Waste Isolation Pilot Plant

Compliance Certification Application

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Submitted in accordance with 40 CFR §194.13, Submission of Reference Materials.

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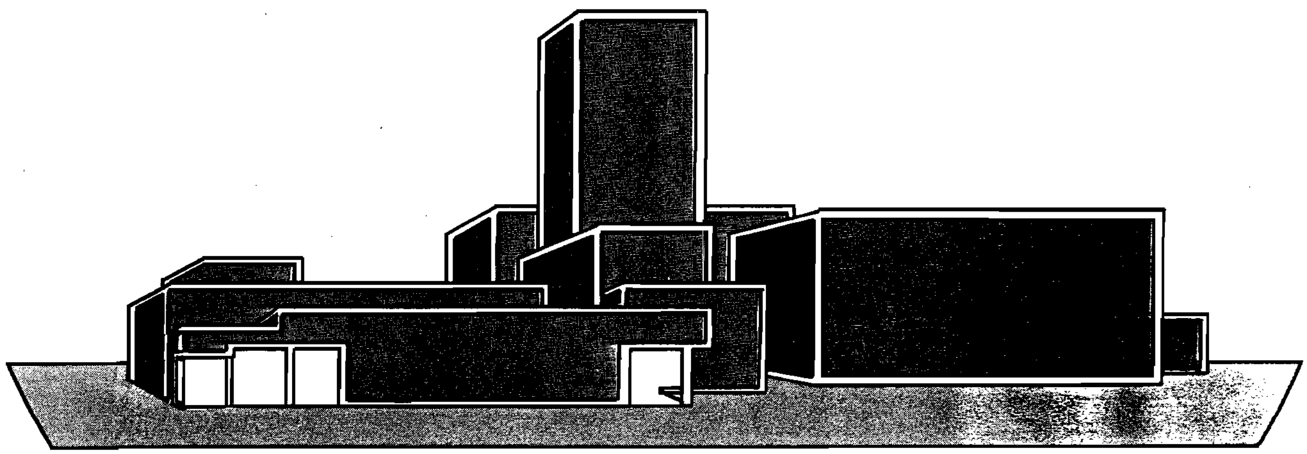
WP 02-9
Rev. 0
May 1990

Final Safety Analysis Report



WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

Volume I

SIGNATURE SHEET

This Final Safety Analysis Report was prepared for the U. S. Department of Energy under contract number DE-AC04-86AL31950 by Westinghouse Electric Corporation, Waste Isolation Division.

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memorandum

JUN 22 10 01 AM '90

DATE: JUN 1 2 1990

REPLY TO ATTN OF: EM-34

SUBJECT: Waste Isolation Pilot Plant Final Safety Analysis Report Approval

TO: Manager, Albuquerque Operations Office

As designated by the Secretary's memorandum to you, dated April 2, 1990, I have been appointed the approving official for the WIPP FSAR. To support my decision, I have weighed input from a number of areas as follows. I have received your recommendation, dated June 7, 1990, that I approve the FSAR. In addition, I have reviewed the status of the reviews performed by the numerous groups who have reviewed the FSAR, including the DOE/AL Safety Programs Division, DOE-HQ Office of Environment, Safety, and Health, the New Mexico Environmental Evaluation Group, the New Mexico Environmental Improvement Division, and the Advisory Committee on Nuclear Facility Safety, as well as my own staff. Based on this information, I hereby approve the WIPP FSAR.

This approval acknowledges the FSAR as a statement and commitment by the Department that the WIPP facility can be operated safely and at minimum risk, if operated in accordance with this FSAR. In addition, we recognize the FSAR as a living document with control of the document in accordance with the attached Policy Statement. However, as delineated in the preface to the FSAR, the document does not address activities associated with the planned test phase. An addendum will be prepared and approved by me prior to initiation of the Test Phase. In addition, I recognize ongoing operational readiness reviews and inspections have not been fully resolved. Remaining appraisal items will be resolved prior to receipt of waste, in accordance with the Secretary's Decision Plan.

I appreciate the effort put forth by you, your staff, and the WIPP Project team in preparing this document and in resolving the issues with the multitude of review organizations.

Leo P. Duffy
Director
Office of Environmental Restoration
and Waste Management

Attachment

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PREFACE

Background

This Final Safety Analysis Report (FSAR) has been prepared for the Waste Isolation Pilot Plant (WIPP) in order to satisfy the commitments made in the Working Agreement for Consultation and Cooperation (Article III, Section C and Article IV, Section K, known as the Working Agreement) between the State of New Mexico and the U.S. Department of Energy (DOE) and the requirements of Order DOE 5481.1B, Safety Analysis and Review System.

The objectives of the Safety Analysis Preparation and Review process, as specified in Order DOE 5481.1B, ensure that:

1. Potential hazards are systematically identified;

2. Potential consequences are analyzed;

3. Reasonable measures to eliminate, control or mitigate the hazards have been taken, including, where applicable, compliance with commitments made in environmental assessments and impact statements;

4. There is documented management authorization of the DOE operation based upon an objective assessment of the safety analysis.

Specific hazards that are analyzed include credible natural hazards such as flood, weather (tornado, wind, etc.) and earthquake; and credible man made hazards such as fire, explosion, radiation, and mining hazards. Mitigating measures include facility design and construction, operational controls, and administrative limits.

This FSAR represents a statement and commitment by the DOE that the WIPP facility can be operated safely and at minimum risk, if operated in accordance with this FSAR. Consequently, this FSAR has been prepared to document that a systematic analysis of the potential hazards associated with operating the WIPP facility has been performed (objective 1 of Order DOE 5481.1B); that potential consequences have been analyzed (objective 2 of Order DOE 5481.1B); and that reasonable measures have been taken to eliminate, control, or mitigate the hazards (objective 3 of Order 5481.1B). In addition, this FSAR documents the implementation of commitments made in the environmental impact statement regarding the mitigation of adverse impacts to the environment (objective 3 of Order DOE 5481.1B).

Note that objective 4 of Order DOE 5481.1B is met by activities performed outside the FSAR. The recommendation for management authorization to begin operations is the result of an activity known as readiness review. This readiness review is a prerequisite to operations and is discussed in this preface.

In the process of preparing and reviewing this FSAR, several review groups have raised concerns regarding the scope and the role of the FSAR in the process for management authorization for the start of operations at the WIPP. This preface addresses these concerns.

Scope of the FSAR

The questions concerning the scope of the FSAR was approached from two standpoints. First, the Advisory Committee on Nuclear Facility Safety (ACNFS) recommended that the DOE define the FSAR as the top-level safety document that serves as a compilation of all commitments necessary to ensure safe operations of the facility. This definition is consistent with the Working Agreement with the State of New Mexico, which defines the Safety Analysis Report (SAR) as the most comprehensive document concerning the WIPP as related to public health and safety. In response to this concern, the DOE acknowledges that this FSAR represents a statement and commitment by the DOE that the WIPP facility can be operated safely, and at minimum risk, if operated in accordance with the FSAR. Readiness of the WIPP facility to operate in accordance with the FSAR is discussed under Prerequisites.

Second, the Environmental Evaluation Group (EEG) and others questioned the validity of the FSAR for the period of time after the initial Test Phase, since no commitment will be made regarding operating the plant past this time until the DOE can demonstrate compliance to applicable long-term performance standards.

The DOE has responded to this question by pointing out that this FSAR makes no commitments to operate the WIPP facility for any predetermined time period. Operating scenarios and quantities of waste will be determined independent of the FSAR in accordance with DOE programmatic needs. To the extent that these programmatic determinations result in modifications to the operational design described in this FSAR, additional safety analysis will be conducted. Consistent with DOE policy regarding the construction of major facilities, the WIPP facility has a nominal design life of 25 years. Consequently, the physical plant (Waste Handling Building and equipment, shafts, radiation monitoring systems, etc.) for the project have been designed and constructed for a 25-year operational period. This FSAR is applicable to operations during the 25 years of waste handling, as currently planned, excluding those portions of the Test Phase that are not anticipated to be design basis operations (such as bin sampling, etc.). A description of the activities planned for the Test Phase and safety analyses of the proposed actions will be available as an addendum to this document prior to the inception of these activities. Also, since an analysis of the suitability of the project for long-term isolation of the waste will not be completed until 1994, the FSAR does not address the questions of long-term performance, i.e. performance to 10,000 years.

Related to this, the EEG has recommended that the health and safety impacts of activities associated with the Test Phase should be included in the FSAR prior to initial approval. The DOE has considered this question and has opted to proceed with documenting the Test Phase activities in a separate document, as described below. The basis for this approach is the FSAR considers operations at waste throughput rates equivalent to the design basis. Lesser throughput rates and shorter operating periods such as those proposed during the Test Phase are bounded by the design conditions. In this regard, the FSAR covers the first five years of operations as a Test Phase during which time various test, experiments, and demonstrations will occur, which are being designed to support a decision regarding full-facility operations. Planning for these tests is proceeding in parallel with the preparation of this FSAR; consequently the tests are not explicitly described in this FSAR. Once these tests are sufficiently well defined, additional safety analysis documentation will be developed, as required. This documentation will be reviewed internally and externally consistent with DOE policy and agreements with outside agencies such as the State of New Mexico. None of the wastes required to conduct these Test Phase activities will be shipped to the WIPP facility until the additional safety analysis has been completed and the proper management approvals have been granted.

Prerequisites

As a result of EEG's review of the FSAR, they identified a number of items that were not included in the FSAR. Most of these items have been identified by the DOE as prerequisites to startup or prerequisites to a decision on retrieval. These items will be used in association with the FSAR in making the decision to start waste operations at the WIPP. Those prerequisites that must be completed prior to management authorization to begin operations are found in the Secretary's Decision Plan for WIPP.

One of the prerequisites is a readiness review. This activity is required by Order DOE 5481.1B to ensure that all systems, structures, and operational policies are consistent with the FSAR, that they provide the required level of safety and protection, and that commitments made with regard to the mitigation of risks have been implemented.

The FSAR does not assess or justify whether the facility is operationally ready to receive waste or makes a determination of the adequacy of the radiation protection program. Similarly, it does not make a determination of the ability to detect radioactivity either above ground or below ground. Documentation of the readiness to receive waste will be contained in the "WIPP Readiness Review Inspection Report," which will be issued prior to receipt of waste.

Another prerequisite is the completion of the safety analysis for the specific activities proposed for the Test Phase, including the retrieval of any wastes emplaced during the Test Phase. This FSAR does not provide a description or justification for proposed activities during the Test Phase period, for the quantities of waste that may be used, or the radiological risks associated with those activities that are significantly different than planned operations. Analyses of the safety of bin and alcove experiments for contact handled transuranic (CH TRU) waste, and potential hazards of retrieval during the test phase will be published as an addendum to the FSAR prior to initiating such activities.

Prerequisites associated with compliance to the Resource Conservation and Recovery Act (RCRA) include the granting of a No-Migration Variance by the U.S. Environmental Protection Agency (EPA). This variance, issued under 40 CFR 268.6 will allow the DOE to place untreated radioactive mixed wastes in the WIPP facility. In addition, the DOE must file Part A of the RCRA permit application with the New Mexico Environmental Improvement Division (NM/EID). Through this action, the DOE will obtain Interim Status as a disposal facility for radioactive mixed wastes.

In this regard, while the FSAR includes a determination of risks associated with the handling of radioactive mixed waste it does not make a final determination of the safety of emplacing chemical hazardous constituents in the waste at the WIPP. This determination is included in the No-Migration Variance Petition, which is currently undergoing EPA review.

Prior to waste emplacement, the DOE must demonstrate the retrievability of the waste to be emplaced during the Test Phase. The DOE is committed to maintaining the retrieval of all wastes emplaced during the Test Phase and will publish a comprehensive report on retrievability before shipping waste to the WIPP. The purpose of this document is to:

- Ensure sufficient preoperational planning so that the retrieval of waste from the WIPP is possible for whatever time period is needed, thereby avoiding becoming a permanent repository by default.
- Enable the required retrieval of waste at the end of the Test Phase to emplace backfill and any potential modifications of the waste form and/or the repository.

Scoping safety analysis of operations to retrieve wastes will be completed as part of the addendum described above covering the activities proposed for the Test Phase, prior to the emplacement of wastes at the WIPP facility.

In addition, the DOE is committed to providing assurance that wastes will be retrievable prior to the decision on permanent disposal. Several measures have been taken to provide this assurance. First, to prevent crushing of containers of waste, backfilling of CH TRU waste will be deferred, and provisions have been taken, such as pattern bolting, wire mesh, and reduced room size, to minimize chances of roof falls in sealed rooms. Second, retrieval demonstrations have been conducted using simulated CH TRU containers. Third, the WIPP facility operating staff is currently planning to conduct periodic demonstrations of retrievability during the Test Phase.

The EEG also provided a description of several items that are prerequisites to making a decision for full-facility operations at the end of the Test Phase. The first item deals with long-term performance. Specifically, the FSAR does not show compliance with any of the requirements of Subpart B of the EPA Environmental Standards for the Management andDisposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR 191), promulgated in September, 1985. These include:

- Probabilistic Risk Assessment
- Assurance requirements including the design of active and passive institutional controls, post-depositional monitoring, engineered barriers, and justification for the selection of the site by evaluating the favorable geological characteristics in light of potential future mineral exploration or extraction

According to the Working Agreement, Chapter 8 of the FSAR is to include a long-term performance assessment of the WIPP facility. Since this assessment will not be available until mid-1994, this portion of the commitment in the Working Agreement is not completely satisfied. Instead, Chapter 8 of this FSAR currently contains a description of the methodology that will be used to complete the performance assessment. This activity will result in the preparation of several intermediate reports. These include Consultation and Cooperation Agreement (C&C) required reports describing the communication modes through which postulated releases from the repository occur. These reports are due to be published in Fiscal Year (FY) 1990. In addition, annual summary reports are scheduled to report the status of the WIPP facility relative to the EPA standards. An initial summary status report is on the Secretary's Decision Plan for issuance in 1990. A final compliance report is currently scheduled to be published in mid-1994. Performance assessment will be completed in time to support the decision regarding the retrieval of waste or the initiation of full-scale operations.

Simultaneous with the performance assessment activity, an evaluation of possible engineering modifications to the waste form or the repository design are being evaluated. This activity has been initiated based on current analyses, which indicate potential problems in meeting the EPA Environmental Standards for Safe Disposal of TRU wastes (40 CFR 191, Subpart B) for certain breach scenarios. If modifications are proposed to the repository design and/or waste form, an analysis of the potential hazards will be performed together with their potential consequences and methods to control hazards to workers. The results will be published in an amendment to the FSAR prior to a decision to implement such modifications.

Modifications

SAR are controlled documents that are updated periodically. The designation "Final" is given to indicate that a SAR is for a facility that is ready to begin operating versus a "Preliminary" SAR, which generally refers to a facility in the design or construction stage. FSARs must be amended to reflect significant changes in operations, design or in the factors that affect operational safety. The Albuquerque implementation of Order DOE 5481.1B (AL 5481.1B) mandates review of the FSAR at least every three years to ensure full compliance with the intent of Order DOE 5481.1B. In addition to the commitments for the FSAR addendum to cover Test Phase activities, and detailed modifications to the FSAR in conjunction with a decision to use the WIPP as a repository, the basis for determining if further safety analysis is needed will be the degree to which proposed activities represent a "significant modification" from the safety analysis performed in this FSAR.

According to Order DOE 5481.1B, the factors that will be considered in determining whether a proposed physical or administrative change constitutes a significant modification are:

- Increases in the risk from a hazard beyond that previously analyzed and reviewed. This may stem from changes in operating characteristics such as speed, temperature, or pressure; increases in the quantity of hazardous materials; and/or changes in design features or administrative controls.
- Reductions in the reliability of any item for which credit has been taken for the reduction or control of a hazard.

- Introduction of a new hazard.
- Application of new regulations.
- Receipt of new information indicating an increased hazard associated with an existing operation.

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CHAPTER 1

INTRODUCTION AND GENERAL DESCRIPTION

1.1 INTRODUCTION

This Final Safety Analysis Report (FSAR) has been prepared by the U.S. Department of Energy (DOE) to support the operation of the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico. The WIPP facility has been designed to accommodate the permanent disposal of transuranic (TRU) wastes. The principle operational functions of the WIPP facility include the receipt, inspection, emplacement in an underground salt repository of containers of unclassified, defense-generated, TRU wastes. Pending the results of a Test Phase, wastes will either be retrieved or left in the underground permanently. The WIPP facility was authorized by Public Law 96-164.[1]

This FSAR has been prepared in accordance with the intent of Order DOE 5481.1B[2] and DOE Albuquerque Operations Office Order AL 5481.1B.[3] Accordingly, the purpose of this FSAR is to document that a systematic analysis of the potential hazards associated with operating the WIPP facility has been performed, that potential consequences have been analyzed, and that reasonable measures have been taken to control or mitigate the hazards. Specific potential hazards that were analyzed include credible natural hazards such as flood, weather (tornado, wind, etc.) and earthquake; and credible man made hazards such as fire, explosion, radiation, and mining hazards. Mitigating measures include facility design and construction, operational controls, and administrative limits.

In addition, this FSAR has been prepared in accordance with Article III of the 1981 Consultation and Cooperation Agreement (C&C Agreement) between the DOE and the State of New Mexico and, as such, represents the most comprehensive document concerning the WIPP facility both in general terms and specifically as related to public health and safety. The C&C Agreement is Reference 4.

In accordance with the guidance in Chapter II of Order 5481.1B, the WIPP facility is classified as a low hazard facility. That is, the hazards associated with the operation of the WIPP facility are "those that present minor on-site and negligible off-site impacts to people or the environment." While Order AL 5481.1B does not normally require a Safety Analysis Report (SAR) for low hazard facilities, the FSAR was deemed appropriate for the WIPP facility for the following reasons:

- The WIPP facility is a first-of-a-kind facility thereby justifying a structured, conservative approach to determination of hazards, the assessment of risks, and the analysis of safety.
- Agreements with the State of New Mexico include the publication of "final facility amendments" to the SAR, which was prepared prior to the initiation of the construction activity at the WIPP facility.

The development of the WIPP facility has been evolutionary to the extent that the DOE implemented a process that included the following steps:

- Selection of the facility location
- Evaluation of the suitability of the location
- Preliminary and final validation of the design of the underground structures
- Conceptual through final design of surface structures and support systems
- Construction

- Turnover and startup of systems

Extensive documentation has been prepared covering these steps. A comprehensive listing of this documentation is provided in Appendix 1A.

This FSAR covers the operational phase of the WIPP facility and is intended to provide a basic understanding of the facility and the health and safety protection afforded the public, workers and the environment during operations. In addition, information is provided in Chapter 8 regarding the long-term impacts of the operation of the WIPP facility. Additional comments on the content of Chapter 8 are provided in a subsequent paragraph. Initial operations at the WIPP facility will include a period of time during which various experiments and operational demonstrations will be conducted. The planning for these experiments and demonstrations is currently underway and involves the preparation of a test plan document. Even though this plan is not yet complete, and decisions have not been made regarding the quantity of radioactive wastes to be handled at the WIPP facility during the test period, preparation of this FSAR has proceeded. The reasons for completing the FSAR prior to finalizing the test program include the following:

> The FSAR describes the facility as designed for full waste operations, therefore, handling quantities of wastes and throughputs less than the design capacity is included. The general consensus at this time is that all such tests will be conducted within the safety envelope described in this document.
>
> If the test plan requires physical or administrative changes to the design or the operational plans for the WIPP facility, Order DOE 5481.1B prescribes factors to be considered in determining the significance of such changes. If a determination is made that the changes constitute significant modifications, additional safety analysis will be performed.

The design basis for the WIPP facility is for a 25-year operating life. Operational scenarios call for the initiation of a Test Phase, generally expected to last five years. During this period of time, experiments and operational demonstrations are planned that will provide the DOE with data key in reaching a decision regarding the permanent isolation of wastes in the WIPP facility. The decision to convert the WIPP facility to a permanent repository for TRU wastes will be made only after successful demonstration that the WIPP facility can meet the environmental standards promulgated by the Environmental Protection Agency (EPA)in 40 CFR Part 191. These standards, entitled "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes' Final Rule" were issued in 1985, but were vacated and remanded by the federal courts back to the EPA for reconsideration. New standards are anticipated within the next two years. A discussion of these standards and the programs to demonstrate compliance are found in Chapters 6 and 8.

TRU waste placed in the WIPP facility during the Test Phase will be readily retrievable. In this way, should the DOE decide that at the end of the Test Phase, the WIPP facility is not the appropriate location of the permanent isolation of these wastes, they can be removed with minimal risk. Such retrieval may take twice as long as the emplacement operations, depending on the quantity of waste involved. Therefore, one operating scenario may involve on the order of 15 years of waste handling operations; five years for emplacement and ten years for retrieval.

The design basis operational scenario calls for the WIPP facility to begin full-scale operations following the Test Phase. In this case, the expectation is for the plant to operate for the full 25 years. It is presently anticipated that additional safety analysis will be performed as part of the decision making process to proceed with full-scale operations. This analysis will consider the following:

- Modifications to systems or operations that are identified during the Test Phase.
- New systems or operations that are the result of the Test Phase.

- Long-term performance assessment of the WIPP facility's ability to successfully isolate TRU wastes after the closure of the facility (See Chapter 8 of this FSAR).

In the area of final facility design and operations, this FSAR is intended to update the previous WIPP SAR and subsequent amendments. This is because the FSAR contains the most current information regarding the structures and systems at the WIPP facility, as well as the results of a great deal of startup testing and evaluation. In particular, Chapter 10, Operational Safety Requirements, was written to reflect actual operations. In the previous SAR, this chapter was based on anticipated, instead of actual, system operations and performance.

One area in the FSAR that has not been prepared as a replacement for the previous versions is Chapter 8, Long Term Performance. In this case, the promulgation of 40 CFR Part 191 has resulted in a change in the approach taken to prepare long-term performance predictions. The basic difference is that the previous analyses were consequence analyses in that certain scenarios were developed, transport models constructed, and consequences calculated. The regulations now require that a cumulative probabilistic risk assessment be performed to assess the adequacy of the facility. This difference has resulted in the need for the WIPP Project staff to initiate a performance assessment (PA) program aimed at quantifying the long-term performance of the facility in the manner required by the EPA standard. This does not necessarily mean that the previous analyses are incorrect, just inappropriate in terms of the current requirements. As a result, Chapter 8 in this FSAR contains a description of the methodology that will be used to complete the performance assessment. The schedule currently calls for the performance assessment to be completed in time to support the decision regarding the retrieval of wastes or the initiation of full-scale operations. The information gained from the performance assessment will be included in an amendment to the FSAR once that information is available. Anyone interested in reviewing the consequence analyses performed for the WIPP facility should obtain a copy of Amendment 9 of the WIPP SAR or a copy of the Final Environmental Impact Statement (FEIS). Supporting documents for this analysis are cited in Appendix 1A, including analyses performed by the Environmental Evaluation Group (EEG).

Preparation of this FSAR has been in process since FY87. This length of time is necessary for two reasons:

- The FSAR itself is a comprehensive report requiring a great deal of analysis and associated documentation.
- The review and approval process is time consuming in order to include review by appropriate organizations within the DOE and by the EEG.

In order to complete preparation of the FSAR in a timely manner, cutoff dates for new information were established. These are as follows:

- Facility modifications - the facility configuration shown is through December 1989.
- Technical information - technical data, unless it directly supports the safety analysis of recent facility modifications, is current through December 1986.
- Demographic and geographic information is current through December 1986.

Any additional data gathered since these dates is generally available in various technical reports (See Appendix 1A). As future amendments to the FSAR are prepared, information will be updated, as appropriate.

Since publication of the FEIS[5] in October 1980 and the Record of Decision (ROD)[6] in 1981 to proceed with the construction and operation of the WIPP facility, several changes have occurred. There is now a need to implement these changes as they relate to the accomplishment of the Test Phase and, eventually, the full operation of the WIPP facility. Therefore, the DOE has prepared a Supplement Environmental Impact Statement (SEIS) to further the purposes of the National Environmental Policy Act (NEPA).

The purpose of the SEIS is to examine potential environmental consequences of (1) changes in the "proposed action" since publication of the FEIS, and (2) changes in information, assumptions, or methods of analysis previously employed. The critical inquiry is to determine the significance of these changes by comparing their consequences with the environmental impacts evaluated by the FEIS. Modifications to the proposed action examined in the FEIS are as follows:

- Changes in the TRU radionuclide inventory including high-curie content waste, high-neutron waste, and elimination of high-level waste experiments
- Emplacement of hazardous chemical constituents of TRU mixed waste
- Changes in waste transportation including packaging, routes, and transportation modes
- Changes to the WIPP experimental program

The SEIS provides a companion document to this FSAR to the extent it provides additional detail regarding certain environmental impacts. Information identified during the SEIS process that indicated a need for additional safety analysis resulted in an appropriate modification to the FSAR being prepared.

Chapter 1 of this document includes a summary of the location and major design features of the WIPP facility. Chapter 1A contains a summary safety analysis, and Chapters 2 through 5 have descriptions of the site characteristics, design criteria, and design bases used in plant design and the plant operations. Chapter 6 contains discussions of radiation protection, environmental protection, industrial safety, industrial hygiene, and security. Chapter 7 includes an accident analysis of the plant. Chapter 8 includes an explanation of the methodology being used to complete an assessment of the long-term waste isolation performance of the WIPP. The final assessment will not be completed until 1992 and will be included in a future amendment to this FSAR. The conduct of operations and operational safety requirements are discussed in Chapters 9 and 10. The quality assurance program is described in Chapter 11. Chapter 12 contains a description of future decontamination and decommissioning of the facility, and Chapter 13 is the glossary of technical terms and acronyms.

Amendments to this FSAR will be made when significant modifications are proposed for the WIPP facility. Among the factors that will be considered in determining whether a proposed physical or administrative change constitutes a significant modification are:

- Increases in the risk from a hazard beyond that previously analyzed and reviewed. This may stem from changes in operating characteristics such as speed, temperature, or pressure; increases in the quantity of hazardous materials; and/or changes in design features or administrative controls.
- Reductions in the reliability of any item for which credit has been taken for the reduction or control of a hazard.
- Introduction of a new hazard.
- Application of new regulations.
- Receipt of new information indicating an increased hazard associated with an existing operation.

The review and authorization levels for significant modifications to DOE operations will be selected based on the hazards associated with the modification and not on the original authorization for the operation. The DOE/WPO will determine the review and authorization level.

1.1.1 LOCATION OF THE PLANT

The WIPP facility is located in Eddy County in southeastern New Mexico, 26 miles east of Carlsbad (Figure 1.1-1). The amount of land that has been set aside for the WIPP facility includes an area of 10,240 acres. The WIPP facility is located in an area of low population density with less than 30 permanent residents living within a ten-mile radius of the facility. The area surrounding the facility is used primarily for grazing and resource development. Resources of potash, oil, and gas that are located in the vicinity of the WIPP facility are documented in several reports listed in Section 6 of Appendix 1A. Development of these resources results in a transient population (non-permanent) consisting principally of workers at three potash mines that are located within ten miles of the WIPP facility. The largest population center nearest the WIPP facility is the city of Carlsbad, 26 miles to the west, with approximately 27,000 inhabitants. Two smaller communities, Loving (population 1500) and Malaga (population 150), are located about 20 miles southwest of the facility. As the result of land use restrictions imposed by the U.S. Bureau of Land Management, and administrative action by the DOE to purchase leaseholdings, no resource development is allowed within the 10,240 acres that have been set aside for the WIPP facility.

1.1.2 MISSION

The WIPP facility is authorized by Public Law 96-164 with the mission to provide "a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States".[1] The WIPP facility is intended to include receipt , handling, and permanent disposal of transuranic waste. In implementing this mission the DOE has designed the WIPP facility as a full-scale facility to demonstrate many technical and operational principles associated with the permanent isolation of TRU waste. Technical aspects are those associated with the design, construction, and performance of the structures and the mined repository; operational aspects are those associated with receiving, handling and emplacing TRU wastes. It is also designed to provide a facility in which studies and experiments related to radioactive waste disposal can be conducted to extend the understanding of the behavior of radioactive waste in salt. These studies and experiments are discussed in numerous publications by Sandia National Laboratories (SNL) and other project participants and are listed in Appendix 1A. Technical programs that are underway are discussed in Section 1.5. The full design storage capacity of the WIPP facility will not be utilized until sufficient operating and scientific data have been accumulated to ensure the safe, long-term disposal of radioactive waste in salt. Within a five-year demonstration period, referred to as the Test Phase, a decision, based on the ability of the WIPP facility to meet EPA standards covering the disposal of TRU wastes, will be reached either to dispose permanently of transuranic waste at the WIPP facility or to retrieve these wastes.

