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2.0 SITE CHARACTERIZATION

The U.S. Department of Energy (DOE) uses the performance assessment ***(PA)*** methodology described in ~~Section 6.1~~ ***Chapter 6.0*** to demonstrate that the Waste Isolation Pilot Plant (WIPP) disposal system will meet the environmental performance standards of Title 40 of the Code of Federal Regulations (CFR) Part 191 Subparts B and C. In order to effectively use ***PA,*** three inputs are necessary: What can happen to the disposal system? What are the chances of it happening? What are the consequences if it happens? The answers to these questions are derived from many sources, including field studies, laboratory evaluations, experiments, and, in the case of some features not amenable to direct characterization, professional judgment. The information used in ***PA*** is described in terms of features of the disposal system that can be used to describe its isolation capability, events that can affect the disposal system, and processes that are reasonably expected to act on the disposal system.

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

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

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

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

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

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

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

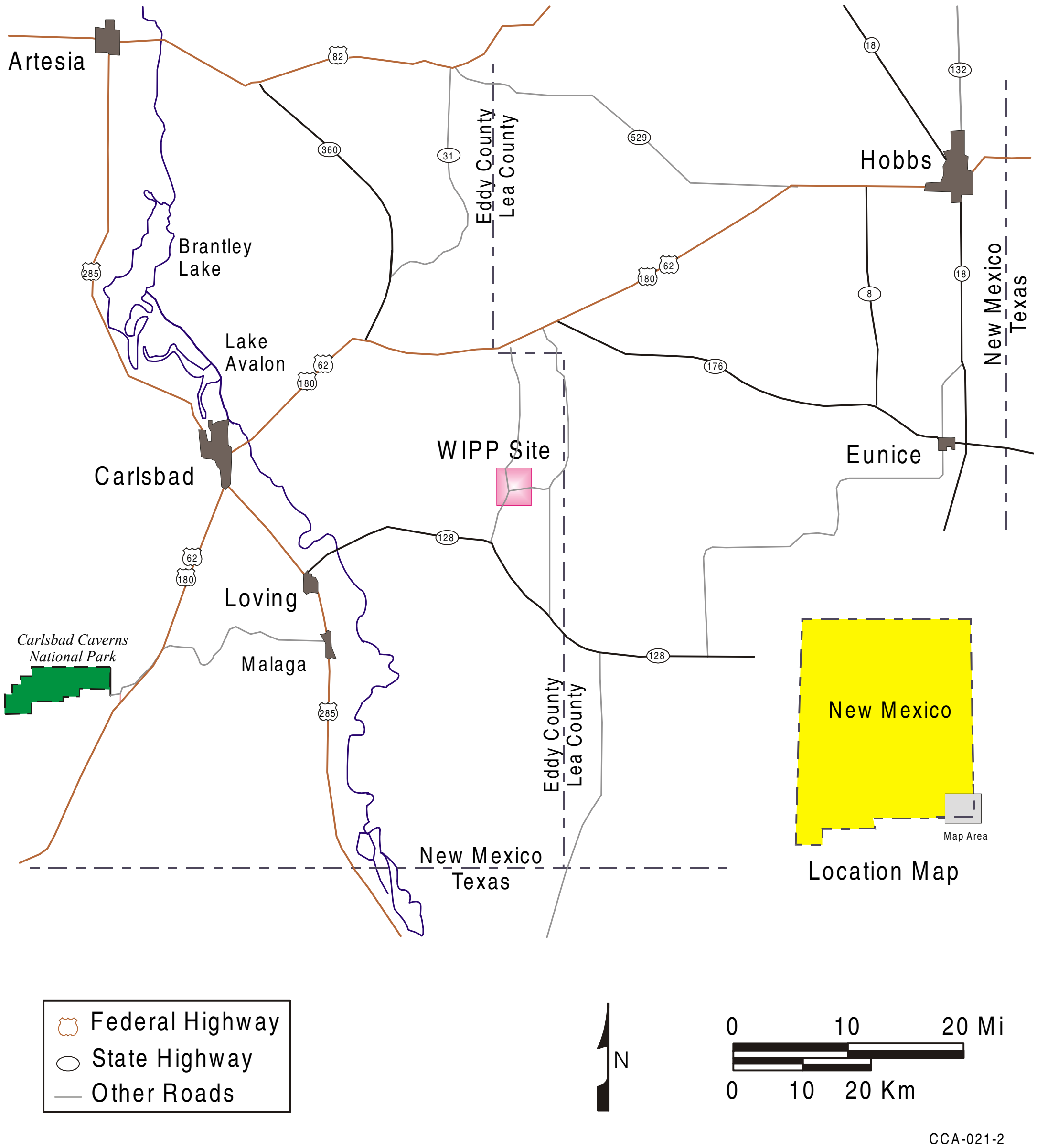

Figure 2-1. WIPP Site Location in Southeastern New Mexico

~~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~~

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~~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 SCR1.2.2.2~~
~~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~~

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

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

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

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

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

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

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

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

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

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

2.1 Geology

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

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

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

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

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

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

2.1.1 Data Sources

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

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

