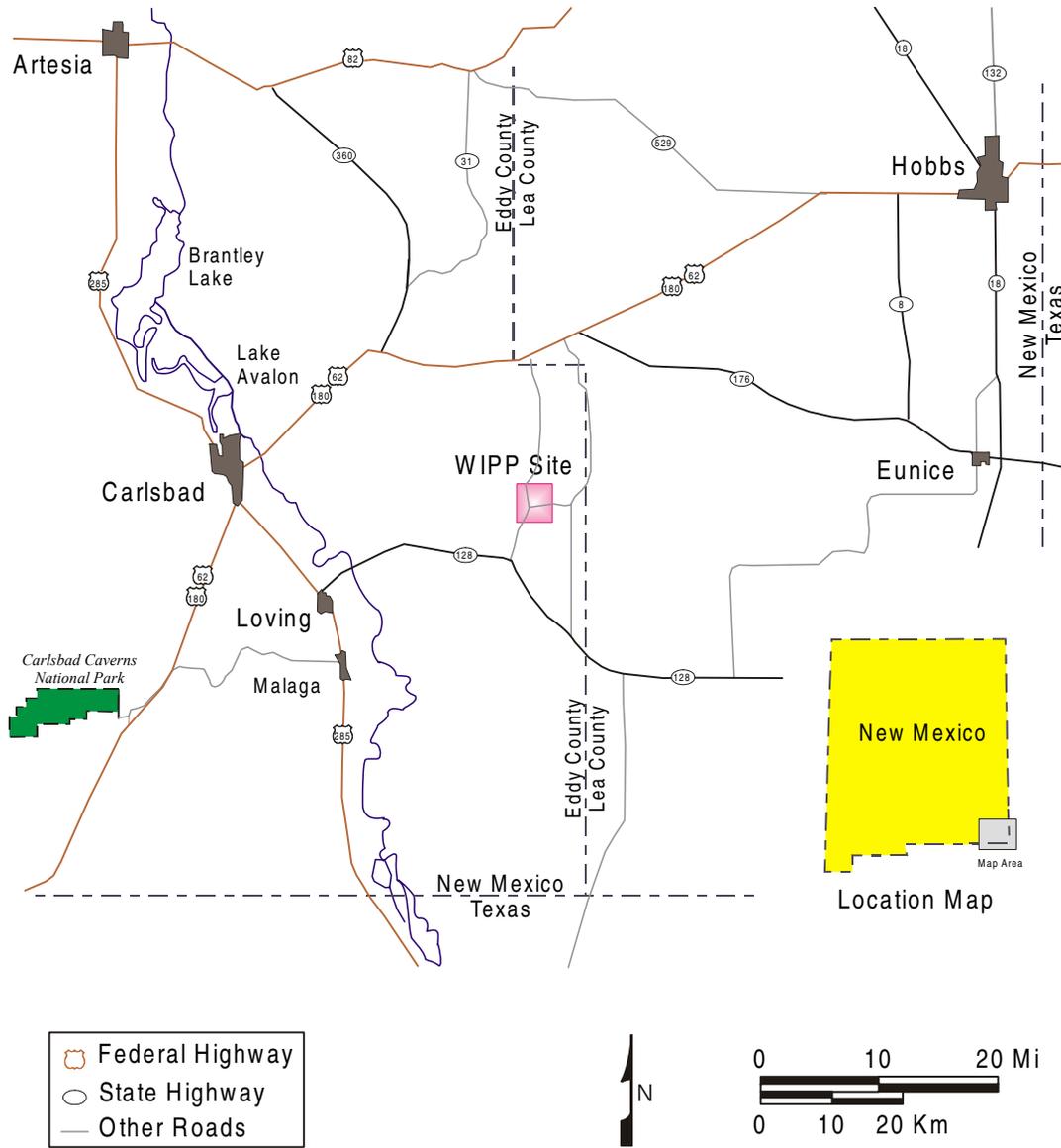
32 The discussion of conceptual models and initial and boundary conditions is in Section 6.4 and  
33 Appendix *PA, Attachment MASS* (~~Sections MASS.2 and MASS.4 through MASS.18~~).  
34 Conceptual models implement scenarios about the future. Scenario development is discussed in  
35 Section 6.3. Scenario 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**