1.1.3 DESIGN CAPABILITIES

The WIPP is designed to receive and handle the following: a maximum 500,000 $feet^3$/yr defense-generated contact handled transuranic (CH TRU) waste, approximately 10,000 $feet^3$/yr defense-generated remote handled transuranic (RH TRU) waste, and quantities of defense radioactive waste to be used for experiments, although these radioactive waste experiments are not currently part of the WIPP facility experimental program. The CH TRU waste is in 55-gallon drums and various sized metal boxes. The WIPP facility was designed to have a storage capacity for CH TRU waste of 6.2×10^6 ft^3 (Reference 5). The RH waste is packaged in steel canisters and transported to the WIPP facility in shielded shipping casks. The WIPP facility has sufficient capacity to handle the 250,000 cubic feet of RH TRU that was established in the ROD[6] as a total volume. In addition, the C&C Agreement[4] limits the total RH TRU activity to 5.1×10^6 curies.

CH TRU and RH TRU wastes are stored at the WIPP facility in a 100-acre storage area on a horizon located 2150 feet beneath the surface in a deep, bedded salt formation. Waste is transferred from the surface to the storage horizon through a waste shaft using a hoisting arrangement.

The WIPP facility is designed for an operating life of 25 years. The facility and equipment are designed to allow for retrieval of CH TRU or RH TRU waste stored during the Test Phase. The design accommodates the time required to reach the waste and retrieve the waste, if such a decision is made. As discussed earlier in this section, the amount of wastes to be handled during the Test Phase has not been determined.

Decommissioning can be performed either after retrieval, or if it is decided to operate the WIPP without retrieval, after completion of its operational phase. Options for decommissioning are discussed in Section 8.11 of Reference 6 and include moth-balling or dismantling surface facilities, backfilling and sealing shafts, and backfilling underground areas. After decommissioning, no other active waste activities will be conducted at the WIPP facility.

1.1.4 SCHEDULE

The first receipt of waste will follow the full construction and operational checkout of the WIPP facility, the withdrawal of federal lands for the purpose of operating the WIPP facility, and the publication of a ROD regarding the SEIS, as well as completing other prerequisites detailed on the Secretary's Decision Plan for the WIPP. This is expected to occur no sooner than July 1990 for CH TRU waste.

Initial emplacements of RH TRU wastes will be scheduled when all needed programmatic activities are completed. The Test Phase is expected to end in FY94. Full operations, if initiated, are anticipated to end in the year 2014.

References for Section 1.1

1. U.S. Congress, "Waste Isolation Pilot Plant, Deleware Basin, New Mexico," Section 213 of Public Law 96-164. December 29, 1979.

2. U.S. Department of Energy, Safety Analysis and Review System, Order DOE 5481.1B, 9-23-86

3. Albuquerque Operations Office; Safety Analysis And Review System; Order AL 5481.1B dated 1-27-88.

4. Working Agreement for Consultation and Cooperation, signed by the U.S. DOE and the State of New Mexico, July 1981 and subsequent revisions.

5. U.S. Department of Energy, "Final Environmental Impact Statement, Waste Isolation Pilot Plant," DOE/EIS-0026, October 1980.

6. U.S. Department of Energy, Record of Decision, Waste Isolation Pilot Plant (WIPP), FR 9162, Vol 46 No 18, January 28, 1981.

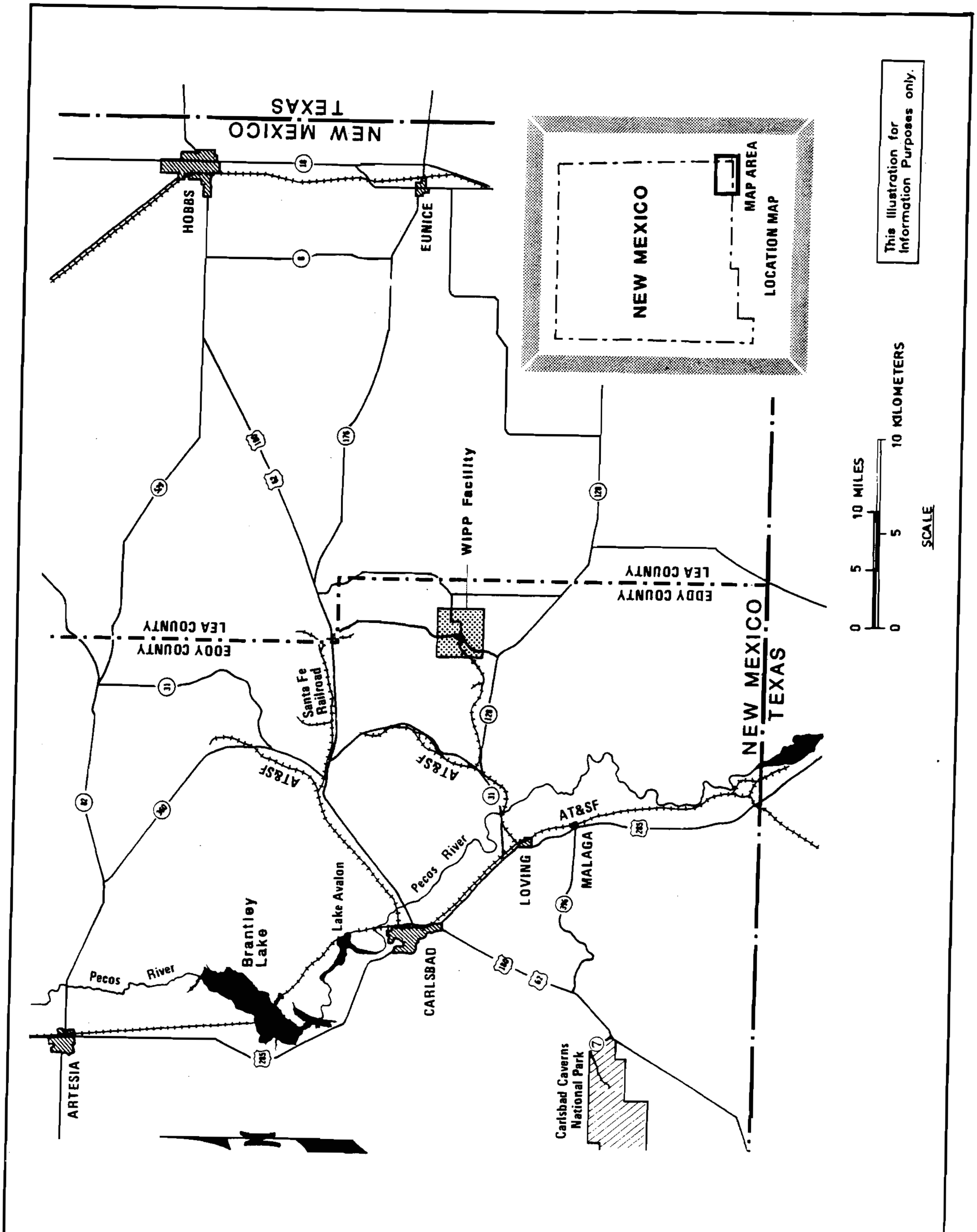

FIGURE 1.1-1
General Location of the WIPP Facility

1.2 GENERAL DESCRIPTION OF THE WIPP FACILITY

The WIPP facility is divided into three basic groups of structures: surface structures, shafts, and underground structures. These are described in the following paragraphs and shown schematically in Figure 1.2-1.

1.2.1 SURFACE STRUCTURES

The WIPP facility surface structures accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of waste from the surface to the underground. The surface structures are located in an area (approximately 35 acres) within a perimeter security fence (Figure 1.2-2).

1.2.1.1 Waste Handling Building

The primary surface operations at the WIPP facility are conducted at the Waste Handling Building (WHB) (Figure 1.2-3), which is divided into several separate areas: the CH TRU waste handling area, the RH TRU waste handling area, the transuranic package transporter (TRUPACT II) maintenance facility, and support areas.

The CH TRU waste handling area includes an outdoor truck loading and offloading area, a shielded storage room, an inventory and preparation area, and an overpack and repair room.

The RH TRU waste handling area includes: a shipping and receiving area, a shielded cell for shipping cask unloading, waste canister inspection, overpacking canisters, as required, and facility cask loading prior to transfer underground.

The TRUPACT II maintenance facility is a radiologically clean dedicated area, adjacent to the CH TRU waste side of the WHB. Decontamination of a TRUPACT II, if required, would be accomplished in the CH TRU waste side of the WHB. A TRUPACT II is shown in Figure 1.2-4.

Other areas within the WHB include; a site-generated waste area, heating, ventilation, and air conditioning (HVAC) equipment area; and mechanical equipment areas.

The site generated waste area, located in the WHB, is provided for the handling of waste produced on the site as a result of decontamination operations. Waste compaction equipment is provided for compacting, if desired, and packaging site produced solid radioactive waste (radwaste). There is also a liquid waste collection system, which contains an accumulation tank for liquid radwaste.

1.2.1.2 Support Structures

The Exhaust Filter Building (Figure 1.2-2) contains banks of high efficiency particulate air (HEPA) filters that will be used to filter contaminated air from the underground in the unlikely event of a release. The underground ventilation system fans are located outside, adjacent to this building.

The Support Building provides office space, radiological control laboratories, change rooms, and houses the CMS computer (Figure 1.2-2).

The other surface structures include the Warehouse Buildings, the Guard and Security Building, the Vehicle Service Building, a sewage treatment plant, and other auxiliary buildings.

1.2.1.3 Salt Storage Area

Salt from the underground mining operations is brought to the surface and stored in the salt pile north of the surface facilities (Figure 1.2-2). The salt is taken to the storage pile by truck. There is also an inactive salt storage pile east of the Exhaust Filter Building, which is not shown in Figure 1.2.2. This salt pile is a result of the Site and Preliminary Design Validation activities.

1.2.1.4 Plant Access

The WIPP is accessible by both road and railway. Access to the site is from U.S. Highway 62/180, about 13 miles to the north, and from Highway 128, four miles to the south (Figure 1.1-1). Rail access to the WIPP is provided by a new rail line connecting with a spur of the Atchison, Topeka & Santa Fe railroad near the Western Ag-Mineral's Nash Draw mine six miles southwest of the site (Figure 1.1-1).

1.2.2 SHAFTS

WIPP has four vertical shafts that extend from the surface to the underground horizon. These are: the Waste Shaft, the Salt Handling (SH) shaft, the Exhaust Shaft, and the Air Intake Shaft (AIS).

The shafts are lined from the shaft collar to the top of the salt formation (about 850 feet below the surface), but are unlined through the salt formation. The shaft lining is designed to withstand water pressure associated with the full piezometric head in any water-bearing units encountered.

1.2.2.1 Waste Shaft

The Waste Shaft is located between the CH TRU and RH TRU areas in the WHB (Figure 1.2-2). It is nominally 19 feet in diameter and is serviced by a hoist utilizing a hoist cage that is primarily used for transportation of CH TRU and RH TRU wastes from the surface to underground storage areas. This shaft is also used to transport personnel, diesel fuel, materials, and large equipment.

1.2.2.2 Salt Handling Shaft

The SH shaft is located beneath the salt handling headframe (Figure 1.2-2). It is nominally 10 feet in diameter and has a combined mancage/bottom dump salt handling skip. This shaft provides the only means of removing mined materials from the underground. It serves as the secondary supply air duct for the underground areas. The SH shaft is a route for power, control, monitoring and communication cables. Personnel can also be transported in this shaft.

1.2.2.3 Exhaust Shaft

The exhaust shaft is located adjacent to the Exhaust Filter Building (Figure 1.2-2). It is nominally 14 feet in diameter and serves as the exhaust air duct for the underground areas.

1.2.2.4 Air Intake Shaft (AIS)

The AIS is located to the west of the warehouse. It is a 16-foot-diameter shaft and is the primary supply of fresh air underground.

1.2.3 UNDERGROUND STRUCTURES

The underground structures are located on the storage horizon and consist of the waste storage area, the shaft pillar area that contains the underground support area, and the experimental area.

1.2.3.1 Storage Area

The storage area has four main entries (two entries for fresh air and two entries for return air) and a number of storage rooms (Figure 1.2-5). The layout of the shafts and entries allows mining and storage operations to proceed simultaneously. The first storage panel is used to store waste while the next panel is being mined. Successive stages follow in a similar manner.

A typical storage panel consists of up to seven storage rooms. Each room is 33 feet wide, 13 feet high, and 300 feet long. The storage rooms are separated by pillars of salt 100 feet wide and 300 feet long. Panel entries at each end of these storage rooms are also 33 feet wide and 13 feet high. These panel entries will also be used to store waste, except in the first 200 feet from the main entries, which are of smaller size (22 feet by 14 feet) and will be used to install the panel plugs.

The underground station located at the lower end of the waste shaft provides access for personnel and equipment to handle the waste (Figure 1.2-5). A radiological control station is located adjacent to the waste shaft.

1.2.3.2 Underground Support Structures

A workshop and warehouse area is located in the shaft pillar area at the storage horizon. Shops consist of a repair bay, a welding bay, a lubrication bay, an electrical shop, several parking areas, and a warehouse. An office, electrical substation, lunch room, and sanitary facilities are also located at the storage horizon.

1.2.3.3 Experimental Areas

The area for experiments using simulated wastes and for geotechnical evaluations consists of several rooms and pillars that are used to perform rock mechanics tests, waste package and waste form experiments, and brine migration tests. In part, these tests provided information used in room and pillar design of the waste storage area.

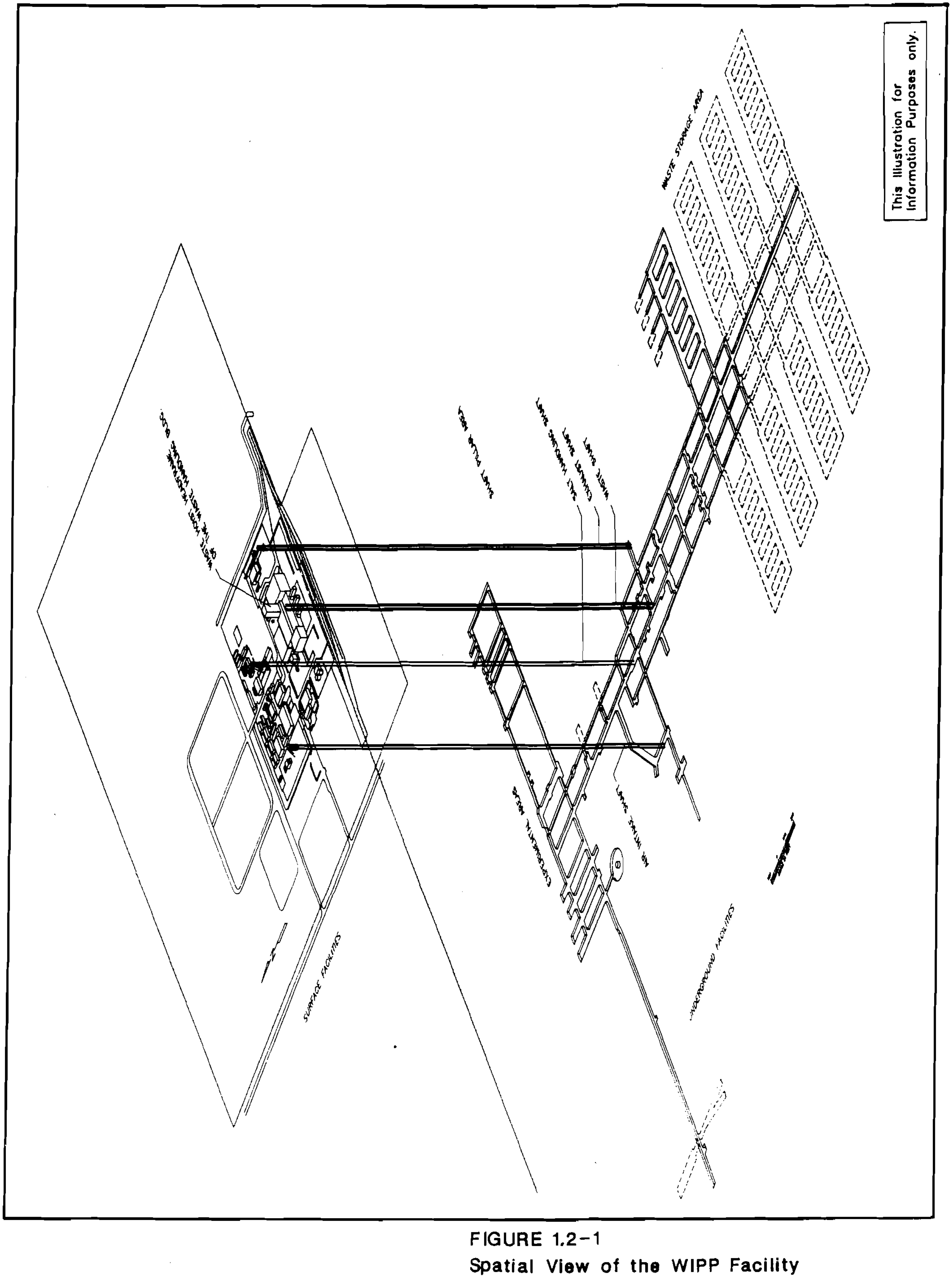

FIGURE 1.2-1
Spatial View of the WIPP Facility

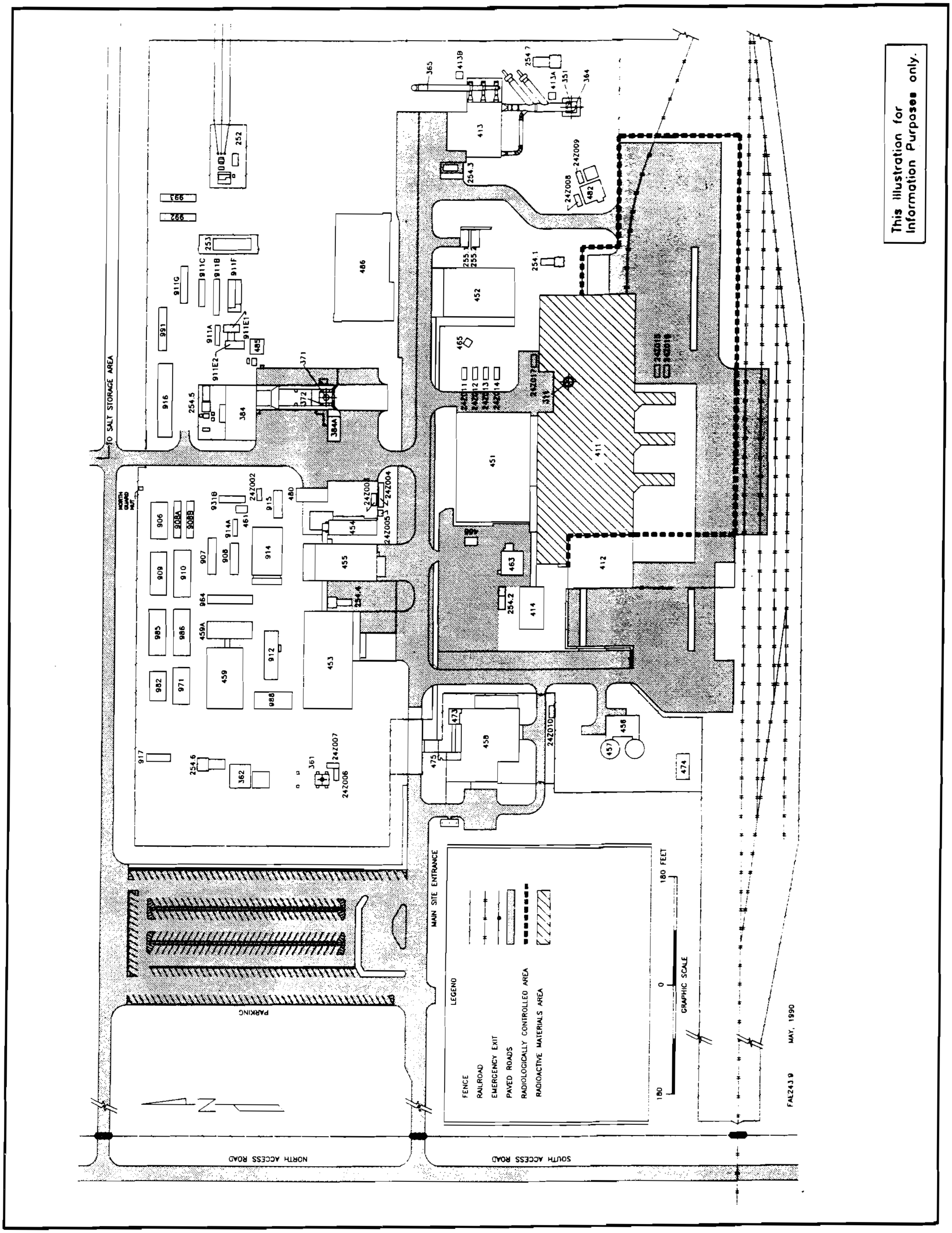

FIGURE 1.2-2
WIPP Surface Structures

FACILITIES, USAGE AND STRUCTURE NUMBERS (FY 1990)

SPS UTILITY SUBSTATION	FAC 252
13.8 KV SWITCHGEAR 25P-SWG15/1	FAC 253
AREA SUBSTATION NO.1 25P-SW15.1	FAC 254.1
AREA SUBSTATION NO.2 25P-SW15.2	FAC 254.2
AREA SUBSTATION NO.3 25P-SW15.3	FAC 254.3
AREA SUBSTATION NO.4 25P-SW15.4	FAC 254.4
AREA SUBSTATION NO.5 25P-SW15.5	FAC 254.5
AREA SUBSTATION NO.6 25P-SW15.6	FAC 254.6
AREA SUBSTATION NO.7 25P-SW15.7	FAC 254.7
ON-SITE GENERATOR #1 25-PE 503	FAC 255.1
ON-SITE GENERATOR #2 25-PE 504	FAC 255.2
WASTE SHAFT	FAC 311
EXHAUST SHAFT	FAC 351
AIR INTAKE SHAFT	FAC 361
AIR INTAKE SHAFT/WINCH HOUSE	FAC 362
EFFLUENT MONITORING INSTRUMENT SHED - "A"	FAC 364
EFFLUENT MONITORING INSTRUMENT SHED - "B"	FAC 365
SALT HANDLING SHAFT	FAC 371
SALT HANDLING SHAFT HEADFRAME	FAC 372
SALT HANDLING SHAFT HOISTHOUSE	FAC 384
UNDERGROUND SERVICES OFFICE	FAC 384A
WASTE HANDLING BUILDING	BLD 411
TRUPACT MAINTENANCE BUILDING	BLD 412
EXHAUST SHAFT FILTER BUILDING	BLD 413
MONITORING STATION A	BLD 413A
MONITORING STATION B	BLD 413B
WATER CHILLER FACILITY	FAC 414
SUPPORT BUILDING - OFFICES, ETC.	BLD 451
SAFETY & EMERGENCY SERVICES FACILITIES	BLD 452
WAREHOUSE/SHOPS BUILDING	BLD 453
VEHICLE SERVICE BUILDING	BLD 454
AUXILIARY WAREHOUSE BUILDING - MAINTENANCE	BLD 455
WATER PUMPHOUSE	BLD 456
WATER TANKS (2)	FAC 457
GUARD AND SECURITY BUILDING	BLD 458
CORE STORAGE BUILDING	BLD 459
DBL. WIDE TRAILER - OFFICE	BLD 459A
MAINTENANCE STORAGE	BLD 461
COMPRESSOR BUILDING	BLD 463
AUXILIARY AIR INTAKE	FAC 465
TELEPHONE HUT	BLD 468
ARMORY BUILDING - ARMORY AND LOCK SHOP	BLD 473
HAZARDOUS WASTE STORAGE BUILDING	BLD 474
GATEHOUSE - MAIN SITE ENTRANCE/EXIT	BLD 475
VEHICLE FUEL STATION	FAC 480
EXHAUST SHAFT HOIST EQUIPMENT WAREHOUSE	BLD 482
SULLAIR COMPRESSOR BUILDING	BLD 485
ADMINISTRATION BUILDING	BLD 486
DBL. WIDE TRAILER	TRL 906
SINGLE WIDE TRAILER - OFFICE	TRL 907
SINGLE WIDE TRAILER - OFFICE	TRL 908
SINGLE WIDE TRAILER - CABLE FABRICATION	TRL 908A
SINGLE WIDE TRAILER - LAB AND CABLE FABRICATION	TRL 908B
DBL. WIDE TRAILER - OFFICE	TRL 909
DBL. WIDE TRAILER - OFFICE AND LAB	TRL 910
SINGLE WIDE TRAILER - VACANT - TO BE EXCESSED	TRL 911A
SINGLE WIDE TRAILER - OFFICE	TRL 911B
SINGLE WIDE TRAILER - OFFICE	TRL 911C
SINGLE WIDE TRAILER - AIS STAGING	TRL 911E1
SINGLE WIDE TRAILER - VACANT - TO BE EXCESSED	TRL 911E2
DBL. WIDE TRAILER - COMPUTER CENTER	TRL 911F
SINGLE WIDE TRAILER - CABLE FABRICATION	TRL 911G
DBL. WIDE TRAILER - OFFICE AND CLASSROOMS	TRL 912
TRAILER COMPLEX (7) - OFFICE	TRL 914
SINGLE WIDE TRAILER - OFFICE	TRL 914A
SINGLE WIDE TRAILER - OFFICE	TRL 915
TRAILER COMPLEX (4) - OFFICE	TRL 916
SINGLE WIDE TRAILER - AIS DATA AQUISITION	TRL 917
SINGLE WIDE TRAILER - CHANGE ROOM	TRL 931B
DBL. WIDE TRAILER - OFFICE	TRL 971
DBL. WIDE TRAILER - OFFICE	TRL 982
SINGLE WIDE TRAILER - OFFICE	TRL 984
DBL. WIDE TRAILER - OFFICE	TRL 985
DBL. WIDE TRAILER - OFFICE	TRL 986
DBL. WIDE TRAILER - OFFICE	TRL 988
SINGLE WIDE TRAILER - OFFICE	TRL 991
SINGLE WIDE TRAILER - LAB	TRL 992
SINGLE WIDE TRAILER - LAB	TPL 993
MOBILE STORAGE BUILDINGS	24Z002 THRU 24Z017

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Explanation to Figure 1.2-2

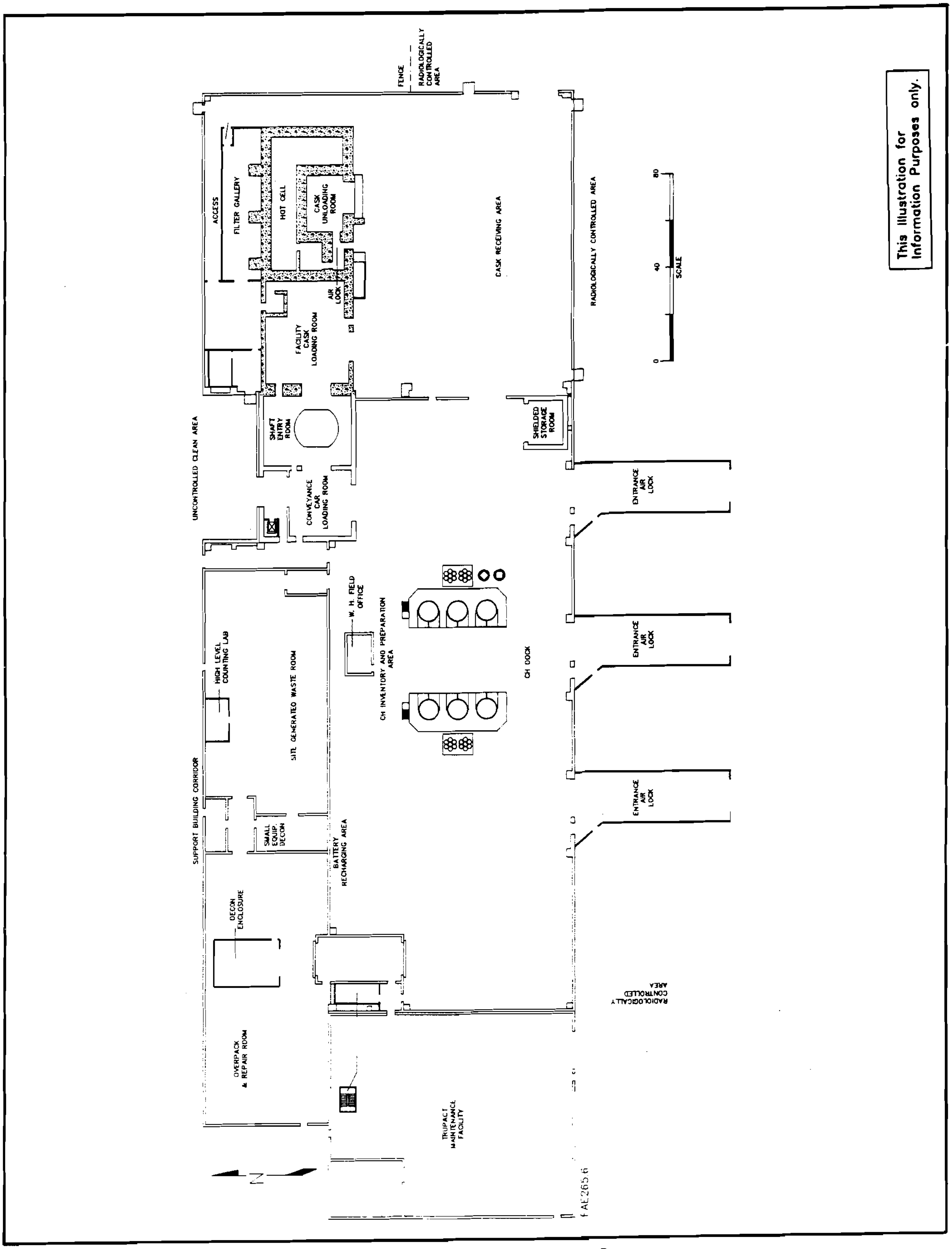

FIGURE 1.2-3
Waste Handling Building Plan (Ground Floor)