The geological data that the DOE has developed explicitly for the WIPP project have been produced over a ***25***~~20~~-year period by different organizations and contractors using applicable national standards (Quality Assurance Program history is described in Section 5.***1***.2). During a rulemaking in 1988 related to the underground injection of hazardous wastes, the EPA addressed the use of older geological data in making a long-term demonstration of repository performance. In response to comments on a proposed rule regarding the permitting of underground injection wells, the EPA concluded that "[e]xcluding historical data or information which might have been gathered off-site by methods not consistent with certain prescribed procedures may be counterproductive." The EPA further stated that such data should be used as long as their limitations are accounted for. In the final rule, the EPA stipulated "that only measurements pertaining to the waste or that result from testing performed to gather data for the petition demonstration comply with prescribed procedures." Further, the EPA stated that "the concerns about the accuracy of geologic data are addressed more appropriately by requiring that the demonstration identify and account for the limits on data quality rather than by excluding data from consideration" (EPA 1988).

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

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

The borehole data set~~s~~ that ~~were~~***was*** used specifically for obtaining ~~Waste Isolation Pilot Plant (~~WIPP~~)~~ geologic information ***is*** included as reference information in ***CCA*** Appendix BH. ~~This appendix provides some summary information and is a pointer for data reports that contain more detailed results.~~ A map of some borehole locations in the data set is provided in Figure 2-2. ***Figure 2-3 shows Culebra monitoring wells within the site boundary as of December 2002, including well C-2737, which was drilled and completed in 2001 (Powers 2002c). Figure 2-4 shows Culebra monitoring wells outside the WIPP site as of December 2002; plugged and abandoned wells formerly monitored are not included in this figure. Figure 2-5 shows the locations of wells configured to monitor the Magenta, including well C-2737. Other hydrostratigraphic units are monitored in wells shown in Figure 2-6, including well C-2811, which was drilled and completed in 2001 to monitor a shallow saturated zone developed since the WIPP surface structures were constructed (Powers and Stensrud 2003).*** Other holes are not shown because they were not of sufficient depth, were not cored, or were not drilled for purposes of site characterization. A more comprehensive drillhole database of the entire Delaware Basin is addressed in Section 2.3.1.2 and is presented in ***Appendix DATA*** ~~Appendix DEL (Figure DEL-4)~~. This database includes all drillholes used in evaluating human intrusion rates for the WIPP ***PA***.

2.1.2 Geologic History

In this section, the DOE summarizes the more important points of the area's geologic history within about 320 km (200 mi) of the WIPP site, with emphasis on more recent or nearby events. Figure 2-~~3~~*7* shows the major elements of the area's geological history from the end of the Precambrian Period.