<b>Features, Events, and Processes (FEPs) —</b>	<b>Discussion</b>
<b>NATURAL FEPs</b>	
— Stratigraphy	
— <b>Stratigraphy</b>	Section 2.1.3
— <b>Brine reservoirs</b>	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	
— <b>Seismic activity</b>	Section 2.6
<b>Crustal processes</b>	
— 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
<b>Geochemical FEPs</b>	
— Dissolution	
— <b>Shallow dissolution</b>	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
<b>SUBSURFACE HYDROLOGICAL FEPs</b>	
— Groundwater characteristics	
— <b>Saturated groundwater flow</b>	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)**

<b>Features, Events, and Processes (FEPs)</b>	<b>Discussion</b>
— <b>Unsaturated groundwater flow</b>	Section 2.2.1
— <b>Fracture flow</b>	Section 2.2.1
— Density effects on groundwater flow	Section 2.2.1
— <b>Effects of preferential pathways</b>	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
<b>SUBSURFACE GEOCHEMICAL FEPs</b>	
— Groundwater geochemistry	Section 2.4.2.1
— <b>Groundwater geochemistry</b>	
— 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
<b>GEOMORPHOLOGICAL FEPs</b>	
— Physiography	
— <b>Physiography</b>	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)**

<b>Features, Events, and Processes (FEPs)</b>	<b>Discussion</b>
— 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
<b>SURFACE HYDROLOGICAL FEPs</b>	
— Fluvial	
— Stream and river flow	Section 2.2.2
— Lacustrine	
— Surface water bodies	Section 2.2.2
— Groundwater recharge and discharge	
— <b>Groundwater discharge</b>	Section 2.2.1
— <b>Groundwater recharge</b>	Section 2.2.1
— <b>Infiltration</b>	Section 2.1.4.2
— Changes in surface hydrology	
— <b>Changes in groundwater recharge and discharge</b>	Section 2.2.1
— Lake formation	Section 2.2.2
— River flooding	Section 2.2.2
<b>CLIMATIC FEPs</b>	
— Climate	
— <b>Precipitation (for example, rainfall)</b>	Section 2.5.2.3
— <b>Temperature</b>	Section 2.5.2.2
— Climate change	
— Meteorological	
— <b>Climate change</b>	Section 2.5.1
— Glaciation	
— Glaciation	Section 2.5.1
— Permafrost	Appendix SCR, Section SCR.1.6.2.2
<b>MARINE FEPs</b>	
— 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)**