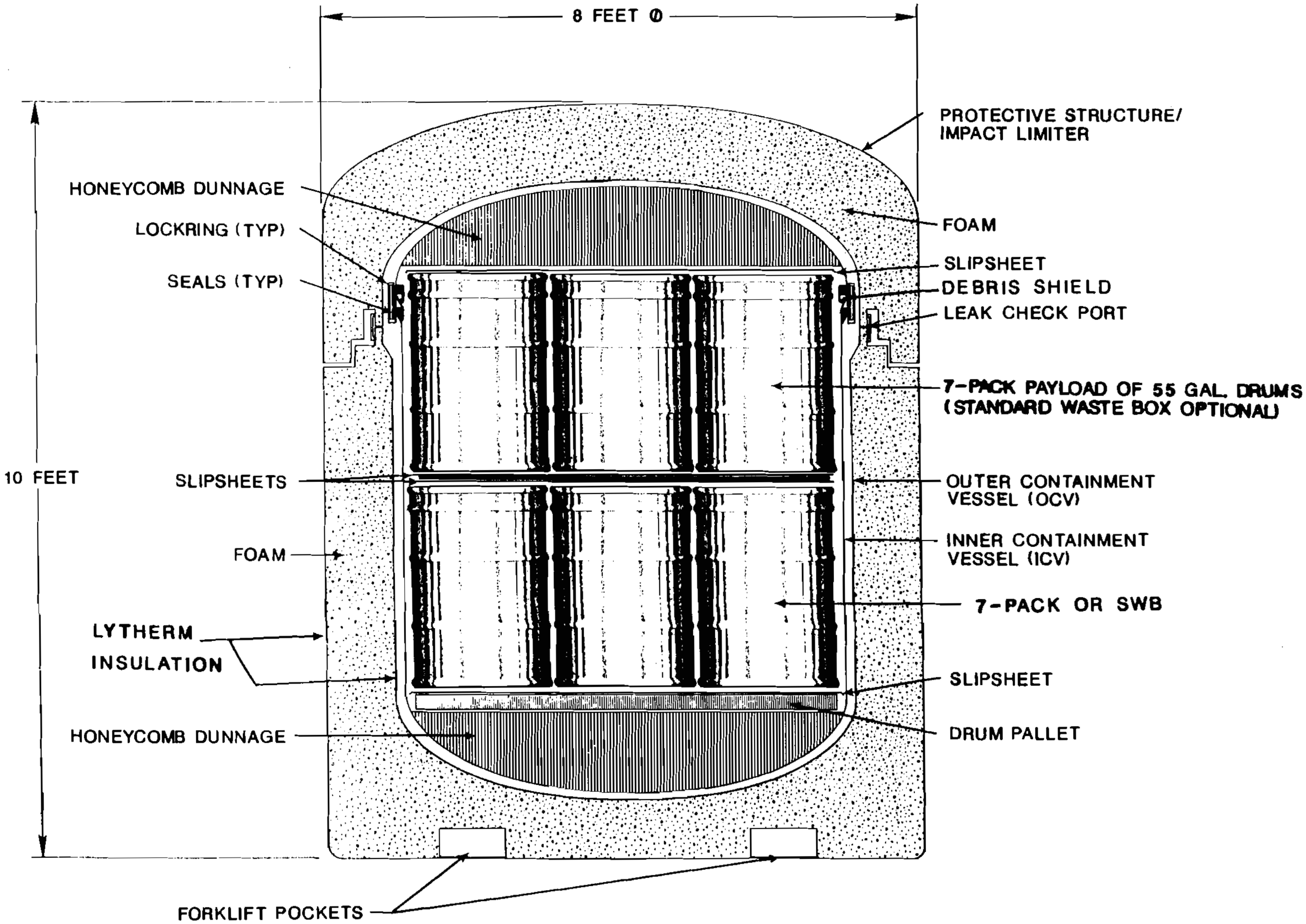

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FIGURE 1.2-4
TRUPACT II Packaging Showing Configuration with Seven-Packs

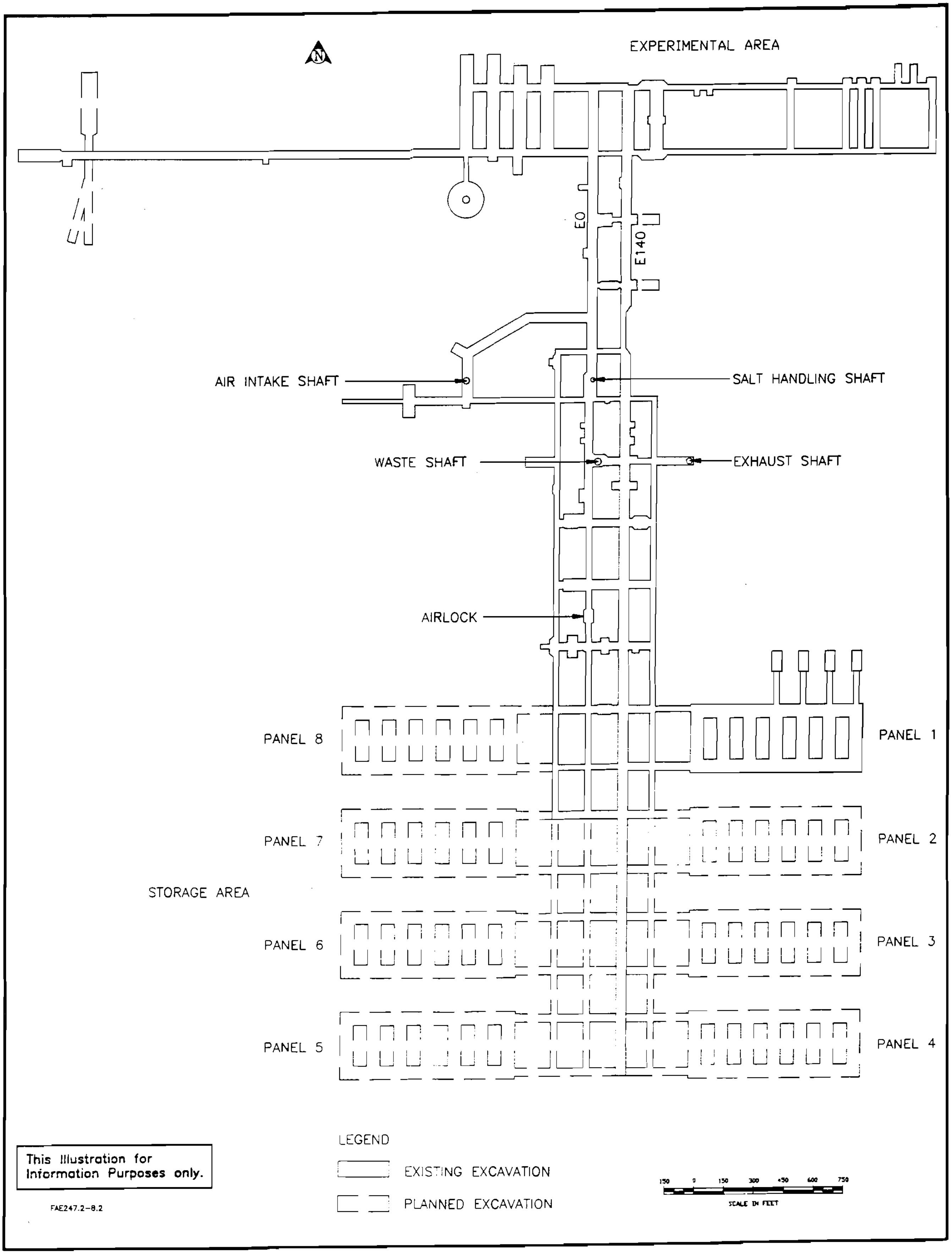


FIGURE 1.2-5
Storage Horizon

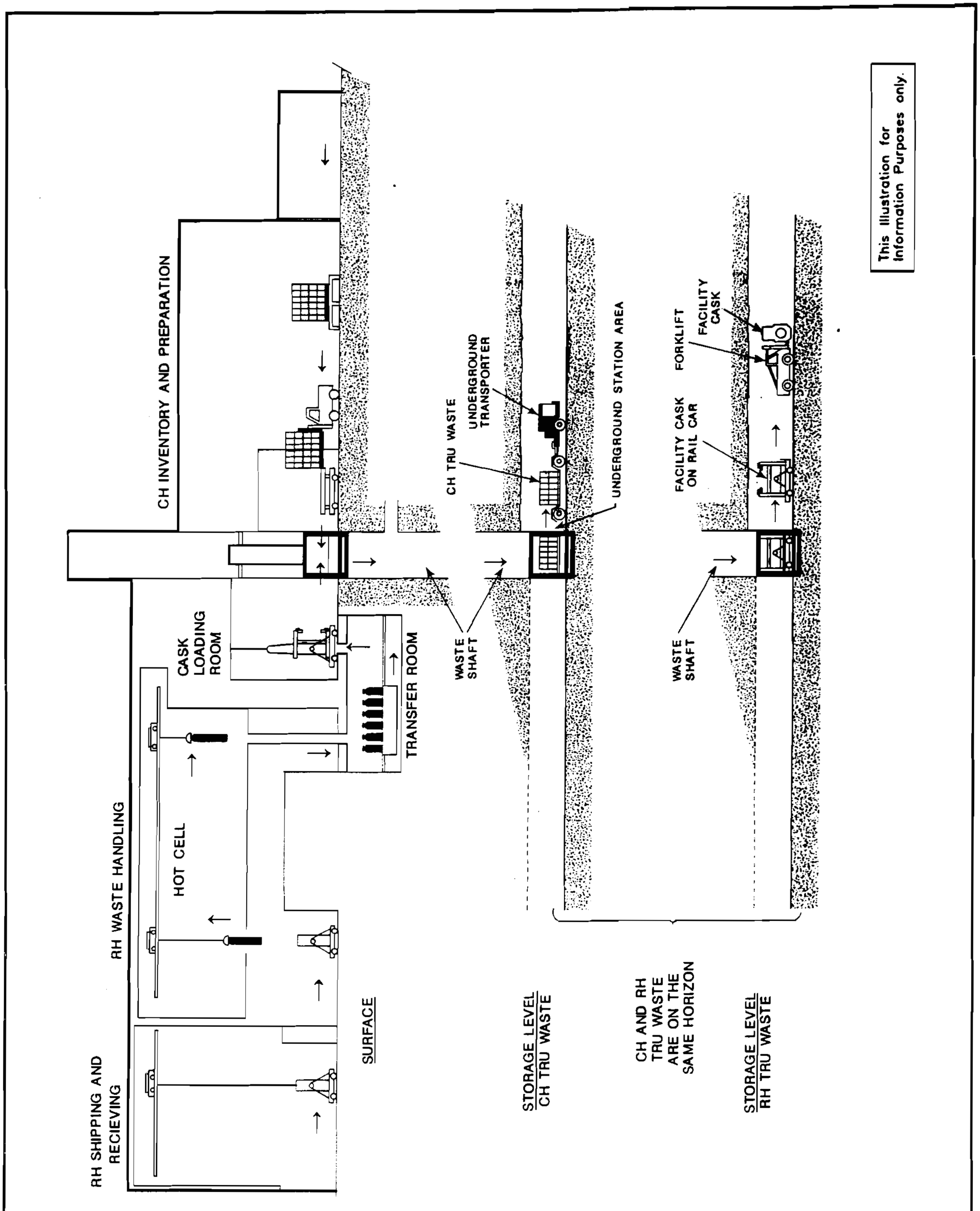


FIGURE 1.2-6
Waste Shaft Area

1.3 GENERAL DESCRIPTION OF OPERATIONS AT THE WIPP FACILITY

Operations at the WIPP facility entail receiving, unloading, and transferring of radioactive wastes from the surface of the site to the underground storage rooms. Transporters carrying radioactive waste arrive at the WIPP facility and are staged outside the Waste Handling Building (WHB) (Figure 1.2-2). The shipments are surveyed for external contamination prior to their movement into the WHB for unloading.

The waste received for placement in the WIPP facility must conform with the WIPP Waste Acceptance Criteria (WAC); however, exceptions to the WIPP WAC may be requested by the shipping sites. All exceptions will be evaluated against the WIPP facility Operational, Health, and Safety Requirements, including this FSAR, the Final Environmental Impact Statement (FEIS), agreements with the State of New Mexico, Order DOE 5820.2A, and any applicable regulations including 40 CFR 191, before approval to ship is given.

The operational philosophy at the WIPP facility is to start radiologically clean and stay radiologically clean. Consequently, any containers of waste that are found to be externally contaminated or damaged will be decontaminated or placed in a larger container (overpacked), as required. Also, any local area of contamination will be isolated and/or decontaminated prior to continuation of the waste handling process.

1.3.1 CH TRU WASTE OPERATIONS

CH TRU waste will be shipped to the WIPP facility in Nuclear Regulatory Commission (NRC)-certified shipping containers. After the CH TRU waste shipping container is inspected for contamination, the loaded shipping container is moved into the WHB and placed on a handling dock. The container is opened, surveyed for radiation and contamination levels, and the waste in its storage container is removed and placed on a facility pallet. This pallet is then transferred to the cage loading car, which is moved into the hoist cage used in the Waste Shaft for transfer to the storage horizon.

At the storage horizon, the pallet is removed from the hoist cage, placed on the underground transporter, and moved to the CH TRU waste storage room. In the storage room, the containers are removed from the pallet and placed in the waste stack. The empty pallet is returned to the surface for reuse.

1.3.2 RH TRU WASTE OPERATIONS

The RH TRU waste handling area of the WHB has an entry for truck or rail shipments. The RH TRU waste will be shipped in shielded NRC-certified casks. The cask is surveyed for radiation and contamination levels, unloaded from the transporter, and placed in the cask transfer car. The cask is inspected and the outer cask lid is removed. It is then moved to the unloading room of the hot cell. The inner cask lid and the RH TRU canister are removed from the cask and lifted into the hot cell.

In the hot cell, the canister is inspected. The canister can be overpacked, if necessary, and is then lowered into the transfer cell. The transfer cell provides a temporary storage area, if needed.

When the RH TRU canister is ready for emplacement, the canister is lifted from the transfer cell into the shielded facility cask. The facility cask is moved to the hoist cage for transfer to the storage horizon. At the storage horizon the facility cask is unloaded from the hoist cage and moved to the storage room. The cask is placed on the emplacement/retrieval machine assembly and the canister is inserted into a predrilled horizontal hole in the room wall. The holes will contain liners (sleeves) in order to facilitate retrieval until such time the decision is made to make the WIPP a permanent repository. A shield plug is inserted in the hole to provide radiation shielding.

1.3.3 RETRIEVAL OPERATIONS

The retrieval of CH TRU waste is essentially the reverse of the storage operation. Personnel will wear the appropriate protective equipment during this operation and contamination control procedures will be in force, if necessary. Any damaged containers will be overpacked prior to their removal from the contamination control area.

RH TRU waste retrieval requires that the facility cask be placed in alignment with the emplaced canister using the same equipment as used for emplacement. The shield plug is removed, and the canister grappled and drawn into the facility cask. The facility cask is closed and returned to the surface reversing the storage sequence.

In order to ensure that the waste will be retrievable during the Test Phase, several precautions have been taken. First, with regard to CH TRU waste, scale model experiments, simulating backfilled storage rooms were conducted to determine the point in the room closure process at which drum deformation begins.[1] These experiments showed that in backfilled rooms, salt backfill will have consolidated sufficiently after eight years to transmit lithostatic loads to the drums and initiate their deformation. As the result of these model studies, the use of backfills for waste emplaced during this phase has been deferred, thereby minimizing the chances that retrieval will require the removal of damaged containers. An appropriate backfill will be placed over the waste once a decision to proceed with full operations is made. Since the specification of the appropriate backfill will be one result of the performance assessment study, it is not possible to fully describe the backfill emplacement process at this time. The range of options include the determination that no backfill is required in the decision to move the waste to another storage room and re-emplace them with the proper backfill. Whatever operation is required, the appropriate safety analysis will be performed prior to any decision to proceed.

Second, storage rooms used during the Test Phase that are required to be accessible to personel will be monitored with both instrumentation and visually. This will allow the operating staff to anticipate deteriorating ground conditions that may impact the retrievability of waste. In areas that are not accessible, the rock bolting program will be enhanced to provide greater assurance that a roof fall will not occur during the Test Phase.

Finally, based on the low amount of moisture in the WIPP underground storage areas, the amount of corrosion to containers during the Test Phase is expected to be minimal. However, prior to any retrieval operations, drums and containers will be inspected for corrosion and for any possible deterioration of integrity and appropriate safety precautions taken in handling any suspect containers.

With regard to RH TRU waste, retrieval is ensured by the use of a sleeve in the emplacement hole. This sleeve is designed to withstand the expected lithostatic forces without deforming to the point where removal of the RH canisters is no longer easy. For full-scale operations, the sleeves will not be used since easy retrieval is not required.

References for Section 1.3

1. VanderKraats, J., Quarter-Scale Modeling of Room Convergence Effects on CH TRU Drum Waste Emplacements Using WIPP Reference Design Geometries, DOE/WIPP 87-012, Westinghouse Electric Corp., November 1987.

1.4 IDENTIFICATION OF AGENTS AND CONTRACTORS

The overall responsibility for the design, construction, operation, and decommissioning of the Waste Isolation Pilot Plant (WIPP) facility rests solely with the U.S. Department of Energy (DOE). Within the DOE, the Assistant Secretary for Environmental Restoration and Waste Management (EM) is responsible for implementing the radioactive waste disposal policy. DOE's Albuquerque Operations Office (DOE-AL) is responsible for implementing the WIPP Project. The WIPP Project Office (WPO) has been established under the direction of DOE-AL to manage and administer all project activities. Figure 1.4-1 depicts the organization of the WIPP Project.

The DOE-AL has contracted with the following organizations to participate in the WIPP Project:

- Sandia National Laboratories (SNL), Department of Waste Management Technology, Albuquerque, New Mexico, to serve as the Scientific Advisor
- Bechtel National Incorporated, Advanced Technology Division, San Francisco, California, to serve as the Architect/Engineer
- Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico, to serve first as the Technical Support Contractor (1978-1985) and later as the Management and Operating Contractor (1985-present)

NOTE: The U.S. Army Corps of Engineers was the construction manager under provisions of an Interagency Agreement prior to transfer of this responsibility to the Management and Operating Contractor (MOC).

SNL, as the Scientific Advisor, has been responsible for developing the conceptual design of the WIPP facility, preparing the Draft and Final Environmental Impact Statements, and performing the site selection and characterization studies. SNL is also responsible both for developing and implementing the in situ experimental testing programs and for completing the performance assessment of the WIPP facility in compliance with 40 CFR 191 Subpart B.

Bechtel, the Architect/Engineer, is responsible for developing the detailed design of the facility, including construction bid package development and design related geotechnical explorations. Bechtel has engaged the services of Rockwell International as consultant for the design of special waste handling equipment.

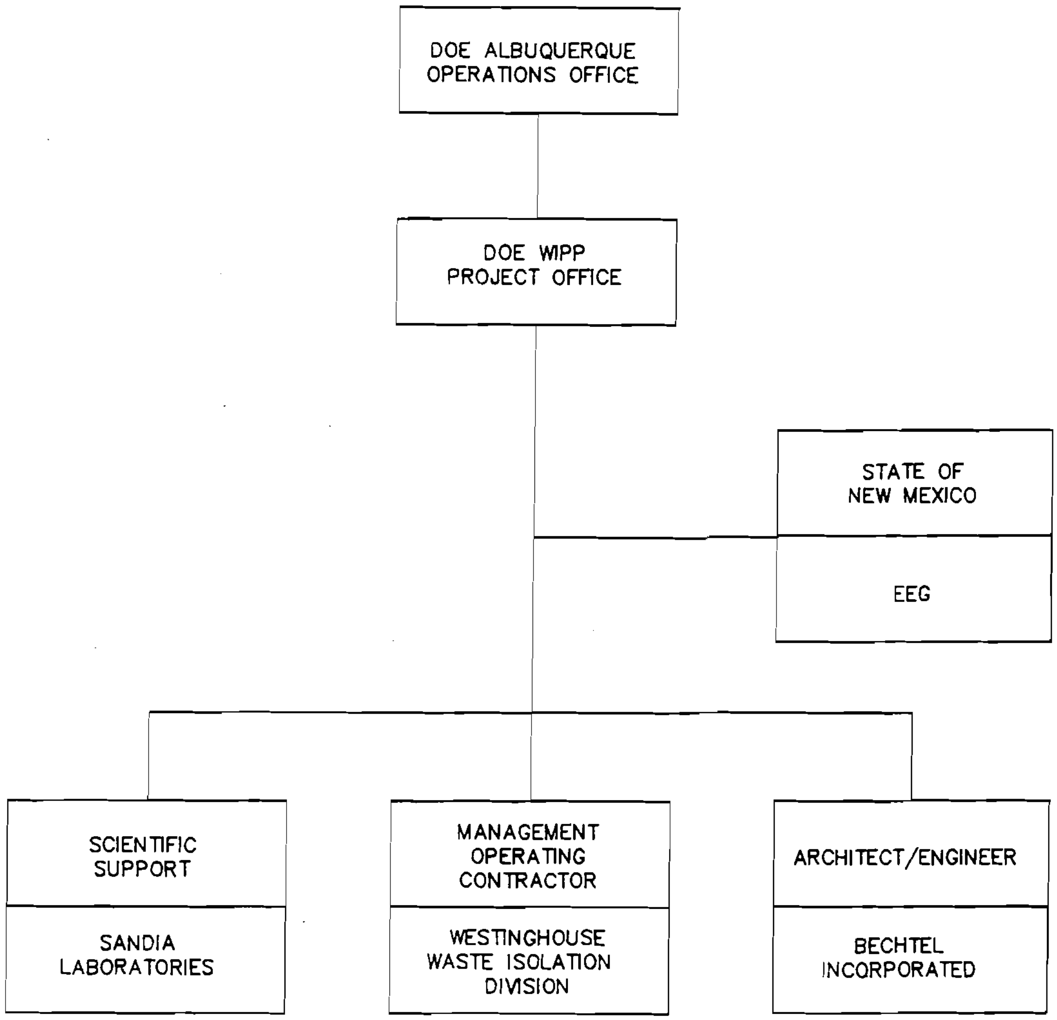
As the Technical Support Contractor (TSC) (from 1978-1985), Westinghouse was responsible for providing general management and procurement support to the WPO. In this role, Westinghouse performed technical reviews of the design, prepared the Safety Analysis Report, supported preparation of the Final Environmental Impact Statement, and provided support in operational planning and quality assurance. In 1985, the DOE/AL contracted with Westinghouse to provide management and operating services as the MOC. In this capacity, Westinghouse is solely responsible for general management and operating services, including operational safety, engineering management, quality assurance and control, project control, construction management, and environmental services. As part of its responsibility as MOC, Westinghouse ensures that all inputs to facility operations are properly reviewed for health, safety, and environmental implications.

The DOE has entered into a formal agreement with the State of New Mexico for the purpose of consultation and cooperation (referred to as the C and C Agreement). This agreement, its associated working agreement and subsequent modifications provide a basis for the Governor of New Mexico to exercise the state's right, granted under Public Law 96-164, to comment on and make recommendations regarding the public health and safety aspects of the WIPP Project. The C and C Agreement designates key events, sets time frames for review, comment and resolution of comments, and establishes procedures for review of the WIPP Project activities and for resolving conflicts.

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the WIPP Project related to the protection of the public health and safety. The EEG was established in 1978 with funds provided by the DOE to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, FY89, Section 1433, assigned the EEG to the New Mexico Institute of Mining and Technology and provided for continued funding from the DOE through Contract DE-AC04-79AL10752.

The EEG performs independent technical analyses and monitoring for background radioactivity in air, water, and soil, both on the site and in surrounding communities.

Figure 1.4-1 lists responsibilities of the WIPP Project participants.



CONCEPTUAL DESIGN

SITE CHARACTERIZATION

R & D PROGRAMS

PERFORMANCE ASSESSMENT

PROJECT INTEGRATION

OPERATIONAL PLANNING

SECURITY SERVICES

SAFETY & ENVIRONMENTAL ASSESSMENT

ENGINEERING SERVICES

INSTITUTIONAL SUPPORT

SITE OPERATIONS, MAINT., & SAFETY SERVICES

CH WASTE TRANSPORTATION PROGRAMS

SITE CONSTRUCTION

FACILITY DESIGN

INSPECTION SERVICES

SAR2.5

This illustration for Information Purposes only.

FIGURE 1.4-1
US Department of Energy WIPP Project Organization and Responsibilities

1.5 TECHNICAL PROGRAMS

The development programs that have been implemented for the WIPP facility are described below. These programs are geotechnical in nature in that they are provided to gain a greater understanding of the geological characteristics and process associated with the facility and the interaction between various facility components and the geology. The technical information generated by these programs is used to demonstrate the safety of the design and more sharply define margins of conservatism and to provide the basis for design improvements, thereby increasing safety margins. In this section, three different types of programs are described: the programs to confirm the adequacy of the WIPP facility design, the programs to demonstrate the margin of conservatism of designs or analyses, and the Site and Preliminary Design Validation Program (SPDV), which began in 1981 and was concluded in 1983.[1] The Design Validation Final Report (DVFR) was published in October 1986.[2]

1.5.1 GEOTECHNICAL VERIFICATION PROGRAM

This program is providing data on the long-term geologic suitability of the WIPP facility.

The geotechnical verification program that consists principally of geologic studies for the WIPP facility includes: preliminary site selection activities, including initial geologic characterization (referred to as site characterization), and ongoing geological studies to further understand the long-range geologic processes that might affect the performance of a waste disposal facility.

Preliminary site selection activities are complete and are summarized in Section 1.5.3 below. These activities consisted primarily of national and regional studies over the past 15 years and resulted in the selection of the region around the WIPP facility as a study area for geologic characterization. The initial geologic characterization, which was primarily oriented towards providing specific data about the present geology of the site, was completed and reported in December 1978.[3,4]

In addition to site characterization, it is necessary to characterize the long-term geologic processes that affect the region around the WIPP facility.

Studies of the interaction between the WIPP facility and natural processes are discussed in detail in Chapter 2 and include meteorology, hydrology, geology, vibratory ground motion, faulting, foundation and slope stability. Observations from these studies are improving and are confirming analytical assumptions and defining conservatism to complete the long-term performance assessment of the WIPP facility. Additionally, studies to address issues raised by the State of New Mexico in its lawsuit against the U.S. Department of Energy over the WIPP Project have been completed. These studies were detailed in the "Stipulated Agreement in Lieu of Preliminary Injunction between the Department of Energy and the State of New Mexico." (Referred to simply as the Stipulated Agreement). A second series of geotechnical studies agreed upon by the State of New Mexico and the DOE are ongoing as described in Appendix II to the Working Agreement for Consultation and Cooperation (C&C). A summary report[5] on site characterization studies from 1983 to 1987 was published in February 1988 to complete a milestone in Article IV, K, Section 12 of the C&C Agreement.

The geotechnical studies completed and those in progress are listed in Table 1.5-1 and are discussed in detail in the appropriate sections of Chapter 2 of this document. In addition, technical reports resulting from these studies are listed in Appendix 1A. The regional hydrology, geopressurized brine reservoirs, and dissolution are discussed in Section 2.5. Site structural and tectonic stability are discussed in Sections 1.5.3, 2.7, 2.8, 2.9, and 2.10.

1.5.2 WIPP EXPERIMENTAL PROGRAM AND ENGINEERING SUPPORT

An Experimental Program has been undertaken to address the research and development mission of the WIPP facility as it pertains to design of underground openings and disposal of wastes generated by the defense programs of the United States. This program does not use radioactive wastes.

This program of in situ experimentation includes investigating:

- Materials and techniques for backfilling and sealing the underground excavations
- The stability of both heated and unheated underground excavations over long periods of time
- The corrosion of and response of various waste package and waste form materials to the in situ environment
- The migration of brine at ambient temperatures and in the presence of heat sources

The experimental areas and room designations referred to in the following discussion are shown in Figure 1.5-1.

These in situ experiments have been preceded by laboratory tests of the physical, thermal, and chemical characteristics of the salt and engineered components such as backfill materials, seal materials, and waste package materials. In some cases, laboratory tests are continuing in parallel with the field tests.