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

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

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

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

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

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

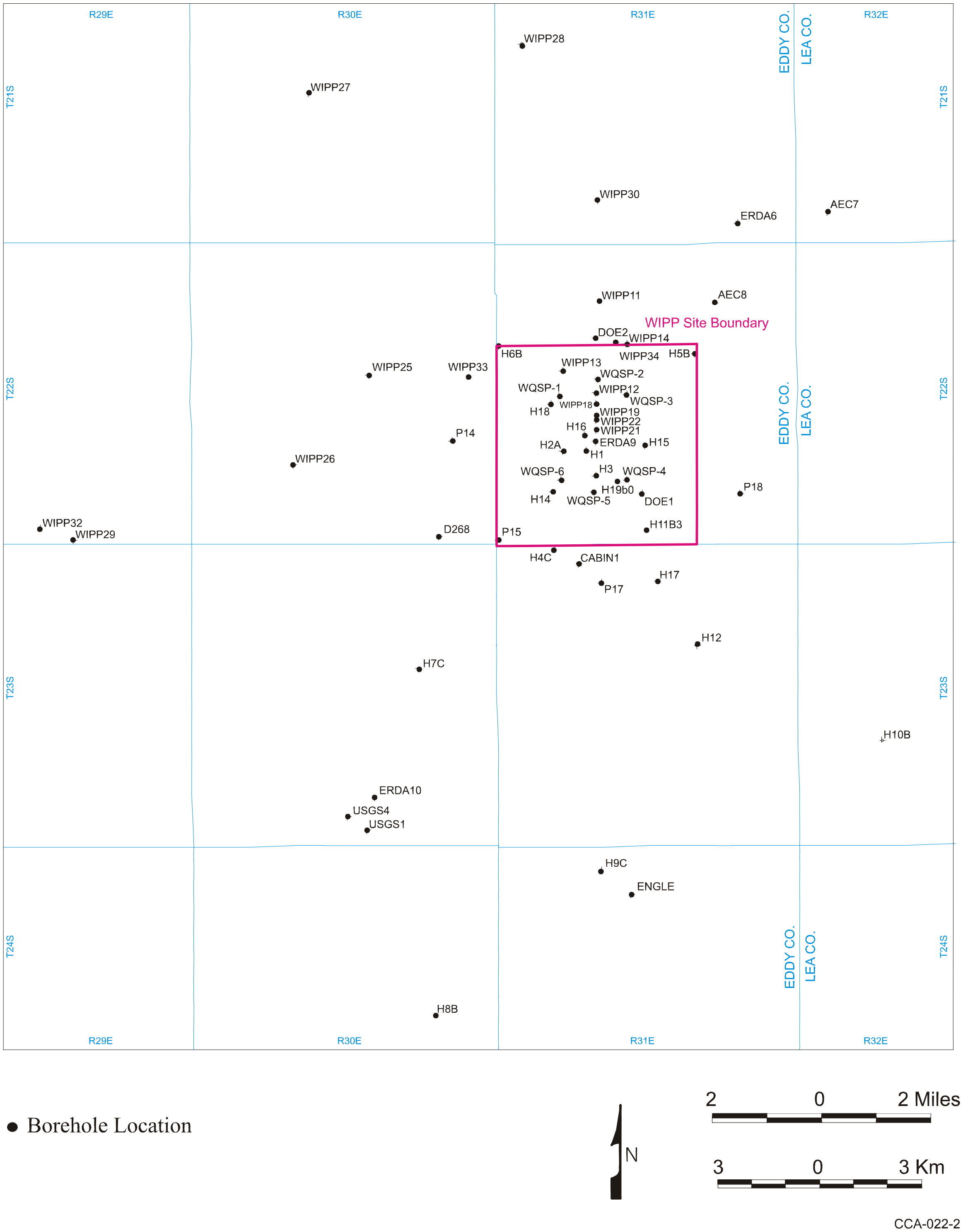

Figure 2-2. WIPP Site and Vicinity Borehole Location Map (partial)