<b>Features, Events, and Processes (FEPs)</b>	<b>Discussion</b>
— 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
<b>ECOLOGICAL FEPs</b>	
— 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>
<b><i>NATURAL FEPs</i></b>		
<b><i>Stratigraphy</i></b>		
<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>
<b><i>Tectonics</i></b>		
<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>
<b><i>Structural FEPs</i></b>		
<b><i>Deformation</i></b>		
<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>
<b><i>Fracture development</i></b>		
<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>
<b><i>Fault movement</i></b>		
<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>
<b><i>Seismic activity</i></b>		
<i>Seismic activity</i>	<i>N12</i>	<i>Section 2.6</i>
<b><i>Crustal processes</i></b>		
<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>
<b><i>Geochemical FEPs</i></b>		
<b><i>Dissolution</i></b>		
<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>
<b><i>Mineralization</i></b>		
<i>Fracture infills</i>	<i>N22</i>	<i>Section 2.1.3.5.2</i>
<b><i>SUBSURFACE HYDROLOGICAL FEPs</i></b>		
<b><i>Groundwater characteristics</i></b>		
<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>
<b><i>Changes in groundwater flow</i></b>		
<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>
<b><i>SUBSURFACE GEOCHEMICAL FEPs</i></b>		
<b><i>Groundwater geochemistry</i></b>		
<i>Groundwater geochemistry</i>	<i>N33</i>	<i>Section 2.2.1.4.1.2</i>
<b><i>Changes in groundwater geochemistry</i></b>		
<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>
<b>GEOMORPHOLOGICAL FEPs</b>		
<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>
<b>Denudation</b>		
<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>
<i>Erosion</i>		
<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>
<i>Sedimentation</i>		
<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>
<i>Soil development</i>		
<i>Soil development</i>	<i>N50</i>	<i>Section 2.1.3.10</i>
<b>SURFACE HYDROLOGICAL FEPs</b>		
<i>Fluvial</i>		
<i>Stream and river flow</i>	<i>N51</i>	<i>Section 2.2.2</i>
<i>Lacustrine</i>		
<i>Surface water bodies</i>	<i>N52</i>	<i>Section 2.2.2</i>
<i>Groundwater recharge and discharge</i>		
<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>
<i>Changes in surface hydrology</i>		
<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>
<b>CLIMATIC FEPs</b>		
<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>
<b>MARINE FEPs</b>		
<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>
<b>ECOLOGICAL FEPs</b>		
<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 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:

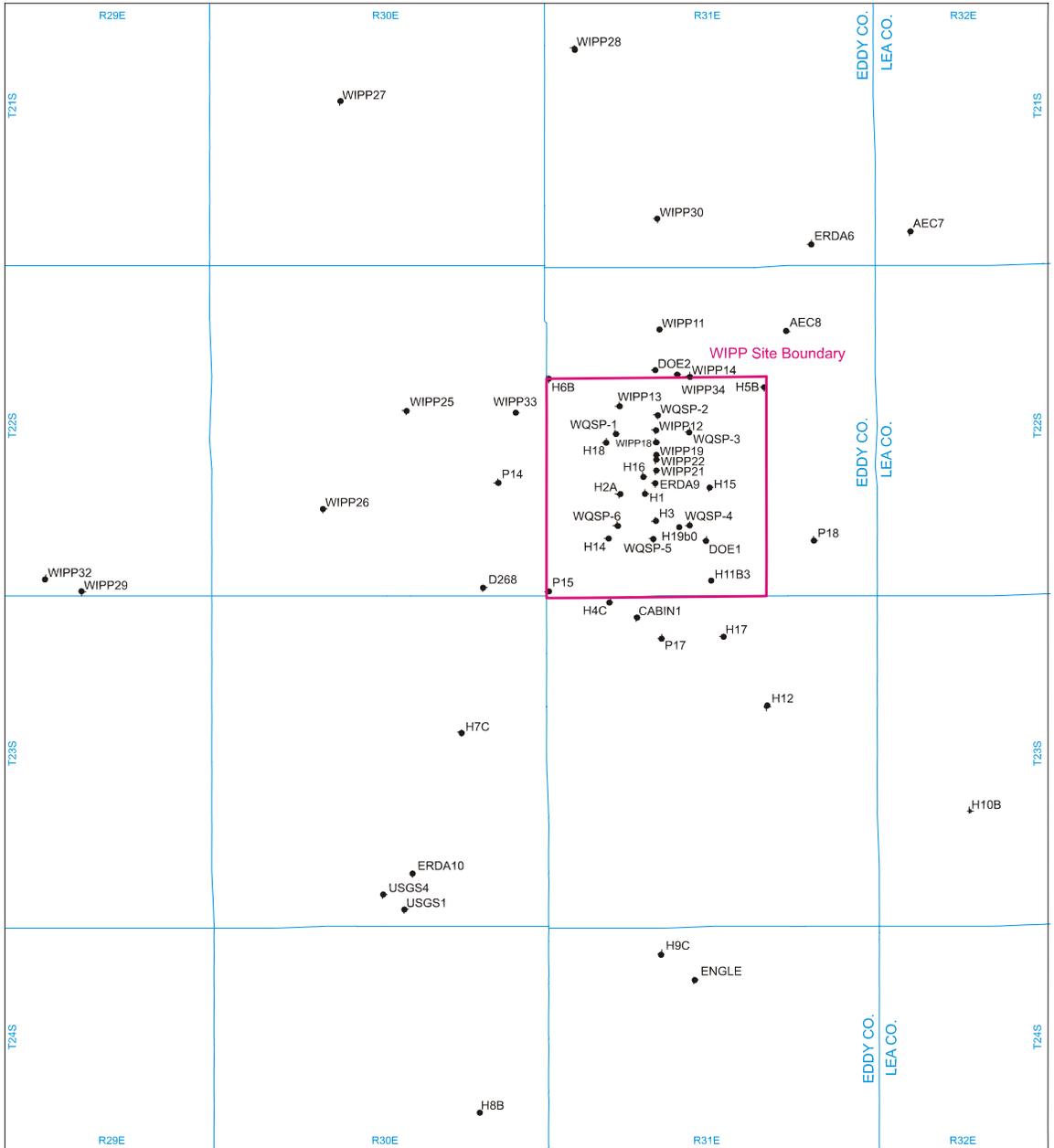
- 19 • A Precambrian Period, represented by metamorphic and igneous rocks ranging in age  
20 from about 1.5 to 1.1 billion years;
- 21 • A period from about 1.1 to 0.6 billion years ago, from which no rocks are preserved.  
22 Erosion may have been the dominant process during much of this period; *and*
- 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.