1.5.2.1 Repository Plugging and Sealing Studies

Plugging and sealing of boreholes and underground mined openings has long been considered an aspect of the engineered barriers concept for limiting the entry of water into and potential escape of waste materials from a disposal site as required by 40 CFR 191. Both plugging of boreholes and sealing of mined rooms and drifts are being studied. To date, studies have built upon laboratory and field investigations of candidate plugging and sealing materials.

Several studies on borehole plugging have been completed and additional studies are being performed by Sandia. The results of the completed studies established the adequacy of the design of plugs and demonstrated the effectiveness of grouts in sealing boreholes.[6,7]

Ongoing testing will further evaluate the procedures and techniques for installing borehole plugs and will evaluate the long-term physical and chemical behavior of candidate materials.[8]

A series of in situ permeability tests referred to as Small-Scale Seal Performance Tests (SSSPT) are providing information on the ability of selected materials to limit the flow of gas and brine within the mined rooms and drifts following closure of the WIPP site. At the present time, seals comprised of salt based concretes, reconsolidated salt blocks, and clay-salt mixtures are being evaluated in Room M of the underground experimental area. Room scale seals will be evaluated later in the program. Test results are germane to the evaluation of the post-closure performance of the WIPP facility.

1.5.2.2 Rock Mechanics Experiments

A variety of experiments are planned and in progress to evaluate the long-term behavior of radioactive waste storage rooms. The SPDV activities were an important element of the evaluation of waste storage area design. To facilitate evaluation of the WIPP facility current disposal panel design, four rooms of the same dimensions and spacings as the emplacement panel design were excavated and monitored as part of the SPDV program (Section 1.5.3).

A multiphase test is in progress in one test area (Room G) to evaluate the geomechanical response of the rock formation to a range of stresses, including stresses in excess of those anticipated to be encountered underground.[9] As a specific part of this test, the state of stress at the facility depth has been measured using a hydraulic fracturing technique.[10] By studying the salt response to a range of stress conditions, the ability to design and to predict the long-term stability of underground excavations will be improved.

In addition, extensive thermal-structural interaction investigations are being conducted as discussed in Section 1.5.2.5.

1.5.2.3 CH TRU Container Performance Experiments

The performance of CH TRU waste drums and proposed waste storage room backfill materials, such as salt and clay mixtures, are being studied in two experiments.[11] The Room J experiment was fielded in mid-1986 and Room T studies began in early 1987. Although no specific credit will be taken for the possible containment of radionuclides by the CH TRU drums, these tests will provide drum corrosion data under both anticipated and severe overtest conditions. In addition, information will be obtained on the consolidation of backfill and compaction of the drums that are subjected to creep closure of the rooms. None of these tests involve radioactive materials.

1.5.2.4 RH TRU Container Performance Experiments

Current plans call for testing of RH TRU waste packages and evaluating the response of the rock to the heat generated by such RH TRU emplacements. A test initiated in Room T during 1986 is evaluating time dependent closure of short horizontal borehole configurations, both with and without backfill. This test subjects the rock to heating levels that approximate: 1) 300 watts/canister, which is the maximum anticipated power output, and 2) 150 watts/canister, which is five times the average power output from RH TRU waste canisters. Studies of the corrosion and behavior of the waste package and borehole backfill materials are planned in these experiments. No radioactive materials are used in these tests.

1.5.2.5 Defense High-Level Waste (DHLW) Simulations

Considerable effort has been expended investigating the behavior of salt and related rocks at the WIPP facility to the emplacement of heat generating defense high-level wastes (DHLW). Usually referred to as thermal structural interaction (TSI) tests, these studies address issues pertinent to the design of future repositories in salt that would be used to dispose of DHLW. These experiments have the dual purpose of increasing knowledge related to the response of salt to heating and extending effective baseline for model validation, and evaluating computer models that are used for repository design.

Three parallel rooms designated A1, A2, and A3 are being used to simulate the behavior of part of a panel in a repository containing DHLW.[12] Following a period of monitoring during construction and at ambient temperature, the heated phase of this test began in October 1985. Data acquisition and analysis are in progress.

Overtest conditions are being evaluated in Room B where heated phase measurements began in April 1985.[13] In this experiment, the temperature has been maintained substantially higher than anticipated during actual DHLW disposal. For both of these tests, heat is generated by electrical heaters rather than by actual radioactive wastes. The migration of brine in response to heating is an integral part of these tests. In addition, the metallurgical behavior of candidate waste package materials is being studied.[14] Interactions of candidate waste-package and waste-form materials in the presence of brine are also being studied in the Room J Materials Interface Interaction Tests (MIIT).

A large cylindrical pillar was mined within a circular room to form Room G, which is the third TSI experiment that is in progress at this time.[15] The behavior of this axially symmetric pillar at both ambient and elevated temperatures and rock mechanics experiments at ambient temperatures in Room G may be used in the evaluation and further development of repository design models.

1.5.2.6 Brine Inflow Studies

A number of activities designed to better characterize brine seepage into the repository excavations are ongoing and described in Section 2.7..2.3 of Reference 16.

The Brine Sampling and Evaluation Program (BSEP) has been in formal existence since 1984, and is an outgrowth of observations that have been made since initial WIPP excavations in 1982. This long-term program has resulted in the generation of a number of reports (See Appendix 1A).

The BSEP characterizes the extent and composition of visually identified brine inflow. This will assist in evaluating brine sources, areal extent and volume of existing and potential brine, relationships between brine and gas occurrences, and the long-term behavior of know occurrences.

Photographic documentation of brine weeps as well as observation and measurements of brine accumulations in drill holes has been ongoing for over six years and will be continued. The existing data document the variation in moisture content that occurs stratigraphically, laterally, and with time since the areas were mined. Salt efflorescences have been dried and weighed to determine the quantity of brine that evaporated to form the deposits. Visual and geophysical logging of boreholes assist in delineating specific zones of higher moisture content. Brine samples have been collected periodically and the chemical composition analyzed.

Additionally, a large number of specific experiments are in progress to supplement the BSEP observational data. These include pore-pressure experiments, constitutive modeling , permeability and hydrologic testing in a variety of bore holes, and the Room Q experiments.

Room Q is 350 feet long and has a circular cross section, which is expected to maximize the fraction of incoming brine that can be collected in instrumented containers and measured directly without the need to infer brine volumes. In this way, the circular cross section addresses the possibility that inaccuracies in brine inflow measurements to test rooms could result from the accumulation of brine in fractures surrounding the room, particularly in the underlying Marker Bed 139 and overlying seams. This curved cross section may also minimize the disturbed zone on the surrounding host rock, further minimizing occurrences of undetected incoming brine.

As the circular cross section brine inflow room was bored, instrumentation measured the pore-pressure response of the host rock. After the room is excavated and sealed, remotely read instrumentation will collect data on humidity, closure, pore pressure vs. distance from the wall, and other variables. The disturbed zone will be characterized using methods such as electrical conductivity and acoustic measurements. Liquid brine inflow will be collected from troughs and shallow sumps to be weighed, measured, and analyzed. Salt samples will also be analyzed for brine content. Finally, post-test studies will be conducted including analyses of core samples and measurements in exploratory boreholes. The data will then be interpreted in terms of brine transport mechanisms.

1.5.3 SITE AND DESIGN VALIDATION ACTIVITIES

The WIPP Project has pursued a phased approach to evaluating the acceptability of the site and the validity of the designs of pertinent structures. The initial phases of this evaluation process are described briefly here.

The earliest phase of the process began in 1975 and consisted of a variety of studies concerning the surface and subsurface characteristics of the region surrounding the location of the WIPP facility. Those studies were conducted from the ground surface and included surface surveys such as seismic, resistivity, and magnetic surveys; and borehole drilling, sampling of subsurface rocks and fluids, and testing. Although these studies produced a considerable knowledge base and provided initial confidence in the potential location for the WIPP facility, exploration, direct observations, and testing at the proposed storage horizon depth were required before a decision could be made to begin full construction of the WIPP facility.

A program of investigation referred to as the SPDV was undertaken to provide confirmation of the characteristics of the facility location and to evaluate the design concepts (Figure 1.5-2). Completed in March 1983, the SPDV program spanned nearly two years. One 12-foot diameter and one 6-foot diameter shaft were drilled to the storage horizon depth of about 2150 feet, four rooms were excavated to the storage-room design dimensions, and connecting and exploratory drifts were excavated in support of this program.

The results of the SPDV program supported the decision to proceed with development of the WIPP facility, geotechnical measurements continued in support of the Design Validation (DV) process, which resulted in the Design Validation Final Report[2] issued in October 1986.

In addition to summarizing the WIPP facility design, construction, exploration, and testing activities to date, the Design Validation Final Report presents the results of the validation process and design modification alternatives and identifies follow-on studies, which may be necessary. These recommended modifications and associated studies are summarized in Table 1.5-2.

Alternative 2 in Table 1.5-2 was selected for the WIPP facility. This alternative allows excavation to proceed using the current reference design dimensions and waste-stack configuration. The potential negative impacts that are anticipated to be associated with the retrieval of crushed and breached drums are avoided with the alternative.

As additional knowledge is gained from ongoing performance assessment, experimental, and operational monitoring activities, modifications to this design may become necessary. Potential interactions between the CH TRU and RH TRU disposal areas are also currently being evaluated. Design modifications will be implemented, as appropriate.

None of the other alternatives is considered to be acceptable. This conclusion was reached by considering: (a) the absence of an identified function for crushed-salt backfill during the period when easy retrieval must be maintained, (b) the current understanding of crushing and breaching of waste containers that are anticipated to occur as creep forces are transmitted through the backfill to the waste stack, and (c) the estimated radiological impact of retrieving crushed and breached waste containers. The estimated consequences are inconsistent with the as low as reasonably achievable (ALARA) philosophy that is followed by the project.

1.5.3.1 Site Validation Program

The testing and exploration programs established during site validation are outlined below. A more complete explanation of these tasks is given in site validation program documentation.[17] These studies continued with some augmentation, in support of design validation.[2] Those studies have resulted in numerous publications which are included in Appendix 1A. Results of many of these studies are reported in Chapter 2 of this FSAR.

Geologic Mapping

Visual mapping of the Salt Handling (SH) shaft, the Exhaust Shaft, and the Waste Shaft (both before and after enlargement), the air intake shaft (AIS), and underground excavations (including the south exploratory drift) were performed to determine the lateral extent and continuity of the salt beds and to detect and describe any notable geologic features. The mapping also provided data to assist in a determination of the thickness and inclination of disposal horizon strata. Geological mapping continues to be done in all new excavations. These data are used to further establish and confirm the continuity and homogeneity of the disposal horizon strata. Should mapping reveal conditions that differ from those anticipated, studies and analysis will be conducted to determine the significance of any differences.

Coring and Core Logging

A number of vertical core holes have been drilled in the roof and floor of the underground workings. Core obtained from these holes were carefully examined and described to obtain information on the geology up to 50 feet above and below the mined areas. Special attention was given to the detection of any discontinuities or irregularities that appeared in the cored intervals, as well as determination of the thickness of the facility strata. Current plans are to provide single 50-foot-deep vertical up and down boreholes in each panel of the disposal area. As with geologic mapping, the drilling of vertical boreholes allows the scientific staff the opportunity to extend their knowledge of geologic conditions and to further confirm the presence of expected conditions. As above, should studies reveal conditions different than those anticipated, the reasons and significance of such differences will be determined.

Laboratory Analyses

Laboratory analyses were performed on samples selected from core obtained by underground drilling and on samples collected from the exploratory and ventilation shafts and underground workings. These analyses were conducted to determine the mineralogy of the disposal strata, the percent fluid content of representative rock samples, the mechanical properties of interbed material (e.g., clay and anhydrite) and the permeability of selected rock core. Additionally, in cases where fluids encountered at the disposal horizon or in the shafts occurred in sufficient quantity to be sampled, samples were collected for major, minor and trace elements and isotopic analyses.

Hydrologic Tests

Information on the water-bearing units penetrated by the SH and Exhaust Shafts was obtained by measuring the rate of fluid inflow into these shafts. Also, piezometers were installed through the SH Shaft liner at the depths of the water-bearing units to measure groundwater pressure. These measurements have continued. These pressures are small compared to the strength of the liners. Therefore, their measurement is not for safety reasons. Instead, pressure changes could be diagnostic of changing conditions in the rock or deterioration of seal materials.

Stratigraphic Studies

Data on the stratigraphy and structure of the strata at and near the location of the WIPP facility were obtained by performing a high resolution gravity survey over much of the area. Also instrumental in the determination of the geology is the correlation of drillhole logs from boreholes drilled near the WIPP facility. Basic data reports on these boreholes were issued as part of the site validation program documentation.

1.5.3.2 Design Validation Program

The purpose of the preliminary design validation was to confirm that the design of excavations performed during SPDV is adequate for safe and efficient operation. Three types of observations were made to provide information for evaluation of the design:

- Geologic observations to reveal unexpected features that might have an impact on the design
- Observations of the excavated surfaces to detect anomalous behavior that may affect operational safety
- Measurements of closure of the excavated surfaces and movement of the rock salt using rock mechanics instrumentation

Reference 1 is a report prepared as part of the SPDV activities for the WIPP facility underground opening reference design. Reference 2 contains additional information gathered after completion of the SPDV Program. This information has been analyzed and evaluated to complete the design validation process for the WIPP facility.

Four types of information were gathered for Reference 2:

- Observations of the behavior of the underground openings
- Descriptions of the geologic conditions encountered during underground construction
- Descriptions of core samples from instrumentation and other holes in the roof and floor of the underground openings
- Data from installed geomechanical instrumentation

The design validation process provides for the collection, analysis and evaluation of in situ data. This process was designed to permit determination of the need to modify elements of the underground opening reference design so that construction and operation of the full facility can proceed in a timely, safe, environmentally acceptable and cost effective manner. Observation and instrumentation data have been collected and evaluated for each of the underground design elements.

Most of the instruments are connected to a computer for automatic data acquisition; this enables the excavation to be monitored continuously. Other instruments are read manually with the resulting data being entered into a computer based data management system for subsequent analysis and reporting.

The facility design is evaluated continuously as additional observations on geology and rock behavior and the instrumentation data are available. In this way, the operating plans can be modified, as necessary, in response to conditions encountered in the course of excavating the underground structures, thereby providing as safe a working environment as possible.

The designs of the shafts and the horizontal openings were evaluated as part of the preliminary design validation. Subsequent to preliminary design validation, visual and instrumental data continue to be collected during full-facility construction. These activities will continue through operations to ensure excavated opening dimensions are within the range to permit safe operation. In addition, during the Test Phase, storage rooms will be monitored using both instrumentation and visual inspection to ensure that wastes in these rooms will be readily retrievable.

1.5.3.3 Operational Geotechnical Instrumentation Program

Operational geotechnical instrumentation measurement programs include ongoing measurement of convergence, brine inflow and hydrostatic pressure buildup behind shaft liners, as well as geologic mapping of new excavations. These are the responsibility of the Engineering Manager of the operating contractor, they are conducted in accordance with the WIPP Geoscience and Procedure Manual.

The safety of the underground excavations is and will continue to be evaluated on the basis of criteria established from measurements of room convergence. These criteria may be modified as more field data are collected and additional experience is gained with the performance of the WIPP underground excavations. The criteria are as follows:

- Increase in measured room closure rate with time
- Deviation of measured room closure rate from a predicted rate that exceeds specified threshold limits

The threshold limit is established from statistical analyses of room closure data and is +0.5 inch above predicted levels. This analysis is updated on a regular basis and is reported in geotechnical data reports.

Once the threshold is crossed at an instrumented location, a study is initiated to determine the cause. If the cause cannot be related to operational considerations, such as mining activity, then additional field monitoring will be undertaken to characterize the ground response. Should the field data indicate that ground conditions are deteriorating, then corrective action will be taken, as required.

In general, ongoing observations and monitoring results are compiled into a data base and documented annually in the Geotechnical Field Data and Analysis Report. This document and associated data are reviewed throughout the MOC and other project participants. It is the responsibility of the Engineering Manager and his staff to report changes in the underground geotechnical conditions to the facility safety and operations staff in a timely manner. Such reports are made, when necessary, at daily planning meetings, weekly interface meetings, or in monthly operations reports, or in any other manner, as appropriate.

1.5.4 RETRIEVAL DEMONSTRATIONS

CH TRU waste and RH TRU waste retrieval demonstrations were performed with non-radioactive "mock" waste forms of CH TRU and RH TRU. These demonstrations evaluated handling equipment prior to commencement of waste receipt. The objective of these demonstrations was to ensure that a fully tested set of underground handling equipment and operating procedures were available prior to the receipt of these waste forms. Storage rooms were configured to simulate the expected conditions after five years. Details of these demonstrations can be found in References 18 and 19.

References for Section 1.5

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17. U.S. Department of Energy, Site Validation Program, Waste Isolation Pilot Plant, WIPP/DOE-116, Rev. 1, October 1982.

18. Stumbaugh, J., Remote-Handled Transuranic Waste Mock Retrieval Demonstration, DOE/WIPP 87-009, Westinghouse Electric Corp., 1987.

19. Westinghouse Electric Corp., Final Report for the Contact-Handled Transuranic Waste Mock Retrieval Demonstration, DOE/WIPP 88-006, January 1988.

Table 1.5-1

MAJOR MILESTONES FOR GEOTECHNICAL DATA ACQUISITION

Program Milestones	Status
Geological Characterization Report	8/78 (Complete)
Final Environmental Impact Statement	10/80 (Complete)
Recovery of Natural Resources	9/82 (Complete)
Breccia Pipes	10/82 (Complete)
Delaware Mountain Group Hydrology	12/82 (Complete)
Aquifer Characteristics	3/83 (Complete)
Dissolution of Evaporites in Delaware Basin	3/83 (Complete)
Site Deformation Report	3/83 (Complete)
Regional Hydrology	3/83 (Complete)
Site Validation Conclusions	3/83 (Complete)
Preliminary Design Validation	3/83 (Complete)
Brine Reservoirs	3/83 (Complete)
Fracture Flow In Rustler Aquifer	6/82 (Complete)
Design Validation	10/86 (Complete)
Simulated Waste Experiments	4/88 (Complete)
Technical Report for DOE-2	6/86 (Complete)
Geologic Structures Within the Salado and Castile Formations in Hole DOE-2	6/86 (Complete)
A Compilation of Hydrologic Data from the Salado and Castile Formations	06/86 (Complete)
Hydrologic Data Reports (Six Completed)	06/85 - 06/88
Multi-Pad and Single-Pad Water-Bearing Zone Tests of the Culebra Dolomite at Hydropad H-3	10/86 (Testing Complete) 03/87 (Reporting Complete)
Single Pad Hydraulic Testing of the Culebra Dolomite at H-11	5/87 (Testing Complete) 9/87 (Reporting Complete)
Single-Well Hydraulic Testing of the Rustler Water-Bearing Zones	12/87 (Reporting Complete)
Convergent-Flow Tracer Tests at Hydropad H-3 and H-4	10/86 (Testing Complete) 12/86 (Reporting Complete)
Interim Sorbing Tracer Test Report*	(Deleted)
Technical Report on Analysis of Water Samples from the Rustler Water-Bearing Zones	04/87 (Testing Complete) 12/87 (Reporting Complete)
Hydrogeochemical Facies in the Rustler Formation	04/89 (Expected Completion)
A Regional Water Balance for the WIPP Site and Surrounding Area	03/85 (Reporting Complete)
2nd Interim Groundwater Modeling Study of the Culebra Water-Bearing Zone	03/88 (Reporting Complete)

Table 1.5-1

MAJOR MILESTONES FOR GEOTECHNICAL DATA ACQUISITION

Program Milestones	Status
Dissolution of Halite and Gypsum, and Hydration of Anhydrite to Gypsum in the Rustler Formation	12/85 (Reporting Complete)
Facies Variability and/or Evaporite Dissolution Within the Rustler Formation	01/88 (Reporting Complete)
Evaluation of the TEM Method for Identification of Castile Brine Occurrences	03/88 (Reporting Complete)
Assessment of Near-Surface Dissolution in the Vicinity of WIPP	02/85 (Complete)
Marker Bed 139: A Study of Drillcore from a Systematic Array	02/85 (Complete)
Complete Reporting of H-11 Multi-Well Test	06/89 (Expected Completion)
Complete Reporting of H-11 Tracer Test	09/89 (Expected Completion)
Complete Reporting of Additional Radiocarbon Analyses	09/90 (Expected Completion)
Complete Numerical Modeling of Culebra Transport in Response to a Breach involving Pressurized	
Brine in the Castile Formation	07/89 (Expected Completion)

* This item was eliminated after modification of the agreement with the State of New Mexico.

Table 1.5-2

SUMMARY OF DESIGN VALIDATION RECOMMENDATIONS[2]

(1) Maintain the reference design storage room dimensions of 13 to 14 feet high and 33 to 34 feet wide and maintain the salt backfill, but reduce the volume of waste to be stored and modify the container stacking configuration for the 5-year demonstration period. Revise the design criteria to require that waste be retrieved before a room exceeds an age of 7 years. This will meet the criteria that the waste containers not be crushed or breached, but it will require a significant number of additional storage rooms.

(2) Maintain the reference design storage room dimensions and maintain the planned waste volume. Revise the design criteria to delete the requirement for salt backfill and to require the waste be retrieved before a room exceeds an age of 7 years. This will meet the criteria that the waste containers not be crushed or breached without requiring additional storage rooms.

(3) Maintain the reference design storage room dimensions, planned waste volume, and salt backfill requirement. Revise the storage operations so that the first-retrieved waste with retrieval effected before the room exceeds 6 years of age. Excavate the room to 14 x 34 feet, then 1 year later, trim the room to its initial 14 x 34 foot dimensions. This will minimize container crushing and breaching. More storage rooms will be utilized during the 5-year demonstration period, but the total number of rooms will remain the same as provided by the reference design. This modification will require changing the design criteria to allow crushing and breaching of the CH waste containers prior to retrieval and handling of crushed and breached containers.

(4) Reduce the reference design storage room width from 33 feet to 28 feet, maintain the room height at 13 to 14 feet, and reduce the pillar width to 84 feet. Maintain the first room for RH waste emplacement at the original reference design dimensions. Reduce the planned waste volume and maintain the salt backfill requirement. Excavate the rooms to 14 x 28 feet, then trim them to this dimension after 1 year. Use a first-in/first-out storage operation. This will reduce the creep to approximately that of a 13 x 25-foot drift. Stability will be enhanced and crushing and breaching will be minimized. The volume of excavation will be approximately the same as for the reference design storage rooms, but with the advantage of a lower creep rate. If this alternative is selected, additional engineering evaluation will be required.

(5) Maintain the reference design storage room dimensions, the planned waste volume, the salt backfill requirement, and the reference design optimized excavation and storage plan. Revise the design criteria, as in alternative number 3, to allow crushing and breaching of the CH waste containers prior to their retrieval. Require a demonstration of the retrieval and handling of crushed and breached containers prior to the receipt of waste during the 5-year demonstration period, but also during permanent storage.

(6) The drifts used for storage will require maintenance and trimming to accommodate the required equipment and storage clearances. Their closure rates are not critical for storage because they will be used only for permanent storage near the end of the permanent storage period.

(7) Add additional rooms to compensate for the space occupied by the plugs in the storage area entry drifts.

(8) Install instrumentation in the storage rooms to obtain in situ data to monitor storage room behavior.

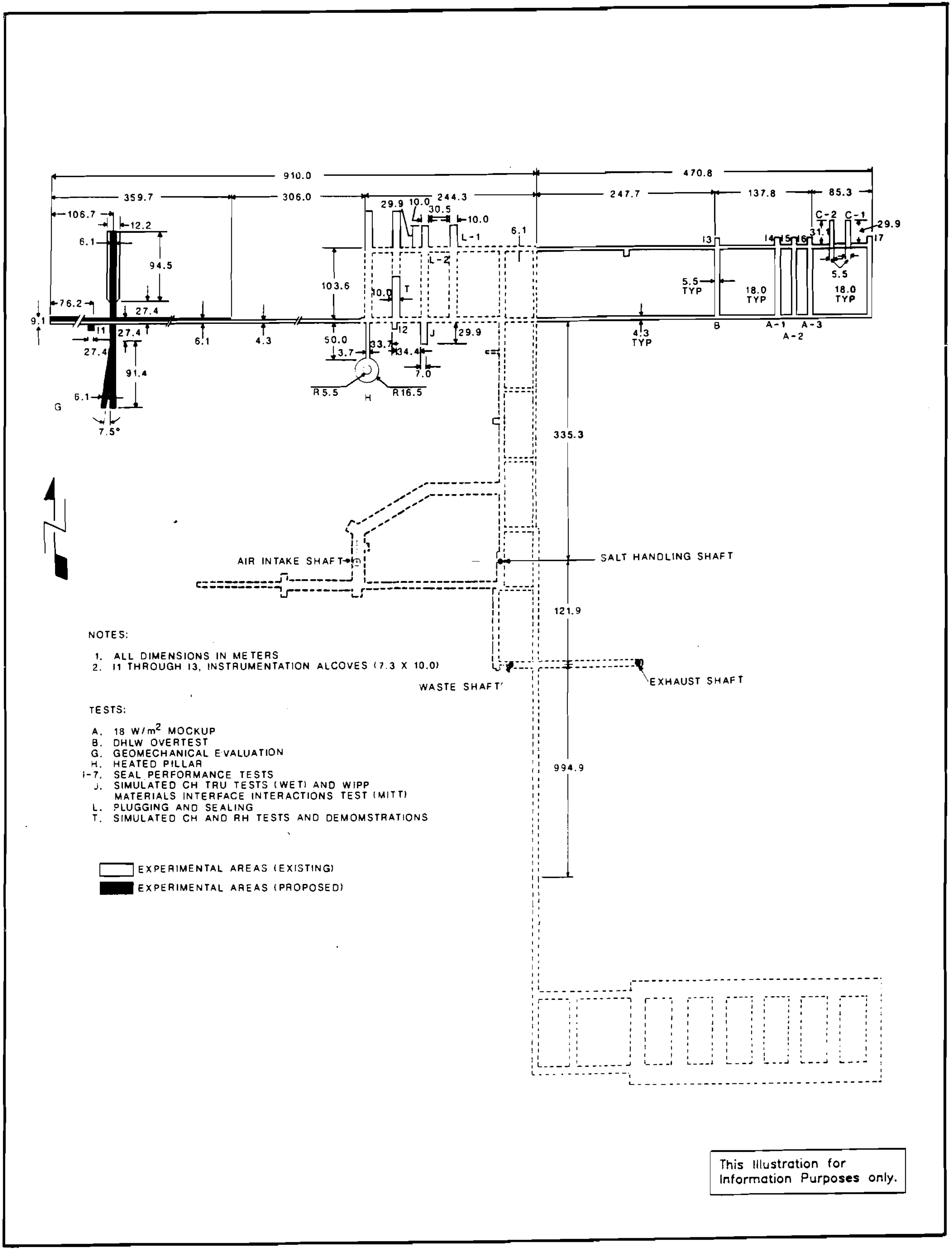

FIGURE 1.5-1
Layout of In Situ Tests for the WIPP Facility

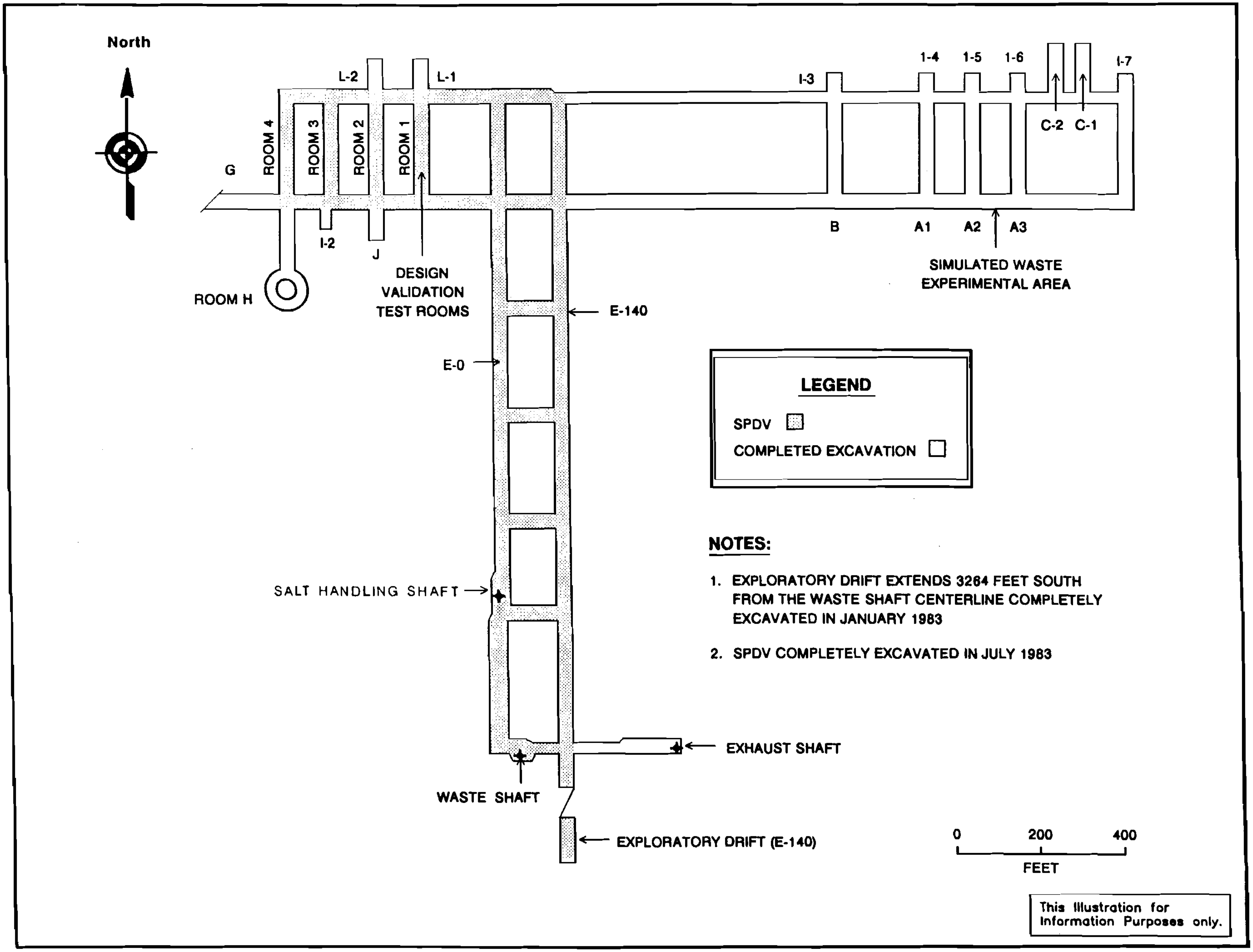

FIGURE 1.5-2
Illustration of Experimental Areas and SPDV

APPENDIX 1A - CONTENTS

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APPENDIX 1A.1

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APPENDIX 1A.3

HYDROLOGY

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APPENDIX 1A.4

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APPENDIX 1A.5

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APPENDIX 1A.6

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APPENDIX 1A.8

WESTINGHOUSE CONTROLLED DOCUMENT LIST

DOCUMENT TITLE	DOCUMENT NUMBER
WIPP Procedures Manual	3 Volumes
WIPP Dosimetry Program Manual	WP 02-2
WIPP Environmental Procedures Manual	WP 02-3
Operational Environmental Permit Compliance Plan	WP 02-4
Environmental Compliance Manual	WP 02-5
WIPP Nonradioactive Hazardous Waste Management Plan	WP 02-6
Radioactive Mixed Waste Compliance Manual	WP 02-7
WIPP Spill Prevention, Control, and Countermeasures Plan	WP 02-8
Facility Operations Manual	WP 04-1
Mining Operations Manual	WP 04-2
Operations Administration Manual	WP 04-3
Central Monitoring Systems CMS Operating Instructions	WP 04-4, 04-5, 04-6
WIPP Operational Safety Requirements Administrative Plan	WP 04-7
Waste Handling Operations Manual	WP 05-1
RH TRU Waste Handling Operations Manual	WP 05-2
WIPP Waste Information System Operations Manual	WP 05-3
WIPP Transportation Policy and Procedures Manual	WP 06-1
WIPP Transportation Manual	WP 06-2
Transportation Monitoring Responsibilities Manual	WP 06-3
Transuranic Waste Program Transportation Management and Operation Plan	WP 06-4
Geotechnical and Geosciences Procedure Manual	WP 07-1
Water Quality Sampling Program	WP 07-2
Geomechanical Instrumentation	WP 07-3