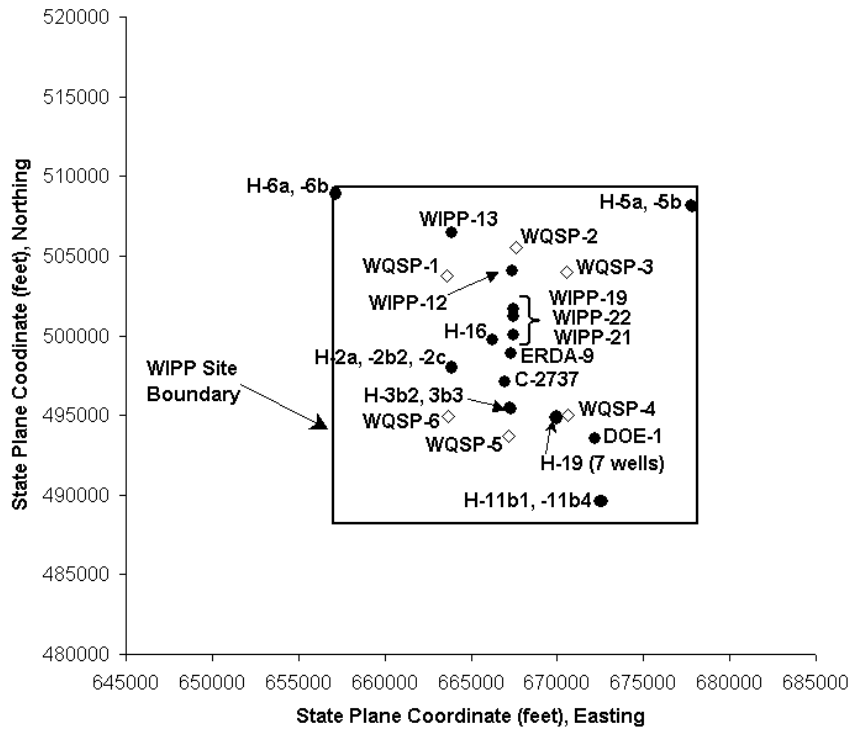

Figure 2-3. Locations of Culebra Monitoring Wells Inside the WIPP Site Boundary

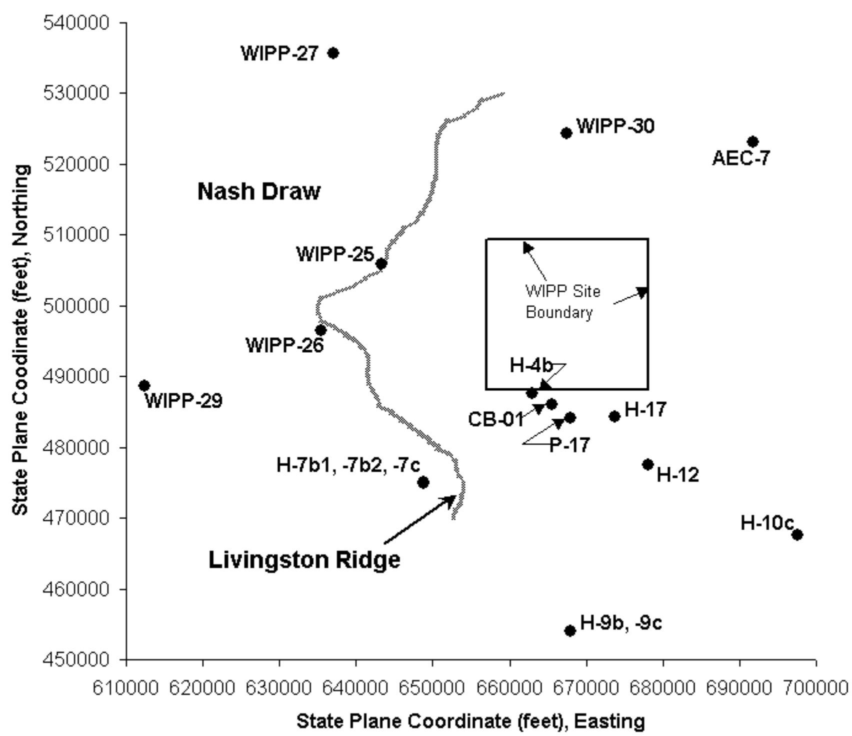

Figure 2-4. Locations of Culebra Monitoring Wells Located Outside the WIPP Site Boundary

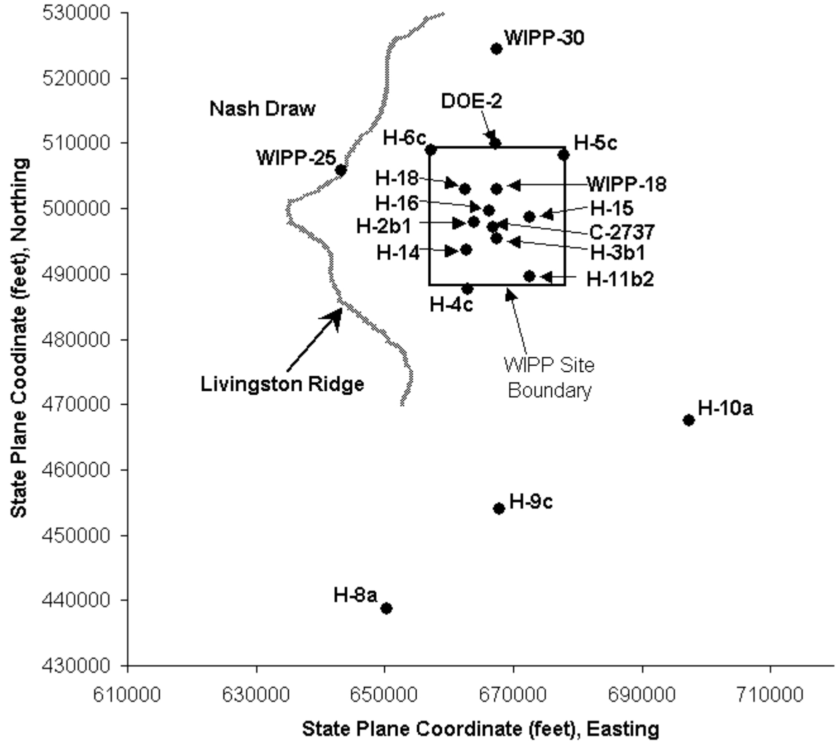

Figure 2-5. Locations of Magenta Monitoring Wells

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.

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.

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).

2.1.3 Stratigraphy and Lithology in the Vicinity of the WIPP Site

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.