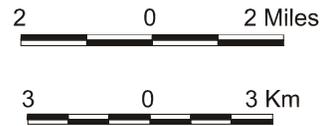
26 Only a few boreholes in the WIPP region have bored deep enough to penetrate Precambrian  
27 crystalline rocks, and, therefore, relatively little petrological information is available. Foster  
28 (1974, Figure 3) extrapolated the elevation of the Precambrian surface under the area of WIPP as  
29 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



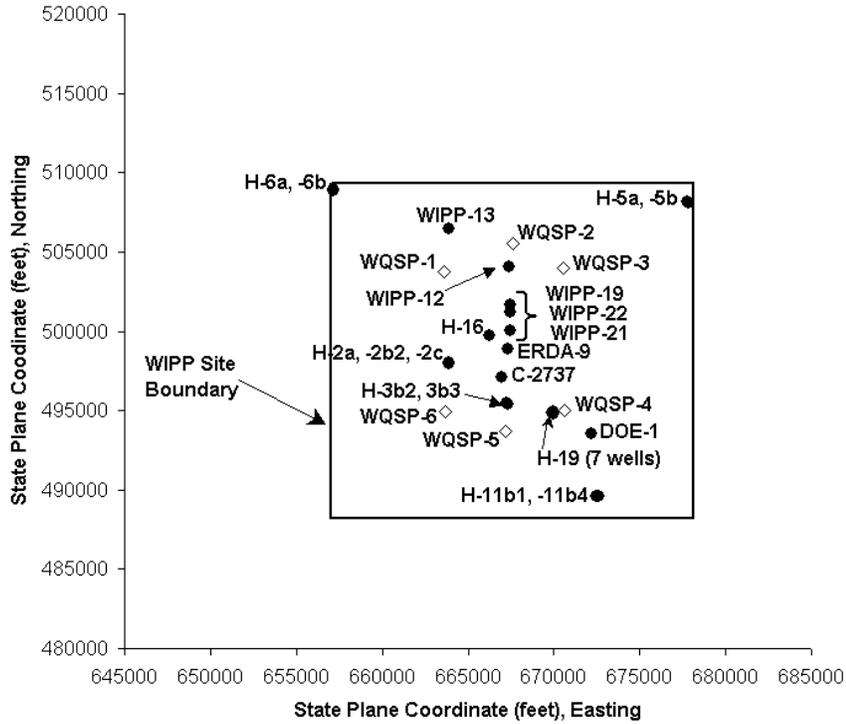
● Borehole Location



CCA-022-2

1  
2  
3

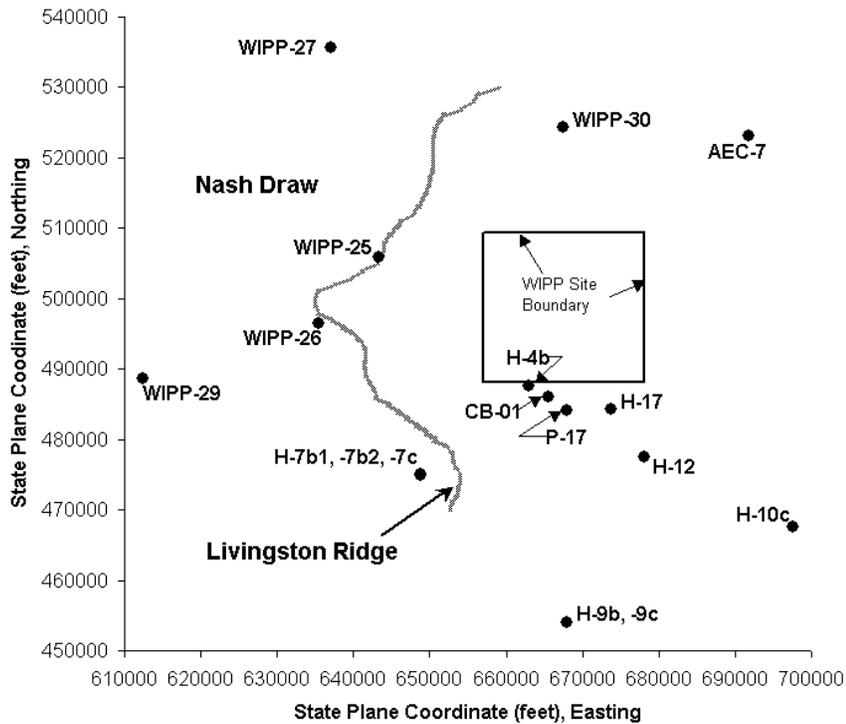
**Figure 2-2. WIPP Site and Vicinity Borehole Location Map (partial)**



1

2

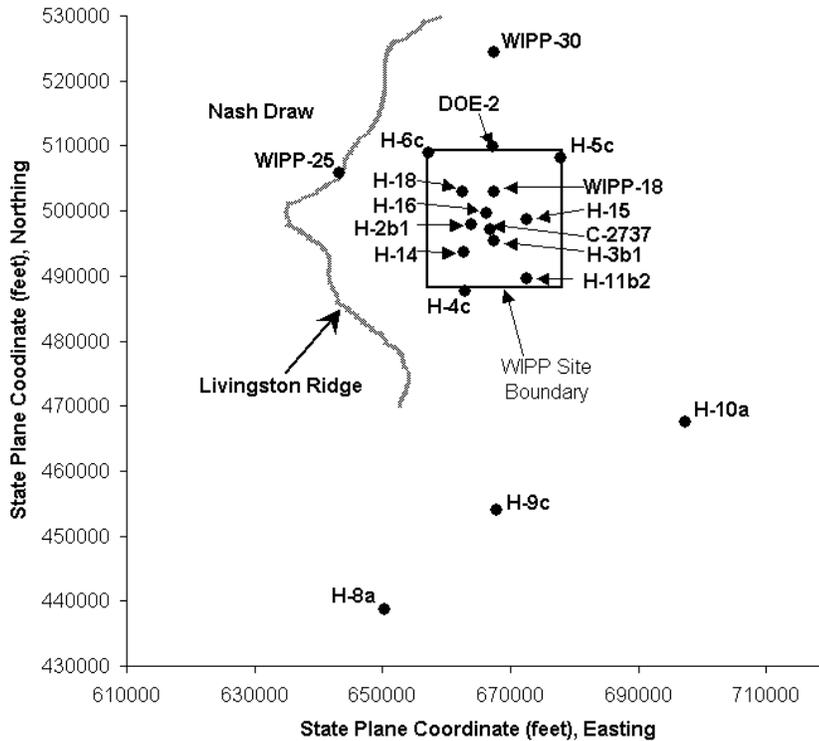
*Figure 2-3. Locations of Culebra Monitoring Wells Inside the WIPP Site Boundary*