DOCUMENT TITLE	DOCUMENT NUMBER
Brine Sampling and Evaluation Program	WP 07-4
Geologic Characterization Program Manual	WP 07-5
Experimental Operations Work Control	WP 08-1
Pressure/Density Survey Program	WP 07-6
Technical Computer Systems Manual	WP 09-4
Welding Manual	WP 09-5
WIPP Site Development Plan	WP 09-6
Construction Management Manual	WP 09-7
WIPP Specification Preparation Style Guide	WP 09-8
Maintenance Manual	WP 10-1
Maintenance Performance Assessment Manual	WP 10-2
Operational Security Plan	WP 11-1
WIPP Security Plan	WP 11-2
WIPP Firearms Safety Manual WP	11-4
WIPP Firearms Safety and Procedures Manual	WP 11-5
WIPP Lock and Key Control Plan	WP 11-6
WIPP Safety Manual	WP 12-1
WIPP Occupational Health Manual	WP 12-2
WIPP Hoisting and Rigging Manual	WP 12-4
WIPP Radiation Safety Manual	WP 12-5
WIPP/DOE Duty Managers and Duty Officers Manual	WP 12-5
Industrial Hygiene Procedures Manual	WP 12-8
WIPP Emergency Plan and Procedures Manual	WP 12-9
Operational Readiness Review Manual	WP 12-10
WIPP Radiation Safety Program Plan	WP 12-11

DOCUMENT TITLE	DOCUMENT NUMBER
WIPP Health Physics Technician Training Manual	WP 12-12
Quality Assurance Program Manual	WP 13-1
WIPP Quality Assurance Instructions	WP 13-2
WIPP Training Program Manual	WP 14-1
WIPP Documentation Plan	WP 15-1
Cost/Schedule Control System Criteria Manual	WP 15-2
WIPP Property Management Manual	WP 15-5
Purchasing Policies and Procedures Manual	WP 15-6
Operation Quality Assurance Program Plan for the WIPP Project	DOE/WIPP 87-007
DOE Management Plan and Directives	WIPP/DOE 103
WIPP Records Management Handbook	DOE/WIPP 89-013
TRU Waste Acceptance Criteria for the WIPP	WIPP/DOE 069
TRU Waste Certification Compliance Requirements for Acceptance of Newly Generated CH Wastes to be shipped to WIPP	WIPP/DOE 114
Quality Assurance Requirements for Certification of TRU Waste for Shipment of WIPP	WIPP/DOE 120
TRU Waste Certification Compliance Requirements for Acceptance of CH Wastes Retrieved From Storage to be Shipped to the WIPP	WIPP/DOE 137
Data Package Format for Certified TRU Waste for the WIPP	WIPP/DOE 157
TRU Waste Certification Compliance Requirements for RH Waste for Shipment to the WIPP	WIPP/DOE 158
Construction Quality Assurance Program Plan	WIPP/DOE 207

Note: WIPP Controlled Documents are not available for general distribution but can be reviewed at the WIPP facility.

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CHAPTER 1A

SUMMARY SAFETY ANALYSIS

Consideration of the operational safety aspects as well as the long-term protection aspects of the WIPP facility began as early as the establishment of site selection criteria. As is detailed in Reference 1, site selection criteria* included factors to minimize risks from natural disasters such as earthquakes, floods, volcanoes, and winds. Also included were factors to select a location with favorable geological and hydrological characteristics so as to minimize the risks associated with more gradual natural processes. Finally, site selection included factors associated with the geotechnical conditions needed to safely construct and operate a mined geologic repository.

Site and Preliminary Design Validation[2] (SPDV) activities confirmed the favorable characteristics of the site for the WIPP facility and for the design of the underground structures.

The result of the systematic approach to site selection and underground structure design has been a minimization of risks due to natural hazards. This notwithstanding this Final Safety Analysis Report (FSAR) considers the consequences of various natural and man-made conditions that may pose a risk to the safety of the worker, the public, or the environment. In accordance with Order AL 5481.1B, only conditions that pose risks of accidents with a probability of occurrence of greater than 10^{-6} per year are analyzed. Those natural conditions analyzed include wind, lightning, floods, earthquakes, tornadoes, and range fires. Man-made conditions analyzed include fires and explosions, loss of power, hazardous atmospheres, external disruptions, mine accidents, hazardous emissions, heat stress, equipment failure and criticality.

A summary of hazards considered in this FSAR is presented in Tables 1A-1 and 1A-2. These tables provide reference to those sections of the FSAR where detailed discussions of the hazard can be found. In addition, the tables list those monitoring and surveillance systems used to detect failures in systems and structures. Additional information on this topic can be found in the Final Environmental Impact Statement[6], and other documents listed in Appendix 1A.

1A.1 SITE ANALYSES

In designing the WIPP facility, design classifications have been assigned to structures and components. Design Class I structures are items whose function is essential to the prevention or mitigation of the consequences of an accident or severe natural phenomena that could result in a 50-year dose commitment beyond the Zone I boundary in excess of 25 rem to the whole body or 75 rem to specific organs. There are no Class I structures at the WIPP facility.

*Site selection criteria were principally specified by Oak Ridge National Laboratories[3] and the United States Geological Survey[4]. Reference 5 (EEG-1) contains an excellent compilation of site selection criteria from 59 different sources. The other structures and component systems at the WIPP facility are assigned to Design Class III.

Class II structures are items that are functionally relied upon to confine, monitor and control radioactive effluents, or provide permanent shielding. Class II structures at the WIPP facility are the Waste Handling Building, the structural portions of the TRUPACT II Maintenance Facility and the Support Building, the Monitoring Station referred to as Station A. There are several Class II component systems. Class II structures and some component systems are for the most part designed to withstand the design basis earthquake (DBE) and the design basis tornado (DBT).

The other structures and component systems at the WIPP facility are assigned to Design Class III.

1A.1.1 NATURAL PHENOMENA

The engineering design of the WIPP facility takes into account risks that are created by various natural phenomena. Specifically, protection against the following hazards is included in the design: earthquakes, high winds, tornadoes, lightning, flood, excessive snow loads, and loss of water supply.

1A.1.1.1 Earthquakes

Seismic risk analysis has defined a conservative DBE for the WIPP facility with a maximum ground acceleration of 3.2 in/s^2 (0.1g) horizontally and vertically, with 10 maximum stress cycles, and based on a 1000-year recurrence interval. This maximum acceleration is used in analysis and design of surface confinement facilities and equipment. Response spectrum analysis was conducted using structural mode shapes and frequencies for two principal horizontal directions, and modal responses (shear, moments, stresses, deflection, accelerations) were combined to assess the contribution to loading from seismic sources. Seismic overturning moment was used to compute foundation reactions and account for vertical earthquake effects. Structures and components at the WIPP that are designed to withstand the DBE include the following:

Waste Handling Building

- Confinement boundary, including hoist tower and tornado-resistant doors
- Cask unloading room, hot cell, transfer cell, and cask loading room

Support Building and TRUPACT II Maintenance Facility

- Structure portions

RH Waste Handling Systems and Equipment

- Floor shield valves, transfer cell/hot cell
- Shield plug supports

Radiation Monitoring and Alarm Systems

- Effluent monitoring system and alarms for HEPA bypass (Station A)
- Portions of the exhaust shaft ducting

Contamination Control (Waste Handling Area)

- Tornado dampers

Handling Equipment Designed to Hold Load in Place in Event of DBE

- Cask receiving bridge crane (140T)
- Remote bridge crane (15T)
- Transfer cell canister shuttle car
- Bridge-mounted power manipulator rail and bridge
- CH unloading overhead crane (5-ton)

1A.1.1.2 Wind

The design wind velocity for the WIPP facility Design Class II buildings and components is 110 mi/h at 30 feet above ground level, with a 100-year mean recurrence interval. The design wind velocity for Design Class III structures is 91 mi/h with a 50-year mean recurrence interval, except for the Support Building and Exhaust Filter Building, which is 99 mi/h with a 100-year mean recurrence interval.

1A.1.1.3 Tornadoes

The DBT used for the WIPP facility has a maximum wind speed of 183 mi/h (including effects of suction vortices), translational velocity of 41 mi/h, tangential velocity of 124 mi/h, a 325 feet radius of maximum wind, pressure drop of 0.5 lb/ft^2, and rate of pressure drop of 0.09 lb/ft^2/s, with a mean recurrence interval of 1,000,000 years. Because atmospheric differential pressure loading tends to force external surfaces of enclosed structures outward, the failure mode for the Support Building was analyzed to ensure that no loss of function of tornado-resistant structures would result.

With regard to the DBT, and other natural phenomena, the WIPP facility is designed on a single failure basis. That is, it is considered incredible that two or more failure events will occur simultaneously. Based on this design approach, it was not necessary to build structures at the WIPP facility to withstand missiles generated by the DBT since such missiles could not simultaneously penetrate the structures and waste containers. Damage to Type B containers used to ship waste to the WIPP facility is anticipated to be less severe than postulated transportation and handling accidents so that the allowable exclusion boundary limit would not be exceeded.

1A.1.1.4 Lightning

Lightning protection and grounding systems are provided for the Air Intake Shaft headframe, waste hoist tower, radio antenna, water tanks, Exhaust Shaft Filter Building, and Salt Handling Shaft headframe, and the site perimeter.

1A.1.1.5 Water

Neither the probable maximum flood for the Pecos River nor floods induced by dam failure represent risk to the WIPP facility because the site is 14 miles from the river and more than 400 feet above the Pecos River floodplain. Protection from flooding caused by intense local precipitation is provided by the diversion of water away from the WIPP facility by a system of peripheral interceptor diversions. Additionally, grade elevations of roads, tracks, and surface facilities are designed so storm water will not collect on the site under the most severe conditions. Shaft collars prevent surface water from entering the shafts.

A 100-year mean recurrence interval snow load of 10 lb/ft^2 was used in calculations. To reduce snow retention, there are no parapets on the roofs. The combined snow load also includes 7 lb/ft^2 required to bring the snow to threshold condition and a conservative two-inch water depth to cause flow (10 lb/ft^2), for a total of 27 lb/ft^2. This figure is employed in place of minimum roof live load in combined loading calculations where such loading is more critical.

1A.1.2 CHARACTERISTICS AFFECTING THE SAFETY ANALYSIS

Characteristics that affect safety analysis for the WIPP facility are the stability of the rock formations and the presence of water.

1A.1.2.1 Stability

1A.1.2.1.1 Surface Structures

Surface structures design takes into account the potential for subsidence of the ground surface due to excavation beneath the WIPP site. Subsidence is a function of salt creep, extraction ration, and properties of the rocks over the waste storage level. A shaft pillar is maintained to reduce effects of subsidence on critical surface structures. The surface is projected to subside a maximum of no more than one inch within a 50-feet radius of the waste shaft. Extensive field and laboratory testing was conducted to determine the static and dynamic properties of the soil and shallow rocks. Design Class II surface structures are founded on Mescalero caliche, Gatuna sandstone, or compacted backfill above caliche.

1A.1.2.1.2 Underground Structures

The only potential stress-related problem for the shafts that were identified in exploratory borings are the clays of the Dewey Lake Redbeds, which would have potential for swelling when wet. These clays were considered in the design of the shaft liners so that these potential effects are mitigated. To prevent water from entering the shafts, they are lined immediately after boring, and surface water is diverted away.

The zone of rock in which waste will be placed is referred to as the facility horizon. It was chosen to minimize the effects of clay seams, which create zones of possible structural weakness if located in or near the roof, floor, or pillars. Formations overlying the Salado Formation are not expected to have any unrelieved residual stresses. The Salado Formation that includes the facility horizon has a stable stress configuration, at lithostatic loading, although there may be minor shear stresses. Hydraulic fracture tests conducted in facility horizon boreholes give relatively good agreement with predicted stress configurations.

Underground openings were analyzed with a finite element model and computer program for creep closure and the general stability of the roofs and pillars. In modeling, creep rates, and the physical properties of the materials, are taken into account. Discrepancies observed in the underground between initial predicted creep rates and actual creep rates are on the order of three to four times greater. These higher discrepancies are addressed in the Final Design Validation Report.[7] Changes to the facility were discussed in Section 1.5.3. Facility design is evaluated continuously based on an increasing data base of in situ measurements.

1A.1.2.2 Water

No significant infiltration of surface water occurs below the Mescalero caliche that could affect the WIPP facility operations. Water-bearing zones have been identified in the shafts at depths ranging from 608 to 632 feet (Magenta) and 714 to 740 feet (Culebra). Shafts are lined and sealed to prevent water from entering the shafts from these water-bearing zones. Average moisture content of the Salado Formation is 1.5 percent by volume. The brines that make up this moisture content represent no special hazard to the WIPP operations. Since the waste container is not considered important to long-term isolation, corrosion of this container due to brines is not considered important.

1A.1.3 EFFECTS OF INDUSTRIAL, TRANSPORTATION, AND MILITARY ACTIVITIES

Nearby industrial, transportation, and military activities are far enough from the WIPP facility that they represent negligible risk to the surface facilities. There are no industrial sites, military sites, water transport routes or railroad routes within five miles of the center of the WIPP facility and the nearest highway is more than four miles from the center of the WIPP facility.

The nearest gas well is about tow and one half miles from the center of the WIPP facility, while the nearest gas pipeline is slightly more than one mile away. At those distances, a gas explosion would not be expected to cause damage to the WIPP surface structures. Although two federal airways pass within five miles of the WIPP facility, the probability of an air disaster occurring at the WIPP facility is very small. Outside activities do not represent a significant risk to the WIPP facility.

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Table 1A.1-1
SUMMARY OF NONRADIOLOGICAL HAZARDS

HAZARD	SYSTEM/STRUCTURE AFFECTED	CONSEQUENCE	MITIGATING ACTION	REFERENCE	MONITORING/SURVEILLANCE SYSTEMS
1. Wind	a. All surface structures	a. Work stoppage or slowdown, possible structural damage	a. Structures designed using wind loading factors derived from the results of a site-specific wind study	a. 3.2.1, 3.2.1.1, 3.2.1.2 Occurrence: 2.3.1.2.5, 2.3.2.2.1	a. Meteorological stations, severe weather observation
	b. Power lines	b. See 7.	b. See 7	b. See 7	b. See 7
2. Lightning	a. Tall structures (hoist towers, headframes, water tanks, antennae, meteorological towers, light posts, flagpoles)	a,b. Electrical systems damage, structural damage, work stoppage	a,b. Lightning protection, grounding systems		a. Lightning protection circuits
	b. Other structures	b. Structural fires			b. Lightning protection circuits, fire alarms
	c. Area around the WIPP facility.	c. Range fire	c. Cleared area adjacent to Zone 1 fence		c. Security patrols
3. Flooding	a. All surface structures	a. Structural damage, work stoppage	a,b. Specific site location chosen as a "Dry Site", peripheral interceptor diversions, grade elevations of roads, tracks, and surface facilities	a,b. The following sections reference: Location- 2.4.3.1, 2.4.3.2, Design- 2.4.2.2, 2.4.2.3, 2.4.3.5 The following sections reference flooding from: Precipitation- 2.4.2.4, 2.4.2.1, 2.3.1.2.1, 2.3.2.2.3 Dam failure- 2.4.4.1	a,b. Chances of major flooding not credible, local flooding avoided by keeping drainage ways open
	b. Shafts and underground.	b. Structural damage, erosion of salt			

Table 1A.1-1
SUMMARY OF NONRADIOLOGICAL HAZARDS

HAZARD	SYSTEM/STRUCTURE AFFECTED	CONSEQUENCE	MITIGATING ACTION	REFERENCE	MONITORING/SURVEILLANCE SYSTEMS
4. **Earthquake**	a. All surface structures	a-d. Structural damage, Work stoppage	a-d. Building and structural designed using DBE criteria	a-d. Design criteria references: 2.8.6, 3.1.7, 3.1.7.5.2 a-d. Remedial action reference: 5.5.3.2	a-d. Seismic monitoring system
	b. All internal systems				
	c. Shafts				
	d. Underground	d. Rock fall	d. See 9		
5. **Tornadoes**	a. All surface structures	a. Structural damage, work Stoppage	a. Building and structural design using DBT criteria	a. Design criteria references: 3.1.7, 3.1.7.5.1, 3.2.2 Occurrences: 2.3.1.2.3	a. Meteorological stations, severe weather observation
	b. Power lines	b. Loss of commercial power	b. See 7	b. See 7	b. See 7
6. **Fire and Explosion:** **o Electrical** **o Spontaneous Ignition** **o Use and handling of highly flammable materials** **o Maintenance operations and thermally hot surfaces**	a. All structures	a. Personal injury, property damage, work stoppage	a. Fixed automatic fire suppression systems, noncombustible construction, susceptible areas separated by fire walls and automatic fire doors, openings to upper floors enclosed to prevent spreading, use of fire-watch system and standby personnel during a high fire risk operation	a,b. 3.3.3, 4.4.3, 5.5.3.2, 6.3.6	a,b. Fire detection systems fire suppression systems, fire protection system inspections
	b. Records/data	b. Loss of information	b. Use of fire resistant safes and structures		
7. **Loss of Commercial Power**	a. All structures	a. Work stoppage, Loss of ventilation, damage to electrical systems, monitoring systems interrupted	a. Manually started emergency power supply (EPS), critical systems have uninterruptible power supply (UPS).	a. All of 4.4.2, 5.5.3.2	a,b. Generator tests, uninterruptible power supply tests, electric power distribution at CMR.

Table 1A.1-1
SUMMARY OF NONRADIOLOGICAL HAZARDS

HAZARD	SYSTEM/STRUCTURE AFFECTED	CONSEQUENCE	MITIGATING ACTION	REFERENCE	MONITORING/SURVEILLANCE SYSTEMS
8. Hazardous Atmospheres	a. Battery charging areas	a. Injury to personnel	a,b,c. All atmospheres constantly monitored, atmosphere checked by safety personnel before confined space entry	a. 4.4.1	a. Hydrogen monitors
	b. Other surface areas c. Underground			b,c. 6.4.3	b. Misc. gas monitors c. Air quality monitoring
9. External Disruptions **o Industrial** **o Gas well explosion** **o Extractive activities** **o Military**	a. All surface structures	a,b. Structural damage	a,b,c. Plant location chosen to be physically removed from this type accident	a,b,c. All of 2.2	a,c. Security patrols
	b. Utility systems c. Area around the WIPP Facility	a,b. Fire and explosion c. Range fire	c. Area cleared adjacent to Zone 1 fence		b. Radio monitoring
10. Mine Accident **o Rock fall**	a. Underground	a,b. Hazard to personnel, Loss of equipment, work stoppage	a. Immediately after mining: Sounding survey followed by scaling and rock bolting	5.6.1	a,b. Geotechnical monitoring, routine inspections
	b. Shafts		a,b. Comprehensive underground safety and maintenance program a. Two hoists must be operational at all times when personnel underground b. Shafts designed for 25 year life		a. Roof soundings
o Hazardous emissions	a. Underground	a. Hazard to personnel, Release of hazardous gases, damage to equipment	a. Use of noncombustible materials in construction, diluting and venting of gases generated, automatic shutdown of fueling by monitoring systems	a. 3.3.3, 4.4.3.1.2, 4.4.3.2.3, 6.3.6, 4.4.1.3	a. Fire detection systems, Fire protection systems, inspections
o Fire	a. Underground	a. Creation of hazardous atmospheres	a. Emissions of underground equipment periodically monitored to ensure compliance within TLV limits	a. 6.4.3, 6.4.3.	a. Confined space entry procedures, air quality monitoring programs

Table 1A.1-1
SUMMARY OF NONRADIOLOGICAL HAZARDS

HAZARD	SYSTEM/STRUCTURE AFFECTED	CONSEQUENCE	MITIGATING ACTION	REFERENCE	MONITORING/SURVEILLANCE SYSTEMS
11. **Civil Disobedience** **o Demonstrations** **o Hostage** **o Sabotage**	a. Surface structures b. Area around the WIPP facility	a. Work disruption a,b. Fire or explosion	a,b. Security force trained to minimize occurrence	a,b. 6.5	a,b. WIPP Facility security program including surveillance, patrols, badging, vehicle inspections
12. **Heat Stress**	a. Underground	a. Personnel health problems, uncomfortable work area	a. Monitoring, protective equipment, annual medical exams, training, ventilation systems. HVAC system to maintain working atmosphere.	a. 6.4.1, 4.4	a. Health monitoring program, procedures to limit exposure
13. **Snow loads**	a. All buildings	Collapse of roof	a. Building designed for maximum expected snow load; no parapets	a. 3.2.7	a. Severe weather monitoring

Table 1A.1-2
SUMMARY OF RADIOLOGICAL HAZARDS

HAZARD		SYSTEM/STRUCTURE AFFECTED		CONSEQUENCE		MITIGATING ACTION		REFERENCE		MONITORING/SURVEILLANCE SYSTEMS
1. Wind	a.	Waste Handling Building	a.	Structural damage resulting in the spread of airborne radioactive particulate	a-c.	Structural design with regard to wind loading factors derived from the results of a site-specific wind study	a-c.	Design: 3.2.1, 3.2.1.1, 3.2.1.2	a,b,c.	Meteorological monitoring
	b.	CMS Monitoring Room	b,c.	Structural damage resulting in loss of protective system			a,c.	Filters: 4.4.1.3.1, 4.4.1.3.2, 6.3.1	c.	Mine exhaust system
2. Flooding	a.	Waste Handling Building	a.	Damage to structures resulting in the contamination of runoff water to the surrounding area	a.	Specific site location, structural design, peripheral interceptor diversions	a.	Location: 2.4.3.1, 2.4.3.2	a.	Not considered a credible accident based on facility design
							a.	Design: 2.4.2.2, 2.4.2.3, 2.4.3.5		
3. Earthquake	a.	Waste Handling Building	a,d.	Structural damage resulting in the release of radioactive material to the surrounding environment	a-e.	Building design using DBE criteria	a-e.	2.8.6, 3.1.7, 3.1.7.5.2	a-e	Seismic monitoring system
	b.	Exhaust Filter Building	b,c,e.	Structural damage resulting in loss of protective systems						
	c.	Mine Exhaust system								
	d.	Waste Hoist								
	e.	CMS Monitoring Room								
4. Tornado	a.	Waste Handling Building	a.	Structural damage resulting in the release of radioactive materials to the surrounding environment	a-d.	Building and structural design using DBT criteria	a-d.	3.1.7, 3.1.7.5.1, 3.2.2	a-d.	Meteorological monitoring, severe weather observation
	b.	CMS Monitoring Room	b,c,d.	Structural damage resulting in loss of protective system						

Table 1A.1-2
SUMMARY OF RADIOLOGICAL HAZARDS

HAZARD	SYSTEM/STRUCTURE AFFECTED	CONSEQUENCE	MITIGATING ACTION	REFERENCE	MONITORING/SURVEILLANCE SYSTEMS
	c. Exhaust Filter Building d. Mine Exhaust System				
5. Fire	a. Waste Handling Building	a-c. Structural damage resulting in the release of radioactive material to the surrounding environment and the release of contaminated fire waste water, release of smoke carrying radioactive particulates	a-c. Fire water containment system to retain water possibly contaminated, HEPA filter system to remove radioactive material from internally generated smoke	a-c. 4.4.1.1	a-c. Fire detection/suppression system
	b. Waste Hoist c. Underground				c. Effluent monitoring system a-c. Radiation monitoring system a-c. Liquid waste surveillance procedures
6. Loss of Commercial Power	a. Waste Handling Building	a,b. Loss of ventilation and negative pressure and dynamic containment systems in WHB and storage areas	a-c. Emergency power (both UPS and EPS) in crucial operations	a-c. 5.5.3, 4.4.2	a,b,c. Generator tests, UPS tests, Power monitoring at CMS
	b. Exhaust Ventilation System c. CMS Control Room	b,c. Loss of protective systems			
7. Fall of TRUPACT II from: Truck, Forklift Dock	a. RCA	a,b. Cause rupture of TRUPACT II releasing contents	a,b. TRUPACT II designed to withstand 30 ft fall as per DOT Type B design, primary confinement barrier (drums) failure independent of TRUPACT failure	a,b. 4.5.1.2, 3.3.1.2.1, 3.3.1.2.2	a. No credible release
	b. Waste Handling Building				b. Radiation monitoring system

Table 1A.1-2
SUMMARY OF RADIOLOGICAL HAZARDS

HAZARD	SYSTEM/STRUCTURE AFFECTED	CONSEQUENCE	MITIGATING ACTION	REFERENCE	MONITORING/SURVEILLANCE SYSTEMS
8a. Failure of overhead crane-CH	a. Waste Handling Building	a. Drop seven-pack configuration causing rupture of waste drums and release of radioactive material in WHB	a. Crane designed using DBE criteria. WHB design to contain contaminates within RMA.	a. 3.2.6.2.3, 3.3.1.2.3	a. Radiation monitoring system
8b. Failure of overhead crane-RH cask	a. Waste Handling Building	a. Rupture of cask and canister causing release of radioactive material to WHB	a. Failure unlikely since RH shipping cask designed to meet NRC requirements, WHB designed to contain contamination	a. 4.5.2.1, 4.5.2.5	a. Radiation monitoring system
8c. Failure of overhead crane RH-canister	a. Waste Handling Building	a. Rupture of canister causing release of radioactive material	a. WHB designed to contain contamination	a. 4.5.2.2	a. Radiation monitoring system
9. Waste Hoist Failure	a. Waste Hoist b. Underground	a,b. Drop of waste down shaft causing rupture of containers and release of radioactive materials	a,b. Hoist design using multiple cable system, and automatic braking system	a,b. 4.3.1.2.1	a,b. Catastrophic waste hoist failure not credible
10. Breach of CH container	a. Waste Handling Building b. Waste Hoist c. Underground	a-c. Release of radioactive material and suspension of material in air	a-c. Secondary confinement barriers contain contamination, dynamic confinement barriers prevent contamination from travelling to the outside environment by way of exhaust air	a-c. 4.4.1, 3.3.1.2.2, 3.3.1.2.3	a-c. Radiation monitoring system b,c. Effluent monitoring system
11. Criticality	a. Waste Handling Building b. Underground	a,b. Fissile material in quantity and configuration to result in accidental criticality	a,b. Waste Acceptance Criteria eliminates possibility of configuration necessary for criticality	a,b. 5.5.2, 3.3.5, 3.3.5.1	a,b. WAC certifications process to ensure no possibility of criticality

Table 1A.1-2
SUMMARY OF RADIOLOGICAL HAZARDS

HAZARD	SYSTEM/STRUCTURE AFFECTED	CONSEQUENCE	MITIGATING ACTION	REFERENCE	MONITORING/SURVEILLANCE SYSTEMS
12. **Snow Loads**	a. Waste Handling Building b. Exhaust Filter Building c. Underground ventilation ducting	a-c. Loss of containment structure	a-c. Maximum expected snow load in design basis	a-c. 3.2.7	a-c. Severe weather monitoring

1A.2 RADIOLOGICAL IMPACT OF NORMAL OPERATION

The radiation protection program of the WIPP facility has been implemented to minimize the impact of radiation to the general public and to the workers. This is accomplished through implementation of Order DOE 5480.11 and through efforts to maintain exposures as low as reasonably achievable (ALARA). The radiation control program includes the following:

- Personnel receive a level of radiation protection training appropriate to their assignments
- Appropriate access control techniques are used
- A respiratory protection program is in place
- Radiation areas are segregated and appropriately posted so that radiation exposure to workers is limited
- Instruments and equipment are properly calibrated so that accurate radiation, contamination, and airborne activity surveys can be performed
- Appropriate personnel dosimetry devices are supplied, and a radiation exposure record system is maintained
- An internal dose-assessment program (whole-body counting and bioassay) is in place
- Shipments of radioactive material are handled in accordance with Waste Acceptance Criteria (WAC) limitations, Department of Transportation (DOT) regulations, and internal operating procedures
- Effluent and environmental monitoring programs are in place to verify that releases to the environment are ALARA and not accumulating in biological media within the limits discussed in Order DOE 5480.11
- Building and structures are designed to minimize radiation exposures by providing contamination containment and shielding features
- Operational procedures are implemented which minimize exposure
- Potentially contaminated ventilation air is filtered by high efficiency particulate air (HEPA) filters

Radiological impacts associated with normal operations have been assessed. The steps involved in performing this assessment include:

- Determination of design criteria
- Determination of sources of radiation exposure
- Determination of a radiation exposure source term
- Calculation of radiological impacts

1A.2.1 RADIOLOGICAL EXPOSURE DESIGN CRITERIA

It is the goal of the WIPP Project staff to keep occupational exposures below the 1 rem per year per person design dose objective. This goal of keeping radiation exposures ALARA is accomplished through the implementation of administrative programs and procedures in accordance with Order DOE 5480.11 and DOE exposure guidance found in DOE/EV/1830-T5. These programs and procedures are contained in the WIPP Radiation Safety Manual, WP 12-5; Waste Handling Operations Manual, WP 05-1; and the Radioactive Mixed Waste Compliance Plan, WP 02-7.