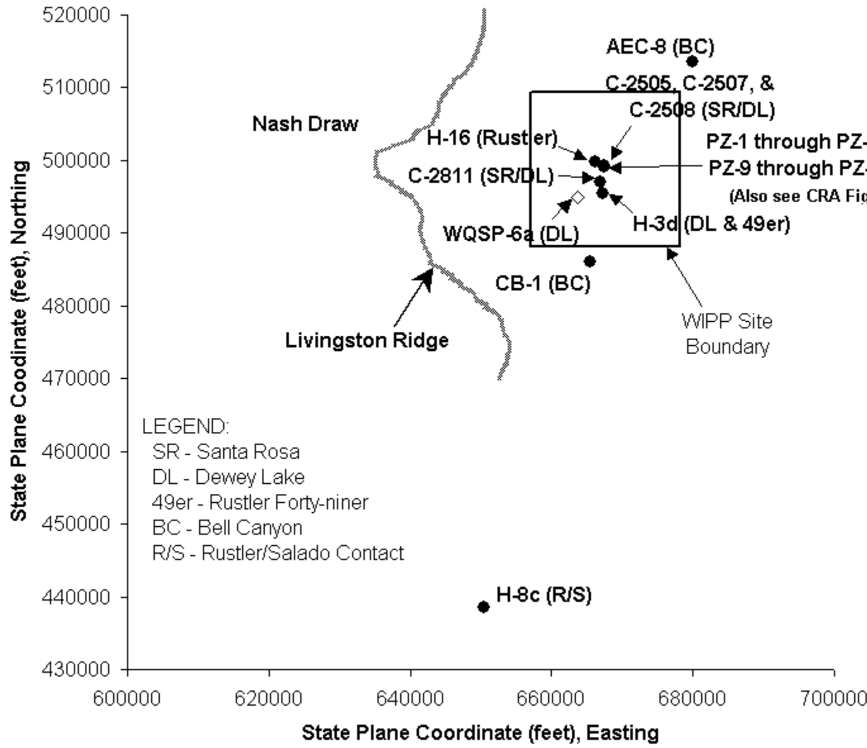

Figure 2-6. Locations of Monitoring Wells Completed to Hydrostratigraphic Units Other Than the Culebra and Magenta Dolomite Members (See also Figure 2-39).

In addition, less important features such as the lithology and the presence ***of*** geochemically significant minerals are provided to support screening arguments in Appendix ***PA, Attachment*** SCR. Consequently, this discussion has focused on the general properties of the various rock units as determined from field studies. Specific parameters used in the modeling described in Sections 6.4.5 and 6.4.6 are summarized in ~~Appendix PAR (Tables PAR-25 to PAR-32 and PAR-34 to PAR-36)~~ ***Appendix PA, Attachment PAR.*** Stratigraphy-related parameters are input as constants. Stratigraphic thicknesses of units considered in modeling are compiled in Appendix ***PA, Attachment*** PAR, Table PAR-~~57~~***49***.

This section describes the stratigraphy and lithology of the Paleozoic and younger rocks underlying the WIPP site and vicinity (Figure 2-4***8***), emphasizing the units nearer the surface. After briefly describing pre-Permian rocks, the section provides detailed information on the Permian (Guadalupian) Bell Canyon Formation (hereafter referred to as the Bell Canyon)—the upper unit of the Delaware Mountain Group—because this is the uppermost transmissive formation below the evaporites. The principal stratigraphic data are the chronologic sequence, age, and extent of rock units, including some of the nearby relevant facies changes. For deeper rocks, characteristics such as thickness and depth are summarized from published sources, and for shallower rocks, they are mainly based on data sets presented in ***CCA*** Appendix BH (above the Bell Canyon). The lithologies of upper formations and some formation members are described. A comprehensive discussion of stratigraphy in the WIPP area is presented ~~in this application~~ in ***CCA*** Appendix GCR. Detailed referencing to original investigations by the USGS and others is included.

ERA	PERIOD	EPOCH	YEARS: DURATION	YEARS: BEFORE PRESENT	MAJOR GEOLOGIC EVENTS - SOUTHEAST NEW MEXICO REGION
CENOZOIC	Quaternary	Holocene	10,000		Eolian and erosion/solution activity. Development of present landscape.
		Pleistocene	1,590,000	1,600,000	Continued deposition of Gatuña sediments.
	Tertiary	Pliocene	3,700,000		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		
		Oligocene	12,900,000		Erosion dominant. No Early to Mid-Tertiary rocks present.
		Eocene	21,200,000		
		Paleocene	8,600,000	66,400,000	Laramide revolution. Uplift of Rocky Mountains. Mild tectonism and igneous activity to west and north.
MESOZOIC	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.
PALEOZOIC	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-~~3~~7. Major Geologic Events - Southeast New Mexico Region