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  
 4 Basin Platform have penetrated the top of the Precambrian (Foster 1974, Figure 3). As  
 5 summarized by Foster (1974, 10), Precambrian rocks in the area considered similar to those in  
 6 the vicinity of the site range in age from about 1.14 to 1.35 billion years.

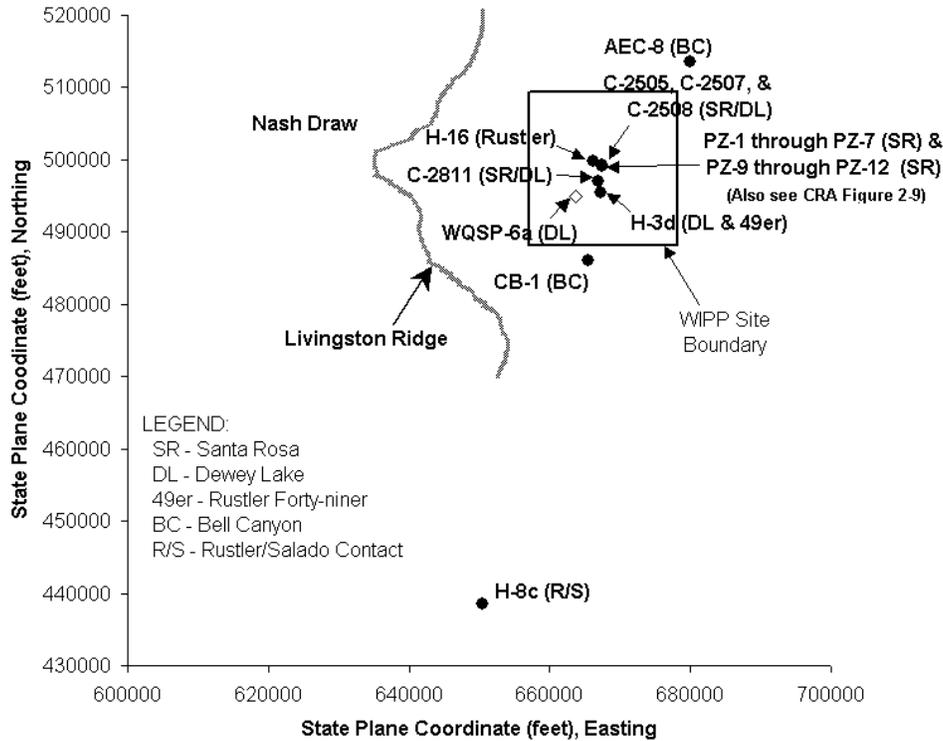
7 For about 500 million years (1.1 to 0.6 billion years ago), there is no certain rock record in the  
 8 region around the WIPP. The most likely rock record for this period may be the Van Horn  
 9 sandstone (McGowan and Groat 1971), but there is no conclusive evidence that it represents part  
 10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

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

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  
 18 rock layers as a model input as described in Section 6.4.2.1. This means that stratigraphic  
 19 information (thickness and lateral extent) provided in the following sections are important inputs.

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				

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

1

2

SYSTEM/ Series		Group	Formation	Members
QUATER- NARY	Holocene	Dockum	surficial deposits	
	Pleisto- cene		Mescalero caliche	
	Pliocene		Gatuña	
	Miocene			
TERTIARY				
TRIASSIC				
			Santa Rosa	
PERMIAN			Dewey Lake	
	Ochoan	Dockum	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				

1

2

*Figure 2-8. Partial Site Geologic Column*