The design goal of the WIPP Radiation Protection Program with regard to public exposures is to maintain exposures as far below the exposure guidelines established in 40 CFR Part 191 (Subpart A) and Order DOE 5480.11, as reasonably achievable. This is accomplished by continuously monitoring airborne effluents from the plant and implementing administrative procedures that preclude the release to the atmosphere of quantities of radioactivity that would pose a threat to the public. Administrative procedures covering the operation of the facility and systems that preclude releases include the Facility Operations Manual, WP 04-1; Waste Isolation Pilot Plant Procedure Manual; and the Environmental Procedures Manual, WP 02-3.

1A.2.2 SOURCES OF RADIATION EXPOSURE

The sources of radiation exposure at the WIPP facility, during normal operations, are limited to the CH TRU and RH TRU waste that will be handled at the facility. Radiation exposure for workers can be in the form of either direct exposure or inhalation of contaminated particulate. Areas within the facility where this exposure could occur include the Waste Handling Building (WHB) and the Underground Storage Areas.

The only radiation exposure pathway to the general public as a result of operations at the WIPP is through a release to the atmosphere of particulate contaminated with radioactivity. These airborne emissions could originate in either the WHB or the Underground Storage Areas.

Ventilation air discharged from the WHB is continuously passed through two stages of HEPA filters prior to discharge. This filtration system has a calculated decontamination factor of 10^{-6}. Details of the HEPA ventilation system are presented in Section 4.4.1.

Ventilation air from the WIPP facility underground areas is not continuously filtered. Instead, the air stream is continuously monitored by a Continuous Air Monitoring (CAM) system that is set to alarm when radiation in the air stream exceeds predetermined set points. Under an alarm condition, ventilation flow is reduced from the rate of 425,000 cfm to 60,000 cfm and diverted through the Exhaust Filter Building (EFB). The HEPA filters in this building have a calculated decontamination factor of 10^{-6}.

1A.2.3 RADIATION EXPOSURE SOURCE TERMS

Radiation source terms have been developed to quantify possible radiation exposures from both direct and airborne radiation sources.

1A.2.3.1 Direct Radiation Sources

The direct radiation sources that are the bases for shielding design are categorized as CH TRU waste and RH TRU waste. Other sources of radiation may include in-plant generated solid or liquid radwaste having radiation levels that are much lower than those of the CH TRU waste; consequently, permanent shielding is not required for the plant-generated waste areas. The source terms described for direct radiation analysis use maximum expected values and conservative assumptions to ensure a conservative basis for radiation shielding design.

The 55-gallon drum is used as the reference CH TRU waste radiation source for shielding analysis because the anticipated activity loading is higher than standard waste boxes. The CH TRU waste source container used for this analysis is 24 inches in diameter and 35 inches high. These containers are stacked two high during handling and three high for emplacement. With regard to the CH TRU wastes, the primary radiation of interest in shielding calculations are gamma rays. Alpha and beta particles within the waste container are essentially shielded by the waste containers themselves and do not contribute to the external dose. For calculations, a spectrum representing typical waste containing TRU nuclides and fission products was derived. The average gamma source strength used in the CH TRU calculations for design purposes (drums and boxes) is 10 mrem/h. Current estimates indicate that the actual average surface dose rates expected for CH TRU workers will be less than 5 mrem/h for standard waste boxes and approximately 14 mrem/h for drums.

The radiation source geometries used for shielding design for RH TRU waste calculations are a cylinder 26 inches in diameter and 121 inches long. The neutron dose rate is much smaller than the gamma dose rate. Thus, gamma source strengths have been primarily used for shielding calculations. The rationale for this assumption is presented in Section 6.1.2.1. The effectiveness of all shielding, from the standpoint of neutron sources, has been reviewed.

1A.2.3.2 Airborne Radiation Sources

Concentrations of airborne radioactive materials that may exist and that could be encountered in areas accessible to personnel during normal operations are the CH TRU waste handling area and the underground storage areas. In these areas the estimated release rate is based on a resuspension mechanism whereby contamination on the surface of the container is suspended in the room air. The calculated concentration of airborne radioactivity is based on experimental measurements of plutonium resuspension from contaminated surfaces and considers the following factors:

- Waste volume fraction (by generator)
- Number of containers received annually
- Container surface area
- Resuspension fraction
- Radionuclide distribution
- Surface contamination

The airborne radioactivity concentrations in the RH TRU waste handling and storage areas have been bounded by assuming that 10 percent of the RH TRU canisters handled at the WIPP facility each year (250 canisters per year) are contaminated to the levels indicated in Chapter 6. The amount of airborne activity that results is estimated using a similar approach to that used for CH TRU waste.

Sources for the calculation of doses to the public are developed by incorporating the exhaust stack features into the estimates of airborne radioactivity from CH TRU and RH TRU waste handling and storage activities. This includes the operation of the HEPA filtration system for the WHB.

1A.2.4 CALCULATION OF RADIOLOGICAL IMPACTS OF NORMAL OPERATIONS

1A.2.4.1 On-Site Doses

Radiological impacts during normal operations have been estimated for the primary occupationally exposed groups involved in waste handling operations at the WIPP facility. The results are representative values, determined by estimating dose rates based on shielding analyses, the characterizations of the waste forms, time and motion/manpower studies for the handling of the waste, and the estimated quantities of waste received. The time and motion/manpower information used is based on the current concept of staffing levels and the organization planned for WIPP facility operations.

For the calculation of external radiation impacts the following items are used in the analysis:

- The average dose rate for CH TRU waste drum is 14.0 mrem/hr at four inches from the surface and for the standard waste box (SWB) is estimated to be 5 mrem/hr.
- The average dose rate for RH TRU waste transport casks and RH TRU facility cask is estimated to be 2.0 mrem/hr at four inches from the cask surfaces

The number of people who could receive radiation exposure in a given area is estimated based on projected manpower studies for occupationally exposed groups considered in the dose assessment. In unshielded areas, estimated exposure rates are based on the dose rates from waste containers and the expected range of distances between radiation sources and personnel. For shielded areas, e.g., immediately outside the hot cell, the exposure rate is conservatively estimated from shielding analyses that consider effectiveness using experimental waste as the design source.

Airborne contaminants can also contribute to the personnel dose and estimates of these annual doses have been made for the affected body organs. The number of people and their expected exposure are estimated based on projected facility operations.

The resultant radiological impacts are shown in Table 1A.2-1. For comparison the applicable radiation protection standards from Order DOE 5480.11 are also provided in this table.

1A.2.4.2 Off-Site Doses

The estimated doses resulting from the normal operation of the WIPP facility are calculated for a hypothetical individual assumed to be living at the WIPP Site Boundary, an area where the received exposure would be higher than for any other member of the general population. Doses are also estimated for the total population within a 50-mile radius of the WIPP facility as a result of normal operating releases.

The AIRDOS-EPA computer code was used to estimate the radiation dose impacts to the general public resulting from the atmospheric releases of radionuclides from the WIPP facility. The code is capable of evaluating continuous releases from as many as six different area or point sources. In general, the code estimates: (1) concentrations of radioactivity in air, (2) rates of deposition on ground surfaces, (3) ground surface concentrations, (4) intake rates by man via food ingestion and air inhalation, and (5) radiation dose received by an adult receptor. The option is provided in the code to calculate either a maximum individual dose or the total dose to an exposed population.

For the purpose of these calculations, the area surrounding the WIPP site facility was modeled as a 50-mile radius circular grid system with the WIPP facility located at the center. Site specific meteorological data typical of annual average conditions are used by the code.

Using the ground-level concentrations in air and ground deposition rates computed from the meteorological input, the code estimates intake rates at specified environmental locations and calculates the resultant doses through various modes of exposures. The modes of exposure include the following pathways: (1) immersion in air, (2) exposure to ground surfaces contaminated by deposited radionuclides, (3) immersion in water such as by swimming in a backyard pool, (4) inhalation of contaminated air, and (5) ingestion of food produced on contaminated land. The total dose to each of the following organs was calculated: total body, lungs, red bone marrow, lower large intestine wall, kidneys, liver, endosteal cells, and thyroid. The doses calculated are 50-year dose commitments resulting from a one-year exposure at the calculated concentrations.

The inhalation factors are based on the International Commission on Radiological Protection (ICRP) Task Group Lung Model, which simulates the behavior of particulate matter in the respiratory tract. The inhalation factors used correspond to activity mean aerodynamic diameters (AMAD) of 0.3, 1.0, and 5.0 microns.

For the calculation of population dose, the population data, agricultural and water intake area assumptions, and beef and dairy cattle data that are specific to the area surrounding the WIPP facility were developed.

The estimated radiological impacts to the public due to normal operations are estimated in Table 1A.2-2.

The results of the dose calculations reported in Table 1A.2-2 serve as a prediction that the WIPP facility will be operated in compliance with the release standards of 40 CFR 191 Subpart A and 40 CFR 61 Subpart H. Once operations begin, actual measurements will be used to report releases.

The parameters used in calculating the dose to the maximally exposed individual are substantially the same as those used in calculating the population dose except that the location of the maximally exposed individual is at the point of highest concentration deposition beyond the WIPP Site Boundary, as determined from site-specific average meteorological conditions.

1A.2.4.3 Summary of Exposure to Hazardous Wastes

An assessment of the potential for occupational and public exposure to hazardous wastes during the operational phase of the WIPP facility is provided. This assessment considers potential release scenarios that may arise during routine operations.

Environmental consequences of possible releases of hazardous chemicals destined for transportation to and emplacement in the WIPP facility are analyzed through a process of risk assessment. Risk assessment is a method of determining the likelihood and extent of adverse consequences to human health and the environment posed by certain activities or events. This section addresses the general methodology used to assess the potential risks posed by the hazardous chemical waste constituents.

In this assessment, hazardous chemicals available for release are predominantly volatile organic gases. The only pathway of concern for exposure and risk from such releases is airborne diffusion and inhalation. The highest air concentration at the WIPP Site Boundary was approximately four orders of magnitude below the minimum detection limit using EPA standard methods. Due to the low air concentrations, the relative insolubility of these chemicals and their tendency to break down in the atmosphere, ingestion exposure from scavenging and deposition of contaminated particles is considered very minor and without significant risks. This pathway is not evaluated. There is little probability that liquids will be released, as only residual liquids are allowed in the waste, and potential pathways for liquids released in ground or surface water are nonexistent.

Metals, such as lead, will be present in the waste. Since the primary source of the lead is shielding, the metal will be present largely as monolithic solid lead rather than particulates. Thus, no routine pathway for exposure to lead particulates is examined. There is the potential for lead to be melted, volatilized at its vapor pressure, and inhaled either in a vapor or a recondensed particulate form. This inhalation pathway is evaluated for severe accidents involving fires.

Because of the types of hazardous chemicals and the physical waste forms associated with the chemical component of RH TRU waste, no release of hazardous chemicals during routine operations or accidents are postulated. RH TRU mixed waste does not contain RCRA-regulated volatile organic compounds. Similar to CH TRU mixed waste, the predominant metal is lead that is present primarily as shielding.

To provide estimates of the potential occupational exposures during underground operations, a hypothetical worker is assumed to be present in a storage chamber for an entire eight-hour shift each workday. This worker was assumed to be exposed to the emissions of 6,000 drums per year. The exposure was based on a room volume of 3,600 m^3 and an air velocity of 0.4 m/s.

To provide estimates of potential exposure to an aboveground worker, a hypothetical receptor is placed at the maximum on-site concentration points as predicted by the air dispersion modeling of underground and aboveground releases. The worker is assumed to remain at that location for the duration of the eight-hour shift.

This exposure model is conservative since airflow in waste chambers will place workers upstream of the face of the storage stack. Table 1A.2-3 gives the estimated air concentrations and maximum daily does of each hazardous chemical for aboveground and belowground workers during routine operations. Health risks associated with these exposures are given in Tables 1A.2-4 and 1A.2-5.

Potential exposures to hypothetical residential populations in the WIPP facility area are calculated based on the highest predicted ground level concentrations at the WIPP Site Boundary. Exposures are modeled as outlined above.

Table 1A.2-6 gives the estimated concentrations in air of hazardous chemicals from aboveground and belowground operations for the hypothetical residential receptor location. The maximum estimated daily intakes for each chemical is also provided in Table 1A.2-6.

Table 1A.2-1

ON-SITE ANNUAL DOSE ESTIMATES DUE TO NORMAL OPERATIONS

DOSES DUE TO DIRECT RADIATION:

ACTIVITY	AVERAGE INDIVIDUAL DOSE rem/person/year
CH TRU WASTE HANDLING	0.68
RH TRU WASTE HANDLING	0.12

DOSES DUE TO AIRBORNE RADIOACTIVITY:

ORGAN CONSIDERED	COMMITTED EFFECTIVE DOSE EQUIVALENT rem/person/50 years
Total Body	0.37
Bone	6.42
Lung	0.85
Liver	1.41

RADIATION PROTECTION STANDARDS - DOE ORDER 5480.11:

Stochastic Effects	5 rem (annual effective dose equivalent)
Non-Stochastic Effects	
Lens of eye	15 rem (annual dose equivalent)
Extremity	50 rem (annual dose equivalent)
Skin of the whole body	50 rem (annual dose equivalent)
Organ or tissue	50 rem (annual dose equivalent)
Unborn Child	
Entire gestation period	0.5 rem (annual dose equivalent)

Table 1A.2-2

RADIOLOGICAL IMPACT ON THE PUBLIC DUE TO NORMAL OPERATIONS

ADULT MAXIMUM INDIVIDUAL	COMMITTED EFFECTIVE DOSE EQUIVALENT (rem)
TOTAL	1.7E-06
BACKGROUND	0.1

POPULATION*	COMMITTED EFFECTIVE DOSE EQUIVALENT (person-rem)
TOTAL	5.3E-04
BACKGROUND	1.13E+04

* Based on population data in Table 2.1-2.

Table 1A.2-3

ROUTINE RELEASES AND OCCUPATIONAL EXPOSURES

	ABOVEGROUND OPERATIONS	
CHEMICAL	CONCENTRATION AT ABOVE GROUND RECEPTOR ($\mu g/m^3$)	ESTIMATED MAXIMUM DAILY DOSE (mg/kg/day)[a]
1,1,1-Trichloroethane	4.5E-07	1.0E-10
Carbon Tetrachloride	5.9E-07	1.0E-10
1,1,2-Trichloro-1,2,2-Trifluoroethane	3.5E-07	6.0E-11
Methylene Chloride	2.0E-06	3.4E-10
Trichloroethylene	2.4E-07	4.1E-11
	UNDERGROUND OPERATIONS	
CHEMICAL	CONCENTRATION AT UNDERGROUND RECEPTOR ($\mu g/m^3$)	ESTIMATED MAXIMUM DAILY DOSE (mg/kg/day)[b]
1,1,1-Trichloroethane	6.5	1.1E-02
Carbon Tetrachloride	8.5	1.5E-05
1,1,2-Trichloro-1,2,2-Trifluoroethane	5.0	8.6E-04
Methylene Chloride	2.9	4.9E-04
Trichloroethylene	3.5	5.9E-04
	UNDERGROUND OPERATIONS	
CHEMICAL	CONCENTRATION AT ABOVEGROUND RECEPTOR (μg/m3)	ESTIMATED MAXIMUM DAILY DOSE (mg/kg/day)c
1,1,1-Trichloroethane	1.6E-03	2.8E-07
Carbon Tetrachloride	2.1E-04	3.6E-08
1,1,2-Trichloro-1,2,2-Trifluoroethane	1.3E-04	2.2E-08
Methylene Chloride	7.2E-04	1.2E-07
Trichloroethylene	8.7E-05	1.5E-08

[a] Estimated daily dose is based on exposure to a constant 42 drum equivalent

[b] Estimated daily dose is based on exposure to a constant 6,000 drum equivalents

[c] Estimated daily dose is based on exposure to 17,600 drum equivalents per year up to a maximum of 88,000 drum equivalents after five years and a subsequent 6,000 drum equivalents for the remaining 20 years of operations.

Table 1A.2-4

MAXIMUM INCREMENTAL LIFETIME EXCESS CANCER RISKS FOR ROUTINE RELEASES OVER 25 YEARS

	RECEPTORS		
	Residential	Aboveground Occupational	Underground Occupational
I. Aboveground Operations			
Carbon Tetrachloride	1.6E-12	1.0E-12	NA
Methylene Chloride	6.0E-13	3.9E-13	NA
Trichloroethylene	6.6E-14	4.2E-14	NA
II. Underground Operations			
Carbon Tetrachloride	9.4E-10	1.1E-10	2.0E-06
Methylene Chloride	3.5E-10	4.5E-10	7.4E-07
Trichloroethylene	3.3E-11	3.9E-11	6.0E-08

Table 1A.2-5

MAXIMUM HAZARD INDICES FOR NONCARCINOGENIC CHEMICALS FROM ROUTINE RELEASES

	RECEPTORS		
	Residential	Aboveground Occupational	Underground Occupational
I. Aboveground Operations[a]			
1,1,1-Trichloroethane	4.2E-11	1.2E-10	NA
1,1,2-Trichloro-1,2,2-Trifluoroethane	6.8E-13	2.0E-12	NA
II. Underground Operations[b]			
1,1,1-Trichloroethane	8.0E-08	4.3E-07	1.8E-03
1,1,2Trichloro-1,2,2-Trifluoroethane	1.2E-09	7.0E-09	2.9E-05

[a] Hazard Index = $\frac{\text{Estimated daily intake based on 42 drum equivalents}}{\text{Acceptable Intake for Chronic Exposures}}$

[b] Hazard Index = $\frac{\text{Estimated daily intake based on 16,000 drum equivalents per year up to 88,000 drum equivalents after five years}}{\text{Acceptable Intake for Chronic Exposures}}$

Table 1A.2-6

ROUTINE RELEASES AND RESIDENTIAL EXPOSURES

CHEMICAL	ABOVEGROUND OPERATIONS CONCENTRATION AT HYPOTHETICAL RESIDENTIAL RECEPTOR ($\mu g/m^3$)	ESTIMATED DAILY DOSE (mg/kg/day)[a]
1,1,1-Trichloroethane	9.3E-07	2.7E-10
Carbon Tetrachloride	1.2E-07	3.5E-11
1,1,2-Trichloro-1,2,2-Trifluoroethane	7.2E-08	2.1E-11
Methylene Chloride	4.1E-07	1.2E-10
Trichloroethylene	5.0E-08	1.4E-11

CHEMICAL	UNDERGROUND OPERATIONS CONCENTRATION AT THE HYPOTHETICAL RESIDENTIAL RECEPTOR (μg/m3)	ESTIMATED DAILY DOSE (mg/kg/day)[b]
1,1,1-Trichloroethane	1.8E-04	5.2E-08
Carbon Tetrachloride	2.4E-05	6.8E-09
1,1,2-Trichloro-1,2,2-Trifluoroethane	1.4E-05	4.0E-09
Methylene Chloride	8.1E-05	2.3E-08
Trichloroethylene	9.7E-06	2.8E-09

[a] Estimated daily dose is based on continuous exposure to 42 drum equivalents

[b] Estimated daily dose is based on continuous exposure to 16,000 drum equivalents per year up to a total of 88,000 drum equivalents after five years and a subsequent 6,000 drum equivalents for the remaining 20 years of operations.

1A.4.3 DOSE CALCULATION MODELS

Doses to individuals located inside the facilities from an accidental release of radioactivity occur via three major pathways: inhalation of contaminated air, external exposure resulting from immersion in contaminated air, and exposure to contaminated ground surfaces. Lesser pathways for the radionuclides under consideration involve ingestion of contaminated food and water and immersion in contaminated water.

For all accidents, the exposed individuals outside the facility were assumed to remain at the location of maximum exposure for the duration of the accident. Simplified meteorological conditions were used that would result in the highest calculated dose at each of the locations. These meteorological conditions were assumed to last for the duration of the accident.

The AIRDOS-EPA computer code[2] was used to estimate the radiation dose to man resulting from the atmospheric release of radionuclides from the WIPP facility. The code estimates: (1) concentrations of radioactivity in air, (2) rates of deposition on ground surfaces, (3) ground surface concentrations, (4) intake rates by man via food ingestion and air inhalation, and (5) radiation dose received by an adult receptor. For the purpose of these calculations, the area surrounding the site was modeled as an 80-kilometer (50-mile) radius circular grid system with the release point, either the Waste Handling Building (WHB) stack or the Exhaust Filter Building stack, located at the center.

1A.4.4 DOSE IMPACTS DUE TO ACCIDENTS

As part of the accident analysis, each accident scenario is described briefly and the extent of damage to the waste container involved and the amount of activity released as a result of the accident are postulated. Since many factors interact to affect the amount of activity released and subsequently available for inhalation, it was necessary to develop assumptions that represent realistic but still conservative estimates from available data. Dose assessments were made for each accident scenario presented. Doses to individuals located outside the secured area boundary (members of the public) are tabulated in Table 1A.4-3. The doses to individuals located on the site (occupational workers) are presented in Table 1A.4-4.

1A.4.5 RISK ASSESSMENT

Fault Tree Analyses and Failure Mode Effect Analyses (FMEA) were performed on selected critical systems within the WIPP facility. The systems evaluated were: the Waste Hoist Hydraulic Brake System, the Construction and Salt Handling Hoist Pneumatic Brake System, and the contact handled portions of the Waste Handling and Exhaust Filter Buildings HVAC Systems.

These studies evaluated the effects of system failures on the protection systems for personal injury, release of radioactive materials, extended loss of functional capabilities, or damage to other equipment.

Background data and information for the Fault Tree Analyses were obtained by conducting walkdowns of the facility, interviews with operators, and a review of operating and maintenance histories. The fault tree work was performed using the Westinghouse GRAFTER code system. A living model of each system studied was created on a personal computer. This permits requantification of the system when changes to the hardware are made, or operational failure rate data becomes available.

1A.3 RADIOLOGICAL IMPACT OF ABNORMAL OPERATIONS

Radiological impacts of abnormal operations have been assessed. These impacts are limited to occupational doses since the only abnormal operations identified for the WIPP facility occur in areas where ventilation air is continuously filtered. Accidents that have been postulated for the WIPP facility are not included in the category of abnormal operations.

Abnormal operations include tasks such as cask and waste container decontamination and repair. It is conservatively assumed for purposes of assessing radiological impacts that 1 percent of RH shipping casks require external decontamination and 1 percent of the CH TRU containers are damaged or contaminated to the extent that decontamination or overpacking is required. External radiation dose to personnel for each abnormal operational activity is shown in Table 1A.3-1.

In the CH TRU waste overpack and repair room, the estimated airborne radioactivity concentrations are based on an assumed release of CH TRU waste from damaged containers. The release of airborne radioactivity in areas accessible to personnel is reduced by providing additional containment for damaged containers and operational procedures to minimize the exposure of operators to airborne radioactivity. The concentrations of airborne radioactivity in this area are based on the estimates of radionuclide release rates into the ventilation flow using conservative assumptions.

The estimated total dose to the personnel working in the CH overpack and repair room is presented in Table 1A.3-1. It is assumed that some RH casks may arrive at the WIPP facility containing external contamination levels that exceed the limits in the Waste Acceptance Criteria but within the Department of Transportation (DOT) limits.

The dose to those workers responsible for cask decontamination is calculated. The estimated total dose to the workers responsible for cask decontamination is reported in Table 1A.3-1.

References for Section 1A.4

1. Westinghouse Electric Corporation TME-069, Rev 2, WIPP Waste Acceptance Criteria, Carlsbad, NM, October, 1985.

2. R. E. Moore, et al., AIRDOS-EPA Estimation of Radiation Doses Caused by Airborne Radionuclides in Areas Surrounding Nuclear Facilities, ORNL-5532 (June 1979).

Table 1A.3-1

SUMMARY OF ESTIMATED DOSES DUE TO ABNORMAL OPERATIONS AT THE WIPP FACILITY

ABNORMAL OPERATING ACTIVITY	ANNUAL EXTERNAL DOSE PERSON-REM/Y
CH TRU WASTE HANDLING	0.11
RH CASK DECONTAMINATION	0.03

1A.4 ACCIDENTS

Accidents that may occur during the handling of radioactive waste in the WIPP facility were analyzed. The postulated accident scenarios were developed from a thorough review of waste handling operations and past experience at other facilities. Each accident is assigned a category according to its expected frequency of occurrence. Furthermore, accidents are grouped according to waste types (CH TRU or RH TRU) and their frequency category. Releases to the environment are determined for each postulated accident. For those events where radioactivity was postulated to be released into the work area, dose assessment calculations were performed to estimate the occupational dose commitment. Effective whole-body dose commitments were calculated for what are considered to be three hypothetical maximum individuals. These include a person at the worst location beyond the security fence, a person living at the WIPP Site Boundary, and a person living at the nearest residence (Mills Ranch).

A typical scenario of an accident releasing waste includes the following events:

- A breach of the waste container
- Exposure of a portion of the waste to the air
- Suspension of a portion of waste that is of respirable size in ventilation air
- Depletion or fallout of waste particles from the airstream where such processes are credible
- Release to the environment
- Dispersion of the airborne radioactivity and calculation of the resultant air concentrations and doses
- Cases where the worker could be exposed, dose commitments are calculated for the worker

1A.4.1 CLASSIFICATION OF ACCIDENTS

Accident scenarios for the WIPP facility were developed and are tabulated in Tables 1A.4-1 and 1A.4-2 along with their estimated frequency.