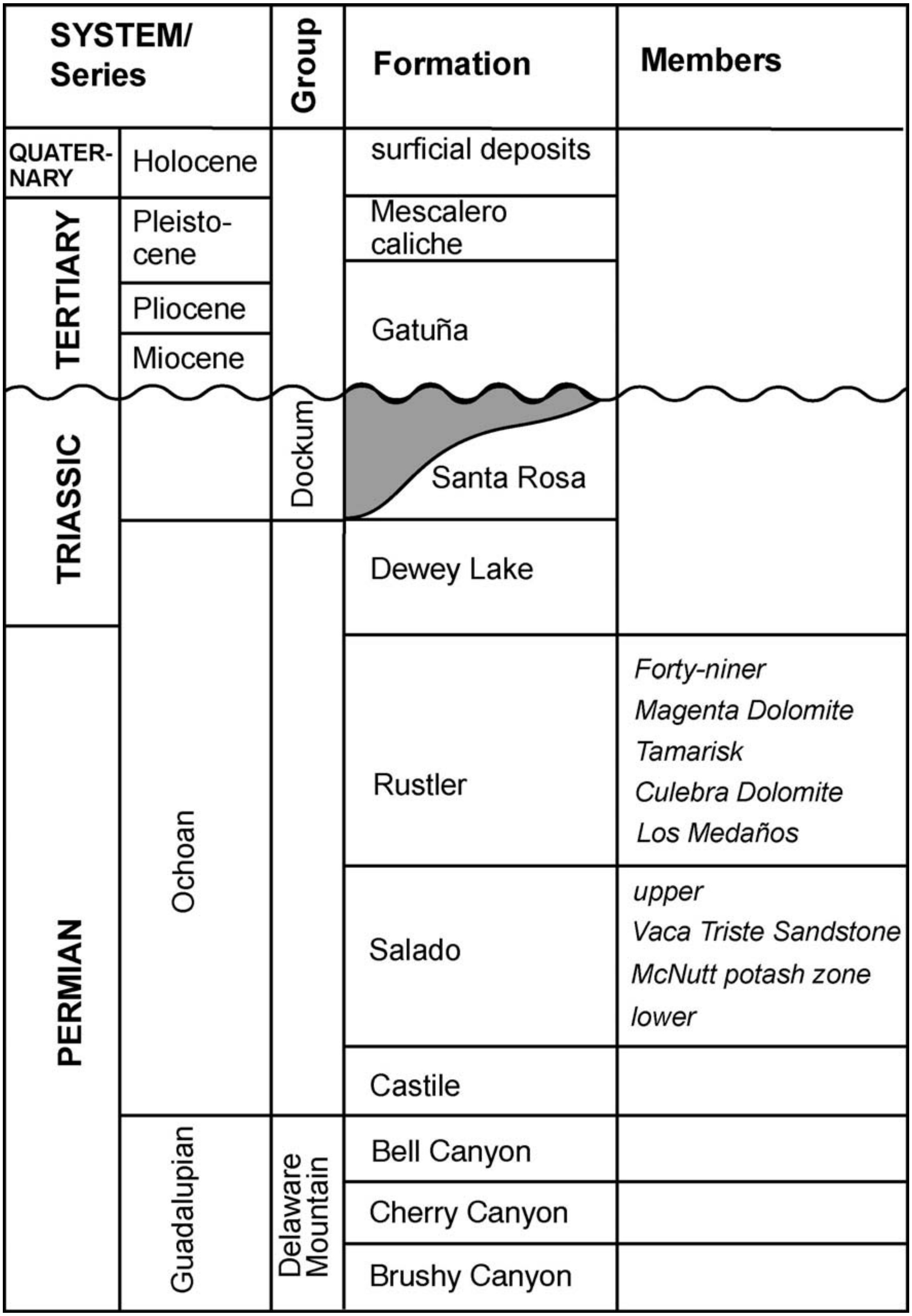

Figure 2-8. Partial Site Geologic Column