Incidents of moderate frequency are those that are assumed to occur once a year. Infrequent incidents are those that are assumed to occur once during the operation of the plant. Limiting incidents are those that are not expected to occur during the life of the facility but are included in the analysis since they yield the maximum credible release of radioactivity. Accidents whose annual probability of occurrence is less than 10^{-6} per year are considered not credible consistent with Order DOE-AL 5481.1B. The consequences of such events are not assessed herein.

1A.4.2 SOURCE TERMS

The source terms used in the analyses were based on waste content information. For events of moderate frequency, those assumed to occur once per year, the average waste package radioactivity content is assumed. For less frequent events, the assumed waste package radioactivity content is based on the overall likelihood of the accident scenario.

Based upon the WIPP Waste Acceptance Criteria (WAC)[1], the maximum amount of respirable radioactive particulates (those less than 10 microns in diameter) is limited to one weight-percent of a waste container content. This respirable fraction is assumed to contain five percent of the radioactivity within the waste.

The following paragraphs are a synopsis of this work.

WASTE HOIST HYDRAULIC BRAKE SYSTEM - For the present system configuration, a catastrophic hoist accident was calculated to occur at a mean time of once every 1000 years. The specific brake system annual probability of failure was calculated to be 2.7E-02. Since this is a relatively high value, sensitivity studies were conducted to determine how the brake system could be made more safe. A number of options were developed. As a result of the incorporation of improvements to the Waste Hoist Hydraulic Brake system no undue safety hazards exist with the Waste Hoist Hydraulic Brake System. Appendix 7B provides additional information concerning this analysis.

SALT HANDLING (SH) HOIST PNEUMATIC BRAKE SYSTEM - The results of the analysis showed that the probability of a catastrophic accident (a skip crashing into the bottom of the shaft or top headframe) is less than once every million years of operation (8.8E-07)/yr. This is a very low probability and is within the guidelines of Order DOE-AL 5481.1B, which states "any event with a probability of less than 1.0E-06/yr is deemed extremely improbable or not credible."

The low probability of a catastrophic accident at the Salt Handling Hoist is due to a very robust and conservatively designed brake system coupled with a modern process control system.

VENTILATION SYSTEMS - WASTE HANDLING BUILDING AND UNDERGROUND BUILDINGS- In order to assess the safety aspects of the ventilation systems in the event of a release of radioactive material, a Fault-Tree Analysis and FMEA were performed on the ventilation filtration system in the Exhaust Filter Building (EFB) and HVAC system in the WHB. The Fault Trees modeled the systems major systems components and operations. The FMEA summarized the findings of the Fault Tree Analysis and added insight to the effects on system operations and personnel safety.

The overall unavailability of the EFB System was calculated to be 1.8E-04 per release event given that a measurable release of hazardous material occurred. This in itself is a very low probability. Two single failures (relay failures) were identified that could cause a release of hazardous material.

The overall unavailability of the WHB HVAC was calculated to be 1.4E-04 per release event - given that a measurable release of hazardous material occurred. No single failure would lead to a measurable release to the environment. Major contributors to these multiple failure sequences included door seal leakage, solenoid valve failure, and operator error.

1A.4.6 SUMMARY OF ACCIDENTAL RELEASES AND EXPOSURES TO HAZARDOUS WASTES

The accident scenarios for hazardous chemical releases and exposures are the same as those discussed for radiological exposures. The methodology and overall approach to modeling risks associated with chemical releases is described in Section 6.1.7. In modeling hazardous chemical releases, it is assumed that all volatile organics in the headspace gas are released instantaneous, if a drum is breached. Accident scenarios, releases and exposures are summarized in Table 1A.4-5. The accident scenarios are assumed to involve potential exposures only to the occupational population because all accidents occur either in the WHB or underground. No significant public exposures are expected to occur due to the initial low concentrations released and the subsequent dilution as a function of distance. The exposures are assumed to occur for a period of 15 seconds, consistent with the 25 cm/s air flow rate in the WHB. Underground exposure duration is also assumed to be 15 seconds, although airflow rate is predicted to be 0.4m/s. This 15-second exposure duration is consistent with radiological occupational exposure calculations.

Table 1A.4-1

ACCIDENT SCENARIOS INVOLVING CONTACT HANDLED TRU WASTE

Area	Accident ID	Estimated Frequency	Possible Accident Scenario
Radiological Control Area Outside of WHB	C0	MF	Forklift knocks TRUPACT II from trailer
Offloading/Loading	C1	MF	Vehicle collision in offloading area
Inventory/Preparation	C2	MF	Drum drops from forklift
	C3	MF	Drum punctured by forklift
Underground Storage	C4	MF	Transporter hits pallet
	C5	MF	Drums drop from forklift
	C6	MF	Other equipment punctures drums
Inventory/Preparation	C7	LIM (NC)	Spontaneous ignition within a drum
Hoist Loading Area	C8	LIM (NC)	A loaded hoist cage drops down Waste Shaft
Underground Storage	C9	LIM (NC)	Diesel fire in storage array underground
	C10	LIM	Spontaneous ignition within a drum

MF - Moderate Frequency

INF - Infrequent

LIM - Limiting

NC - Not Credible

Table 1A.4-2

ACCIDENT SCENARIOS INVOLVING REMOTE HANDLED TRU WASTE

Area	Accident ID	Estimated Frequency	Possible Accident Scenario
Receiving	R1	MF	Crane strikes shipping cask
	R2	INF	Shipping cask drops from crane
	R3	INF	Shipping cask drops in the cask preparation area
Hot cell	R4	INF	RH waste canister drops from hot cell into transfer cell
Hoist cage loading area	R5	LIM (NC)	A loaded hoist cage drops down waste handling shaft with a canister of RH TRU waste
Underground storage	R6	LIM	Fire in RH waste storage area

MF - Moderate Frequency

INF - Infrequent

LIM - Limiting

NC - Not Credible

Table 1A.4-3

DOSE COMMITMENTS TO INDIVIDUALS OFF SITE

Accident	Environmental Release, PE-Ci	Location of Exposure	Committed Effective Dose Equivalent (rem)*
C0	None	-------	-------
C1	None	-------	-------
C2	1.6E-10	Maximum Individual	5.6E-10
		WIPP Site Boundary	4.8E-10
		Mills Ranch	3.5E-10
C3	2.9E-10	Maximum Individual	1.0E-09
		WIPP Site Boundary	8.7E-10
		Mills Ranch	6.4E-10
C4	1.3E-04	Maximum Individual	4.6E-04
		WIPP Site Boundary	3.9E-04
		Mills Ranch	2.9E-04
C5	**	-------	-------
C6	2.3E-04	Maximum Individual	8.1E-04
		WIPP Site Boundary	6.9E-04
		Mills Ranch	5.1E-04
C7	NC	-------	-------
C8	NC	-------	-------
C9	NC	-------	-------
C10	5.0E-01	Maximum Individual	1.7E+00
		WIPP Site Boundary	1.5E+00
		Mills Ranch	1.1E+00
R1	None	-------	-------
R2	None	-------	-------
R3	None	-------	-------
R4	5.0E-10	Maximum Individual	1.8E-09
	3.3E-10+	WIPP Site Boundary	1.5E-09
		Mills Ranch	1.1E-09
R5	NC	-------	-------
R6	None	-------	-------

* These values derived using AIRDOS-EPA computer code (see Section 7.2.2.1.2)

**Bounded by C4

+Mixed fission and activation products

NC - Not Credible

1A.5.2 CONCLUSIONS WITH REGARD TO STRUCTURES

The WIPP facility is divided into three basic groups of structures: surface structures, shafts, and underground structures. These are described in the following paragraphs.

The WIPP facility surface structures accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of waste from the surface to the underground.

The primary surface operations at the WIPP facility are conducted at the Waste Handling Building (WHB) which is divided into several separate areas: the CH TRU waste handling area, the RH TRU waste handling area, the TRUPACT II maintenance facility, and support areas.

The Exhaust Filter Building (EFB) contains banks of high-efficiency particulate air (HEPA) filters that will be used to filter air from the underground when an alarm condition is indicated. The underground ventilation system fans are located outside, adjacent to this building.

The Support Building provides office space, radiological control laboratories, change rooms, and houses the Central Monitoring System (CMS) computer.

The other surface facilities include the Warehouse buildings, the Guard and Security Building, the Safety and Emergency Services Building, a sewage treatment plant, and other auxiliary buildings.

Salt from the underground mining operations is brought to the surface and stored in the salt pile north of the surface facilities. While stored salt does not pose a threat to human health, it is actively monitored to ensure environmental effects are minimal.

The WIPP facility is composed of four shafts connected to a single underground facility level. The Salt Handling (SH) Shaft provides the only means for removing mined materials from the underground. The Air Intake Shaft (AIS) serves as the primary air intake opening. The Waste Shaft is designed to permit the transport of radioactive waste between the surface waste handling structures and the underground storage area in addition to transport of personnel. The Exhaust Shaft exhausts all air from the underground facility. All four shafts have three principal constituents: a lined section penetrating the rock overburden; an unlined section penetrating the salt; and a key at the rock/salt contact to act as a transition from the lined section to the unlined section.

The storage level contains all of the underground structures for waste handling, waste storage, operations and maintenance. All of the underground horizontal openings are rectangular in cross section except for a small number of experimental openings. The drift configurations range from 8 feet to 13 feet high and 12 feet to 33 feet wide.

A typical storage panel consists of up to seven storage rooms. Each is 33 feet wide, 13 feet high, and 300 feet long. The storage rooms are separated by pillars of salt 100 feet wide and 300 feet long.

As part of the safety analysis for the WIPP facility, Failure Mode and Effects Analysis (FMEAs) were performed for the following:

- Waste Hoist
- Waste Handling Building HVAC System
- Exhaust Filter Building Ventilation System

Table 1A.4-4

DOSE COMMITMENTS TO EXPOSED WORKERS

Accident* +	Committed Effective Dose Equivalent (CEDE) (rem)
C2**	0.7
C3**	1.3
C4	5.2
C6	9.2

* For the accidents not listed, the accident is considered to be either not credible, no release is expected, or no worker is present. See the text for details.

\+ Calculated CEDEs based on average container loading of 12.9 PE-Ci

** Calculated to worker located at 20 feet.

When the RH TRU canister is ready for emplacement, the canister is lifted from the transfer cell into the shielded facility cask. The facility cask is moved to the hoist cage for transfer to the storage horizon. At the storage horizon the facility cask is unloaded from the hoist cage and moved to the storage room. The cask is placed on the emplacement/retrieval machine assembly and the canister is inserted into a horizontal borehole in the room wall. The boreholes will contain liners (sleeves) to facilitate retrieval until the decision is to make the WIPP facility a permanent repository. A shield plug is inserted in the hole to provide radiation shielding.

The retrieval of CH TRU waste if required will be essentially the reverse of the storage operation. The personnel will wear the appropriate protective equipment during this operation and contamination control procedures will be in force, as necessary. Any damaged containers will be overpacked prior to their removal from the contamination control area.

RH TRU waste retrieval requires that the facility cask be placed in alignment with the emplaced canister using the same equipment as used for emplacement. The shield plug is removed, and the canister grappled and drawn into the facility cask. The facility cask is closed and returned to the surface reversing the storage sequence.

FMEAs have been prepared for both the CH and RH TRU waste operations. The conclusion from these FMEAs is that the plant can be operated in a manner that protects the public and the environment and that restricts the radiation dose to operators to as low as reasonable achievable (ALARA). This objective is accomplished through the imposition of operating procedures that reflect the specifications provided in the WIPP Operational Safety Requirements.

Analysis of operator doses indicate that the goal of keeping doses to less than 1 rem/year is achievable for normal operations. Potential accidents that would result from a failure in operations are shown to have no significant impact on the public. This leads to the conclusion that the operations of the WIPP facility are sufficient to protect the health and safety of the public and workers, and to protect the environment.

1A.5.4 CONCLUSION REGARDING LONG-TERM PERFORMANCE

Initial consequence analysis[4] projecting the long-term performance of the WIPP facility showed that no significant consequences were expected to occur for thousands of years and confirmed the favorable characteristics of the site. These initial consequence analyses are summarized in Chapter 8. New standards have promulgated since the completion of the consequence analysis. These standards (40 CFR Part 191) require that the DOE calculate a probabilistic assessment of performance and compare the result to certain standards. This latter activity is still in process as described in Chapter 8. No conclusions can be made at this time as to the ability of the reference design to meet these standards.

Table 1A.4-5

RELEASES, WORKER EXPOSURES, AND ESTIMATED INTAKES FROM PROJECTED ACCIDENTS DURING WIPP FACILITY OPERATIONS

Accident[c]	Chemical	Release (g)	Concentration at Receptor[a] (mg/m^3)	Estimated Intake[b] (mg/exposure)
C2	CCl_4	2.7E - 01	5.8E - 01	1.4E - 02
	MeCl	6.9E - 02	1.5E - 01	3.7E - 03
	TCA	1.9E + 00	4.1E + 00	1.0E - 01
	Freon	1.8E - 01	3.8E - 01	9.5E - 03
	TCE	1.0E - 01	2.2E - 01	5.4E - 03
C3	CCl_4	8.2E - 01	1.7E + 00	4.3E - 02
	MeCl	2.1E - 01	4.4E - 01	1.1E - 02
	TCA	5.8E + 00	1.2E + 01	3.1E - 01
	Freon	5.4E - 01	1.1E + 00	2.9E - 02
	TCE	3.1E - 01	6.5E - 01	1.6E - 02
C4/C5	CCl_4	2.7E - 01	3.3E + 00	2.1E - 02
	MeCl	6.9E - 02	8.3E - 01	5.2E - 03
	TCA	1.9E + 00	2.3E + 01	1.5E - 01
	Freon	1.8E - 01	2.2E + 00	1.4E - 02
	TCE	1.0E - 01	1.2E + 00	7.8E - 03
C6	CCl_4	8.2E - 01	9.8E + 00	6.2E - 02
	MeCl	2.1E - 01	2.5E + 00	1.6E - 02
	TCA	5.8E + 00	7.0E + 01	4.4E - 01
	Freon	5.4E - 01	6.5E + 00	4.1E - 02
	TCE	3.1E - 01	3.7E + 00	2.3E - 02
C10	CCl_4	2.7E - 01	3.3E + 00	2.1E - 02
	MeCl	6.9E - 02	8.3E - 01	5.2E - 03
	TCA	1.9E + 00	2.3E + 01	1.5E - 01
	Freon	1.8E - 01	2.2E + 00	1.4E - 02
	TCE	1.0E - 01	1.2E + 00	7.8E - 03
	Lead	2.7E - 07	4.3E - 08	1.6E - 07

[a] Modeled as a hemispheric cloud expanding at a rate equivalent to the ventilation flow rate in the accident area.

[b] Estimated intakes are based on the formula: Intake = Receptor Conc. x Respiratory Volume x Exposure Period. The transfer coefficient is assumed to be 1.00 for all chemicals. Respiratory volume is assumed to be 12 m^3/work day and the exposure periods are given in Section 7.3.

[c] A detailed description of the accident scenarios is given in Section 7.3.

1A.5 CONCLUSIONS

The Waste Isolation Pilot Plant (WIPP) facility is being developed by the U.S. Department of Energy (DOE) as a research and development facility to demonstrate the safe disposal of radioactive waste from U.S. defense programs. The facility is located in southeastern New Mexico, about 25 miles east of the city of Carlsbad. Underground development is at a depth of about 2,150 feet in thick deposits of bedded salt. The facility operation will include in situ nonradioactive experiments addressing technical issues for defense waste programs and storage of defense related contact handled (CH) and remote handled (RH) transuranic (TRU) waste. In addition, a test plan is being prepared for the first five years of operation of the WIPP facility. This plan will include experiments and evaluations to support compliance activities and operational demonstrations. Details of this program will be available once the test plan is formally issued. This section provides conclusions with regard to the adequacy of the location of the WIPP facility, the WIPP facility itself, and the facilities, and the operations to protect the safety of the public and the workforce and the environment.

1A.5.1 CONCLUSIONS REGARDING THE LOCATION OF THE WIPP FACILITY AND UNDERGROUND DESIGN

Geologic characterization of the location of the WIPP facility began with a literature review and continued with the collection of field data. Special emphasis was placed on correlating data obtained from seismic reflection and resistivity surveys and borehole drilling. Design information regarding stratigraphy for the ground surface to about 250 feet below the underground facility level was developed from geologic data obtained from drill holes and from exploratory and ventilation shafts. The engineering designs for the WIPP surface and underground structures began with the conceptual design, initiated in 1975 and completed in 1977.[1] The conceptual design provided the basis for the development of the preliminary design of both the surface and underground structures, which was completed in January 1980.[2] The preliminary design incorporated the conventional room and pillar method for underground development.

Design of the WIPP facility provided for the access and storage openings to remain stable and provide minimum clearance for equipment during waste emplacement and for an additional ten years, even though these openings will eventually close due to salt creep. Modeling techniques were used to estimate the geomechanical behavior and structural stability of the openings. The preliminary design included numerical modeling of the selected underground opening configurations. These models were used to predict opening closures and augmented other conventional mining industry methods of stability evaluation.

The adequacy of the WIPP facility underground reference design was subjected to a design validation process. Design validation of the WIPP facility was the process by which the reference design of the underground openings was confirmed by determining the compatibility of the design criteria, design bases and reference design configurations using site-specific information. The design validation process consisted of an assessment of the condition and behavior of shafts, drifts and a full-sized, four-room test panel.

Site investigations including the Site and Preliminary Design Validation (SPDV) program, and subsequent design validation activities have led to the conclusion that all design criteria could be met, that the design for the WIPP underground structure is suitable, and that the facility could be used for its intended purpose in a safe manner. Recommended modifications are detailed in the Design Validation Report (DVFR)[3] that were needed to meet all the design criteria. These modifications were necessitated by initial creep rates three to four times higher than expected in the underground openings. Modifications include the deferral of backfilling during the Test Phase and an increase in underground monitoring and have been implemented to ensure the retrievability of TRU wastes. These modifications are discussed in Section 1.5.3.

Table 1A.2-1

ON-SITE ANNUAL DOSE ESTIMATES DUE TO NORMAL OPERATIONS

DOSES DUE TO DIRECT RADIATION:

ACTIVITY	AVERAGE INDIVIDUAL DOSE rem/person/year
CH TRU WASTE HANDLING	0.68
RH TRU WASTE HANDLING	0.12

DOSES DUE TO AIRBORNE RADIOACTIVITY:

ORGAN CONSIDERED	COMMITTED EFFECTIVE DOSE EQUIVALENT rem/person/50 years
Total Body	0.37
Bone	6.42
Lung	0.85
Liver	1.41

RADIATION PROTECTION STANDARDS - DOE ORDER 5480.11:

Stochastic Effects	5 rem (annual effective dose equivalent)
Non-Stochastic Effects	
Lens of eye	15 rem (annual dose equivalent)
Extremity	50 rem (annual dose equivalent)
Skin of the whole body	50 rem (annual dose equivalent)
Organ or tissue	50 rem (annual dose equivalent)
Unborn Child	
Entire gestation period	0.5 rem (annual dose equivalent)

- CMR and Instrument Shop HVAC System
- Support Building Laboratory Areas HVAC System
- Underground Ventilation System
- Surface Electrical System
- Underground Electrical System
- Waste Handling and Support Building
- Fire Protection System
- Site-Generated Waste Treatment System
- Security and Access Control Waste Handling and Support Buildings
- Underground Fuel Area

These FMEAs show that the structures and equipment are adequately protected to prevent a failure that would jeopardize the safety of the public or operating personnel or the environment.

In addition, accident scenarios which consider the radiological consequences of potential equipment failures were analyzed. The conclusion from these analysis is that under no circumstances will the public health and safety be subjected to significant risks. Details of these accidents are provided in Chapter 7 and in Reference 4.

1A.5.3 CONCLUSIONS REGARDING OPERATIONS

The WIPP facility operations entail receiving, unloading, and transferring of radioactive wastes from the surface to the underground storage rooms. Transporters carrying radioactive waste arrive at the WIPP facility and are surveyed for external contamination prior to their offloading the TRUPACT IIs in the Radiologically Controlled Area (RCA) adjacent to the WHB.

The waste received for placement in the WIPP facility must conform with the WIPP Waste Acceptance Criteria[5] (WAC), unless an exception to the WAC has been approved as a result of examination in relation to this FSAR. The CH TRU waste shipping container is moved from the RCA to the CH TRU handling area of the WHB and placed in an unloading dock. The container is vented, opened, surveyed for radiation and contamination and the waste is removed and placed on a facility pallet. This pallet is then transferred to the cage loading car, which is moved into the hoist cage used in the Waste Shaft for transfer to the storage horizon.

At the storage horizon, the pallet is removed from the hoist cage, placed on the underground transporter, and moved to the CH TRU waste storage room. In the storage room, the containers are removed from the pallet and placed in the waste stack. The empty pallet is returned to the surface for reuse.

The RH TRU waste handling area of the WHB has an entry for truck or rail shipments. The RH TRU waste will be shipped in shielded Nuclear Regulatory Commission NRC-certified casks. The cask is surveyed for radiation and contamination levels, unloaded from the transporter and moved to the cask preparation station. The cask is inspected and the outer lid is removed. It is then moved to the unloading room of the hot cell. The inner cask lid and the RH TRU canister are removed from the cask and lifted into the hot cell.

In the hot cell, the canister is inspected. The canister can be overpacked, if necessary, and then lowered into the transfer cell. The transfer cell provides a temporary storage area, if needed.

Table 1A.2-2

RADIOLOGICAL IMPACT ON THE PUBLIC DUE TO NORMAL OPERATIONS

ADULT MAXIMUM INDIVIDUAL	COMMITTED EFFECTIVE DOSE EQUIVALENT (rem)
TOTAL	1.7E-06
BACKGROUND	0.1

POPULATION*	COMMITTED EFFECTIVE DOSE EQUIVALENT (person-rem)
TOTAL	5.3E-04
BACKGROUND	1.13E+04

* Based on population data in Table 2.1-2.

References for Section 1A.5

1. Sandia National Laboratories, WIPP Conceptual Design Report, SAND 77-0274, April, 1977.

2. Bechtel National Inc., WIPP Title I Design Report, 1980.

3. Bechtel National Inc., Waste Isolation Pilot Plant Design Validation Final Report, DOE-WIPP-86-010, October 1986.

4. U.S. Department of Energy, Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026, October 1980.

5. Westinghouse Electric Corp., WIPP Waste Acceptance Criteria, TME-069, Rev 2, October 1985.

Table 1A.2-3

ROUTINE RELEASES AND OCCUPATIONAL EXPOSURES

CHEMICAL	ABOVEGROUND OPERATIONS CONCENTRATION AT ABOVE GROUND RECEPTOR ($\mu g/m^3$)	ESTIMATED MAXIMUM DAILY DOSE (mg/kg/day)[a]
1,1,1-Trichloroethane	4.5E-07	1.0E-10
Carbon Tetrachloride	5.9E-07	1.0E-10
1,1,2-Trichloro-1,2,2-Trifluoroethane	3.5E-07	6.0E-11
Methylene Chloride	2.0E-06	3.4E-10
Trichloroethylene	2.4E-07	4.1E-11

CHEMICAL	UNDERGROUND OPERATIONS CONCENTRATION AT UNDERGROUND RECEPTOR ($\mu g/m^3$)	ESTIMATED MAXIMUM DAILY DOSE (mg/kg/day)[b]
1,1,1-Trichloroethane	6.5	1.1E-02
Carbon Tetrachloride	8.5	1.5E-05
1,1,2-Trichloro-1,2,2-Trifluoroethane	5.0	8.6E-04
Methylene Chloride	2.9	4.9E-04
Trichloroethylene	3.5	5.9E-04

CHEMICAL	UNDERGROUND OPERATIONS CONCENTRATION AT ABOVEGROUND RECEPTOR (μg/m3)	ESTIMATED MAXIMUM DAILY DOSE (mg/kg/day)c
1,1,1-Trichloroethane	1.6E-03	2.8E-07
Carbon Tetrachloride	2.1E-04	3.6E-08
1,1,2-Trichloro-1,2,2-Trifluoroethane	1.3E-04	2.2E-08
Methylene Chloride	7.2E-04	1.2E-07
Trichloroethylene	8.7E-05	1.5E-08

[a] Estimated daily dose is based on exposure to a constant 42 drum equivalent

[b] Estimated daily dose is based on exposure to a constant 6,000 drum equivalents

[c] Estimated daily dose is based on exposure to 17,600 drum equivalents per year up to a maximum of 88,000 drum equivalents after five years and a subsequent 6,000 drum equivalents for the remaining 20 years of operations.

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SITE CHARACTERISTICS

Information on the location of the WIPP facility and a description of the characteristics of the local environment that influence the design bases of the WIPP facility are presented in this chapter.

2.1 GEOGRAPHY AND DEMOGRAPHY OF THE AREA AROUND THE WIPP FACILITY

2.1.1 WIPP FACILITY LOCATION AND DESCRIPTION

The Waste Isolation Pilot Plant (WIPP) Facility is located in Eddy County in southeastern New Mexico (Figure 2.1-1). The center of the WIPP facility is approximately 103°47'27" W longitude and 32°22'11" N latitude.

Prominent natural features within five miles of the center of the WIPP facility are described in detail in Section 2.7 and include Livingston Ridge and Nash Draw, which are located about five miles west of the WIPP facility. Livingston Ridge, the most prominent physiographic feature near the WIPP facility, is a northwest facing bluff (about 75 feet high) that marks the east edge of Nash Draw (a shallow drainage course about five miles wide). Descriptions of Nash Draw and Livingston Ridge are presented in Section 2.7.1.

Other prominent natural features are the Pecos River which is about 14 miles west of the WIPP facility at its nearest point (river mile 430), and Carlsbad Caverns National Park which is more than 42 miles west southwest of the WIPP facility. The nearest prominent man-made features are the city of Loving (with a 1986 population of approximately 1450) which is 18 miles west southwest, and the city of Carlsbad (with a 1986 population of about 27,000) which is 26 miles west of the WIPP facility.

2.1.1.1 WIPP Facility Area

The area of land that lies within the WIPP Site Boundary and committed to the WIPP facility is a square four miles on a side. It contains 10,240 acres (16 mi^2) including Sections 15-22 and 27-34 in township T22S, R31E. The area containing the WIPP facility surface structures is surrounded with a chain link fence and covers about 35 acres in Sections 20 and 21 of T22S, R31E. This fenced area is known as Zone I (Section 4.1.2.2). The location and orientation of the WIPP facility surface structures are shown in Figure 2.1-2. These structures include the Waste Handling Building (WHB) where radioactive waste is received and prepared for underground storage, a TRUPACT II Maintenance Facility for the inspection, maintenance, and minor repair of TRUPACT IIs, four shafts to the underground area, a Support Building containing laboratory and office facilities, showers, change rooms and equipment storage areas for underground workers, an Exhaust Filter Building (EFB), a water supply system, sewage stabilization ponds, and other auxiliary buildings. In addition, there are two mined-rock (salt) piles, and an evaporation pond for collecting salt pile runoff. A sanitary landfill location is shown on WIPP facility drawings, but a decision has been made not to develop this landfill at this time.

There are no industrial, commercial, institutional, recreational or residential structures within the WIPP Site Boundary and no through public highways, railways or waterways traverse the WIPP Site Boundary. County Road 802 crosses the WIPP Site Boundary as the south access road, but it will be blocked to control traffic prior to receipt of waste. There are four natural gas pipelines that traverse the vicinity of the WIPP facility. One pipeline that is within the WIPP Site Boundary is oriented northeast southwest and is about 1.2 miles north of the center of the WIPP surface structures at its closest point. This pipeline, along with other pipelines in the area of the WIPP facility, is discussed in Section 2.2.4.

The areas that have been designated as subdivisions within the WIPP Site Boundary are defined below and depicted in Figure 2.1-3.

Zone I is an area of approximately 35 acres surrounded by a chain link fence. Most of the WIPP facility surface structures are to be located within this area. Structures not located here include the salt storage piles, the proposed sanitary landfill, and the wastewater stabilization ponds.

The Secured Area (not shown in Figure 2.1.3) is an area of approximately 1,500 acres surrounded by a barbed wire fence. Access to this area will be restricted.

Zone II overlies the maximum extent of the area for underground development.

The WIPP Site Boundary provides a minimum of a one mile wide buffer area of intact salt around Zone II.

The WIPP Site Boundary encompasses an area of 10,240 acres (16 sections). The DOE will not permit subsurface mining, drilling, or resource exploration unrelated to the WIPP Project within the WIPP Site Boundary during facility operation or after decommissioning. This prohibition precludes slant drilling under the WIPP facility from within or outside the WIPP facility.

Information regarding control of activities in each zone is presented in Section 2.1.2.2.

2.1.1.2 Boundaries for Establishing Operational Effluent Release Limits

The Radiologically Controlled Area (RCA) in the southern portion of Zone I, including the WHB and areas where the waste transporters are stored, is surrounded by a chain link fence. This area is shown in Figure 2.1-2. Within this area, radioactive material concentration limits in the plant effluents shall be in accordance with Order DOE 5480.11. The requirements of this order will also be fulfilled outside of the RCA. The related "As Low As Reasonably Achievable (ALARA)" provisions of Order DOE 5480.11 shall apply to all areas.

It should be noted that the boundary of the RCA does not correspond with the boundary for Control Zone I (Section 2.1.2.2). The RCA is about one third the size of Control Zone I and is contained entirely within it. Only specifically authorized persons will have access to the RCA.

During routine operations, releases of radioactive effluents will be very small. Releases will be restricted so as to limit doses to any member of the public to limits established by the requirements of 40 CFR 191 Subpart A, and consistent with limits established by the DOE, based on guidelines recommended by the International Council of Radiation Protection. Dose limits specified are as follows:

RADIATION STANDARDS FOR PROTECTION OF THE PUBLIC
IN THE VICINITY OF DOE FACILITIES

A. Dose Limits

1. All Pathways (Order DOE 5480.11)

The effective dose equivalent for any member of the public from all routine DOE operations (natural background and medical exposures excluded) shall not exceed the values given below:

	Effective Dose Equivalent mrem/year	(mSv/year)
Occasional annual exposures	500	(5)
Prolonged period of exposure	100	(1)

No individual organ shall receive a committed effective dose equivalent of 5 rem/year (50 mSv/year) or greater.

2. All Pathways (Limits of 40 CFR 191, Subpart A)

	Dose Equivalent mrem/year	(mSv/year)
Whole-body dose	25	(0.25)
Any organ	75	(0.75)

For the purposes of applying these dose limits, 40 CFR 191 Subpart A defines the receptor as "any member of the public in the general environment." Any member of the public is any individual except when he/she is a worker at the WIPP facility. The general environment incorporates areas outside the WIPP Site Boundary. The WIPP Site Boundary is defined in Section 2.1.1.

The WIPP facility was designed to conform to the requirements of Order DOE 6430.1, Chapter 1, Section 3i(5), which delineates radiological siting requirements for nonreactor facilities. For the purpose of demonstrating compliance with these design requirements for accident analysis, the dose resulting from an accidental release is based on calculations to an individual located at the point of highest concentration within any public access area around the WIPP facility.

2.1.2 EXCLUSION AREA LAND USE AND CONTROL

2.1.2.1 Authority

The 10,240 acres that lie within the WIPP Site Boundary are on federal land. During construction all the federal lands within the WIPP Site Boundary were managed in accordance with the terms of Public Land Order 6403 and a DOE/BLM Memorandum of Understanding (MOU) and the BLM Resource Management Plan.

During operations, the area within the WIPP Site Boundary will remain under federal control. This includes all facility areas described in Section 2.1.1.1

Consistant with the mission of the WIPP facility, lands within and around the WIPP Site Boundary are administered according to a multiple land use policy. These uses include agricultural uses, mineral extractions, and others.

2.1.2.1.1 Agricultural Uses

All the land within the WIPP Site Boundary has been leased for grazing, which is the only significant agricultural activity in the vicinity of the WIPP facility. There are two leaseholders as shown in Figure 2.1-4. The Smith Ranch, owned by Kenneth Smith, Inc. of Carlsbad, New Mexico, has lease rights to 2880 acres within the northern portion of the WIPP Site Boundary. J. C. Mills of Abernathy, Texas, owner of the Mills Ranch, has lease rights to 7360 acres within the southern portion of the WIPP Site Boundary.

2.1.2.1.2 Potash Leases

Previously about one sixth of the land inside the WIPP Site Boundary has been leased or has applications pending for potash exploration. As shown in Figure 2.1-5, 1600 acres are now leased by one company that is already operating a mine in the Carlsbad potash area. This lease is not being developed currently. This lease is being sought by the DOE. Should the BLM receive an application to develop a lease on federal land they will notify the DOE. Upon notification, the DOE will evaluate the development plans and take appropriate action. No potash development will be allowed within the WIPP Site Boundary during or following waste operations.

2.1.2.1.3 Oil and Gas Leases

Previously, a large amount of land within and around the WIPP Site Boundary was leased to oil companies for oil and gas exploration. Since the beginning of studies in the vicinity of the WIPP facility, all oil and gas leases within the WIPP Site Boundary have expired. These expirations were necessary to keep the salt beds intact since exploratory drill holes could penetrate the salt, which the underground storage areas will occupy.

2.1.2.1.4 Water Use

There are no significant uses of surface or groundwater in the vicinity of the WIPP facility. Several windmills have been erected throughout the area to pump groundwater for livestock watering. Additionally, several ponds have been created to capture runoff for livestock.

2.1.2.2 Control of Activities Unrelated to Plant Operation

The WIPP facility is divided into areas defined in Section 2.1.1.1 and shown in Figure 2.1-3.

Within Zone I, public access is restricted to employees and approved visitors. Within the Secured Area access is restricted to authorized personnel and vehicles. Only drilling and mining associated with the WIPP Project is permitted in Zone I and the Secured Area. Zone II has an area of about 1800 acres and overlies the maximum extent of underground development. All radioactive waste is emplaced underground in this zone. Most of Zone II lies within the Secured Area perimeter fence. In addition, small areas have been fenced to control access to material storage areas, borrow pits, the wastewater treatment plant, and biological study plots. Livestock will be permitted in this zone until current lease arrangements established with the Bureau of Land Management expire. Only drilling and mining carried out by the DOE is permitted within this zone.

A buffer zone between Zone II and the WIPP Site Boundary has an outside diameter of four miles and an area of about 8190 acres. It is not fenced, and grazing is permitted. With the DOE's permission, shallow wells may be drilled for watering livestock, but no other drilling or mining is permitted.

The buffer zone provided between Zone II and the WIPP Site Boundary consists of a minimum of one mile of intact salt surrounding the waste emplacement areas. This thickness was specified based on recommendations made by Oak Ridge National Laboratory[1] (ORNL). The ORNL recommendation of one to five miles for the size of the buffer zone was to preclude unacceptable penetration of the salt formation. The ORNL stated that the actual size of the buffer must be based on site dependent factors including drilling operations, mining operations and salt dissolution rates. This was addressed in the Geological Characterization Report[2] where the authors state that the one mile buffer should provide more than 250,000 years of isolation using very conservative flow assumptions.

This buffer zone is considered to be adequate for protection from potential mining activities as well. In this regard, two considerations are mineral extraction by solution mining and conventional mining activities using explosives.

Regarding solution mining, Section 9.7.1.6 of the FEIS discusses solution mining and provides rationale as to why solution mining poses no threat to long-term isolation at the WIPP. Blasting effects are not considered a threat because of the limited use of explosives for mining (currently only one company uses conventional mining) and the relatively small sizes of the charges used. The DOE will not exercise any control or impose any restrictions on land use outside the WIPP Site Boundary, with the exception of rights of way granted for highway, railroad, power line,and waterline access to the WIPP facility. In addition, due to the low level of radioactive releases during any postulated accident, as discussed in Chapter 7 immediate evacuation will not be necessary for persons involved in activities outside Zone I.

2.1.2.3 Arrangements for Traffic Controls

The unimproved roads that traverse the area within the WIPP Site Boundary are not to be controlled because traffic is sporadic. Since the area is not traversed by state or federal highways, railways, or waterways other than the WIPP access roads and a rail line, control of local traffic in the event of an emergency will be accomplished with barricades.

2.1.2.4 Abandonment or Relocation of Roads

No public roads have to be relocated because of the WIPP construction or operations.

2.1.3 POPULATION DISTRIBUTION

Towns and cities within 50 miles of the WIPP facility are shown in Figure 2.1-1. The WIPP facility and the area within 10 miles are shown in Figure 2.1-6.

2.1.3.1 Population within 10 Miles

Within a 10 mile radius of the WIPP facility, there are currently 26 permanent residents. Eight people live at the Mills Ranch about 3.5 miles south southwest of the WIPP facility.[3] Ten people live at the Smith ranch about 5.5 miles west northwest of the WIPP facility[4] (Figure 2.1-6). Three people live at Pue's store, about nine miles west northwest of the WIPP facility.[5] Five people currently reside at the newly constructed Mobley ranch, seven miles southwest of the WIPP facility.[5]

There are no communities within 10 miles of the WIPP facility. The nearest community is Loving, which is 18 miles from the WIPP facility (Figure 2.1-1).

2.1.3.2 Population within 50 Miles

The area within a 50 mile radius of the WIPP facility is shown in Figure 2.1-1. In 1976, there were about 94,000 people living within 50 miles of the WIPP facility as shown in Table 2.1-1.[6] By the year 2005, the estimated population will be about 204,000.[7] Tables 2.1-2 through 2.1-5 show projected populations for the years 1985, 1990, 1995, and 2005. Population projections are made assuming maximum impact on Carlsbad. Growth rates were taken from the University of New Mexico Bureau of Business and Economic Research[7] (BBER) report "Population Projections for New Mexico Counties 1980-2005, 1986." Figure 2.1-7 shows the population within 50 miles of the WIPP facility by sector for 1985.

The University of New Mexico's Bureau of Business and Economic Research has recently (November 1986) published population data for Lea and Eddy County for 1985, and estimates of growth rates through 2005.[7] Population and growth rates for selected cities within these counties for 1980-1984 were compiled by the U.S. Census Bureau.[6] Southwestern Public Service Company (SPS) has also published population figures for 1980 and 1985 for selected cities.[8-11] In addition, a phone survey of city managers and the Chamber of Commerce for cities within 50 miles of the WIPP facility was conducted in February 1987 to provide data on 1986 populations.[12-19] There were discrepancies in 1980 figures among these sources. An average "urban" population growth rate was calculated from all available data for each city. Sectors containing these cities were then projected to grow at the same rate as the cities. Sectors without major population areas were projected to grow at the same rate as the county they are in. Where sectors encompass more than one county, the population growth rate was apportioned by relative area and growth rate of each county. Where sectors divide a city, population was apportioned according to the ratio of city area in each. Population projections for Texas counties were not available.

Sectors in these counties were projected to grow at the same rate as the adjoining county in New Mexico. In some sectors, the 1980 population was shown as zero. Based on current land use, ownership and potential for development, no future growth was projected for these sectors.

Determinations of current population within 10 miles of the WIPP facility were made by field survey.

Population projections for 1990, 1995, and 2005 were made using projected county rates for these years in the BBER (November 1986) report. Projections beyond 2005 are not available. Projections assume a county-wide uniform growth rate, for developed as well as unincorporated areas, and should be interpreted cautiously. Most urban areas in these counties will develop at different rates than rural areas, some of which are held as BLM lands or as leased mineral development lands. The projections are made using a uniform average density and growth rate in each sector.

2.1.3.3 Transient Population

The transient population within five miles of the WIPP facility is associated with ranching, maintenance of oil and gas wells and hunting. The three ranches with property within 10 miles of the WIPP facility are the Mills, Smith and Mobley ranches. Only Mills Ranch, owned by J.C. Mills, has a ranch house located within five miles of the WIPP facility. It is 3.5 miles south southwest of the WIPP facility and has a permanent population of eight. During two months in the spring and one month in the fall, an additional twelve seasonal part-time employees work at the ranch and take part in cattle roundup. The Smith ranch house is about 5.5 miles west northwest of the WIPP facility. The ranch has a permanent population of ten from March through April and September through October. About 18 seasonal part-time employees work at the ranch and participate primarily in cattle roundup. The Mobley ranch, seven miles southwest of the WIPP facility has a permanent population of five. There may be as many as three to four persons on any day working on the maintenance of oil and gas wells within five miles of the WIPP facility.

Within the five miles area there are as many as 100 to 150 hunters on weekends during the hunting season, with the largest number of hunters in the area from the third weekend in November to the third weekend in January.[20] Another recreational activity, four-wheel vehicle driving, occurs within this area. This involves about one to two vehicles a week, year round.

From five to 10 miles from the WIPP facility, the major transient population is associated with potash mining. The three mining operations within 10 miles of the WIPP facility employ a maximum of 359 people per shift with 451 people present during shift changes.[21-23] The locations of the mines are shown in Figure 2.1-6; the number of employees may vary at the various mining operations within the 10 mile radius. During the 1966-1970 period, the number dropped significantly because of a decrease in demand for potash from the Carlsbad area. A similar decline in potash production began in 1985, resulting in reductions in work forces at most mines. Fluctuations in potash production in response to demand will probably continue; however, expectations are that the maximum mining employment (Table 2.1-6) will not be exceeded.

2.1.3.4 Population Center

The nearest significant population center is the city of Carlsbad. It is about 26 miles west of the WIPP facility, and in 1986, it had an estimated population of 27,000 people. Two smaller communities are Loving (with a 1986 population of 1,450) about 18 miles west southwest, and Malaga (with a 1986 population of about 200) about 20 miles west southwest. The transient population within 10 miles of the WIPP facility is small and is, therefore, not considered in establishing the population center.

Most of the population within 50 miles of the WIPP facility is concentrated in and around incorporated places such as Carlsbad, Hobbs, Lovington, and Artesia. Past growth patterns indicate that growth will be restricted to the larger existing communities.

2.1.3.5 Population Density

The cumulative 30 mi radius resident population for 1990, is estimated to be 44,857. This represents a population density of about 16 people per square mile. Near the end of the plant life, year 2005, only 68,606 are expected to reside within a cumulative 30 mile radius. Assuming a uniform population density, this yields about 24 people per square mile.

Table 2.1-7 and Table 2.1-8 indicate the population densities for the periods of initial operation and the end of the plant's operating life, respectively. The densities are for areas 0-5, 0-10, 0-20 and 0-30 miles from the WIPP facility.

2.1.4 USES OF ADJACENT LAND AND WATER

A major use of land within 10 miles of the WIPP facility is cattle ranching. There are about 500 head of cattle within five miles of the WIPP facility and about 1,500 head of cattle from five to 10 miles of the WIPP facility. At present, none of the ranches within 10 miles use well water for their livestock. The Smith ranch used well water until 1978, but the quality was poor and they now use water supplied by pipeline. Drinking water comes from International Mineral and Chemical Corporation (IMCC), which has its own well system tapping the Capitan aquifer, while stock water comes from IMCC and from New Mexico Potash Corporation, which has a well system tapping the Ogallala Formation.

As of 1987, two dairies were operating within 50 miles of the WIPP facility. These are in the vicinity of Hobbs, 45 miles east northeast of the WIPP facility. The Goff dairy in Hobbs has a herd of about 75 cows,[24] and the Bar Four Dairy operates about 800 cows.[25] Locations of dairy herds in relation to the WIPP facility are shown in Figure 2.1-8.

2.1.5 MARKETS OF AGRICULTURE

Since beef cattle in the area are raised in feedlots and on ranches, market areas for both had to be determined. Three of the feedlots in the area (the Seven Rivers Feedlot, the Paul Morgan Cattle Company and Kershaw's K-Bar Inc.) were contacted. According to these feedlots, the market area for the cattle ranges from throughout the United States and a part of Canada to an active local market in El Paso, Lubbock, Clovis, and Roswell. Harbridge House, Inc. was contacted about the market of ranching operations in the area of the WIPP facility. They were asked for results from an environmental impact statement being prepared for the BLM office in Roswell. Of the ranching operations interviewed by Harbridge, only three market their cattle year round. The most prevalent market period is the fall, with about 75 percent of the actual marketing of beef occurring at this time. There is little or no marketing pattern, except that the cattle are sold at the ranch or at auctions, which are generally local.

Dairies in the area were contacted about their markets. Dairies sell their milk to processing outlets, either directly or through the Association of Milk Producers, Inc. Consequently, the milk is probably consumed in west Texas and southeastern New Mexico, and possibly as far away as Lubbock, Midland and El Paso, Texas.

Estimates of cattle within a 10 mile radius of the WIPP facility were made by ratioing the average grazing density for each BLM range management district within 10 miles times the area of each within each ordinate segment at one mile intervals. Average cattle grazing densities are shown in Figure 2.1-9.

Between 10 and 50 miles, BLM and County Agricultural District estimates[26] of grazing densities at approximately eight cows per section were used. Densities were adjusted for WNW sector 30-40 miles to allow for 1986 Feedlot maximum population of 28,000 cattle. There are no resident herds of sheep, although about 450 ewes are pastured outside Loving for the winter.

Estimates of agricultural utilization within a 50 mile radius of the WIPP facility were obtained from Eddy County Extension Agent and published New Mexico agricultural statistics.

There is no farming activity within a 10 mile radius of the WIPP facility. There are three pecan orchards between 25-30 miles west of the WIPP facility, with a combined 1986 yield of approximately 2000 pounds, and a small commercial truck farm raising asparagus about three miles northwest of Loving, yielding approximately 1.5 tons.

In addition, there are potentially up to 11,000 acres of wheat, and approximately 1500 acres of barley raised within 50 miles of the WIPP facility, depending on market and seasonal conditions. This is not considered a significant agricultural region. Cotton is also raised within the 50-mile radius of the WIPP facility, but was not considered in agricultural land use (Figure 2.1-10) as it does not represent any potential pathway of exposure to man.

References for Section 2.1

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11. Community Survey, Hobbs, New Mexico, Lea County, December 1985, Southwestern Public Service Company, Amarillo, Texas, 1986.

12. Carlsbad Department of Development, Chamber of Commerce, 302 S. Canal Street, Carlsbad, New Mexico, December 1986.

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14. Personal Communication, City Clerk, Artesia, New Mexico, February 11, 1987.

15. Personal Communication, Community Clerk, Loving, New Mexico, February 12, 1987.

16. Personal Communication, City Clerk, Eunice, New Mexico, February 11, 1987.

17. Personal Communication, City Clerk, Jal, New Mexico, February 11, 1987.

18. Personal Communication, City Manager, Hobbs, New Mexico, February 11, 1987.

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20. Personal Communication, John Spain, Range Manager, Bureau of Land Management, Carlsbad Division, Carlsbad, New Mexico, December 12, 1986.

21. Personal Communication, Bobbie Bloss, Chief Accountant, Western Ag-Minerals, Mine Site, Carlsbad, New Mexico, December 10, 1986.

22. Personal Communication, Cotton Spears-Personnel, New Mexico Potash, Carlsbad, New Mexico, December 10, 1986.

23. Personal Communication, Mr. Bennigan, Personnel, International Minerals and Chemical Corp., Carlsbad, New Mexico, December 10, 1986.

24. Personal Communication, Goff Dairy, Hobbs, New Mexico, February 18, 1987.

25. Personal Communication, Bar Four Dairy, Hobbs, New Mexico, February 18, 1987.

26. New Mexico Agricultural Statistics, United States Department of Agriculture, New Mexico Crop and Livestock Reporting Service, Las Cruces, New Mexico, 1984.

Table 2.1-1

1976 RESIDENT POPULATION WITHIN 50 MILES OF THE WIPP FACILITY*

Sector	Distance From WIPP Facility, Miles: 0-5	5-10	10-20	20-30	30-40	40-50	Total
N	0	0	35	25	175	25	260
NNE	0	0	25	5	55	5,585	5,670
NE	0	0	0	25	75	6,735	6,835
ENE	0	0	15	70	185	30,595	30,865
E	0	0	5	15	3,190	155	3,365
ESE	0	0	5	10	3,035	295	3,345
SE	0	0	5	15	25	30	75
SSE	0	0	0	25	10	40	75
S	0	0	5	15	60	15	95
SSW	0	0	5	30	90	15	145
SW	0	0	55	15	10	45	125
WSW	0	0	1,495	185	50	65	1,795
W	0	0	70	29,045	40	35	29,190
WNW	0	10	5	190	55	50	310
NW	0	0	30	20	65	11,505	11,620
NNW	0	0	15	5	250	10	280
Radius Total	6	10	1,770	29,695	7,370	55,200	94,050
Cumulative Total	6	16	1,785	31,480	38,850	94,050	--

*Figures for all areas beyond a 10-mile radius are rounded to the nearest five persons.

Table 2.1-2

1985 RESIDENT POPULATION WITHIN 50 MILES OF THE WIPP FACILITY

	Distance From WIPP Facility, Miles					
Sector	0-10	10-20	20-30	30-40	40-50	Total
N	0	29	23	195	29	276
NNE	0	29	6	58	6,418	6,511
NE	0	0	29	81	8,224	8,334
ENE	0	12	81	215	36,128	36,436
E	0	6	17	3,700	186	3,909
ESE	0	6	12	3,322	313	3,653
SE	0	6	23	23	35	87
SSE	0	0	29	12	46	87
S	0	6	17	56	17	96
SSW	8	6	28	105	17	164
SW	5	50	17	11	44	127
WSW	0	1,707	171	55	72	2,005
W	0	66	35,409	39	33	35,547
WNW	13	6	164	50	44	277
NW	0	28	17	61	15,080	15,184
NNW	0	17	6	237	11	271
Radius Total	26	1,974	36,049	8,220	66,697	112,966
Cumulative Total	26	2,000	38,049	46,269	112,966	--

Table 2.1-3

1990 PROJECTED RESIDENT POPULATION WITHIN 50 MILES OF THE WIPP FACILITY*

	Distance From WIPP Facility, Miles					
Sector	0-10	10-20	20-30	30-40	40-50	Total
N	0	34	27	230	34	325
NNE	0	34	7	68	7,567	7,676
NE	0	0	34	95	9,686	9,825
ENE	0	14	95	253	42,595	42,957
E	0	7	20	4,362	219	4,608
ESE	0	7	14	3,917	369	4,307
SE	0	7	27	27	41	102
SSE	0	0	34	14	54	102
S	0	7	20	66	20	113
SSW	9	7	33	124	20	193
SW	6	59	20	13	52	150
WSW	0	2,013	202	65	85	2,365
W	0	78	41,747	46	39	41,910
WNW	15	7	193	59	52	326
NW	0	33	20	72	17,779	17,904
NNW	0	20	7	279	13	319
Radius Total	30	2,327	42,500	9,690	78,635	133,182
Cumulative Total	30	2,357	44,857	54,547	133,182	--

*Based on growth rate for Lea and Eddy Counties as projected by University of New Mexico Bureau of Business and Economic Research, November 1986.

City growth rate projected at county rate.

Table 2.1-4

1995 PROJECTED RESIDENT POPULATION WITHIN 50 MILES OF THE WIPP FACILITY*

Sector	Distance From WIPP Facility, Miles					
	0-10	10-20	20-30	30-40	40-50	Total
N	0	40	32	270	40	382
NNE	0	40	8	80	8,869	8,997
NE	0	0	40	111	11,364	11,515
ENE	0	16	111	297	49,921	50,345
E	0	8	23	5,112	257	5,400
ESE	0	8	16	4,591	432	5,047
SE	0	8	32	32	48	120
SSE	0	0	40	16	63	119
S	0	8	23	77	23	131
SSW	11	8	39	145	23	226
SW	7	69	23	15	61	175
WSW	0	2,359	237	76	100	2,772
W	0	91	48,927	54	46	49,118
WNW	18	8	226	69	61	382
NW	0	39	23	84	20,837	20,983
NNW	0	23	8	327	15	373
Radius Total	36	2,725	49,808	11,356	92,160	156,085
Cumulative Total	36	2,761	52,569	63,925	156,085	--

*Based on growth rate for Lea and Eddy Counties as projected by University of New Mexico Bureau of Business and Economic Research, November 1986.

City growth rate projected at county rate.

Table 2.1-5

2005 PROJECTED RESIDENT POPULATION WITHIN 50 MILES OF THE WIPP FACILITY*

	Distance From WIPP Facility, Miles					
Sector	0-10	10-20	20-30	30-40	40-50	Total
N	0	52	42	353	52	499
NNE	0	52	10	104	11,576	11,742
NE	0	0	52	145	14,833	15,030
ENE	0	20	145	388	65,159	65,712
E	0	10	29	6,672	336	7,047
ESE	0	10	20	5,992	564	6,586
SE	0	10	42	42	62	156
SSE	0	0	52	20	83	155
S	0	10	29	101	29	169
SSW	15	10	51	189	29	294
SW	9	90	29	19	79	226
WSW	0	3,079	310	99	130	3,618
W	0	119	63,861	70	60	64,110
WNW	24	10	295	90	79	498
NW	0	51	29	110	27,197	27,387
NNW	0	29	10	426	19	484
Radius Total	48	3,552	65,006	14,820	120,287	203,713
Cumulative Total	48	3,600	68,606	83,426	203,713	--

*Based on growth rate for Lea and Eddy Counties as projected by University of New Mexico Bureau of Business and Economic Research, November 1986.

City growth rate projected at county rate.

Table 2.1-6

MAXIMUM NUMBER OF EMPLOYEES FOR MINES WITHIN 10 MILES OF THE WIPP FACILITY

Name of Mine	Distance and Direction, Mi	Maximum Total Employees	Maximum Per Shift	During Shift Change
Western AG-Minerals Nash Draw Mine	5.5 WSW	75	58	75
International Minerals and Chemical Corporation	9.0 WNW	204	174	197
New Mexico Potash Corporation	9.5 N	235	127	179
Estimated Total		514	359	451

Table 2.1-7

POPULATION DENSITIES WITHIN 30 MILES OF THE WIPP FACILITY FOR 1990

Miles from WIPP Facility	Cumulative Population Densities (persons per square mile)
5	<1
10	<1
20	2
30	16

Table 2.1-8

POPULATION DENSITIES WITHIN 30 MILES OF THE WIPP FACILITY FOR 2010

Miles from WIPP Facility	Cumulative Population Densities (persons per square mile)
5	<1
10	<1
20	4
30	23

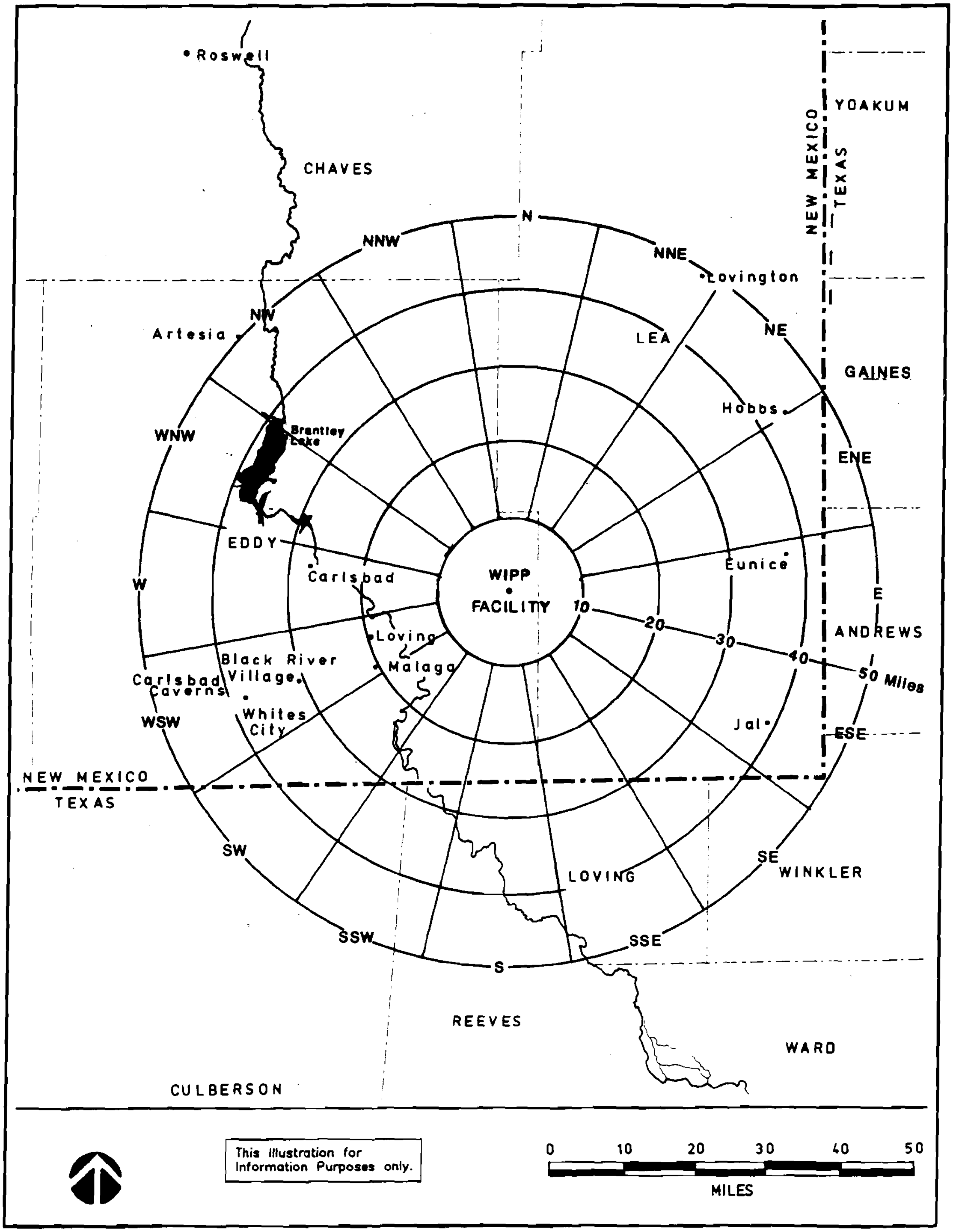


FIGURE 2.1-1
Region Surrounding the WIPP Facility

WIPP FSAR

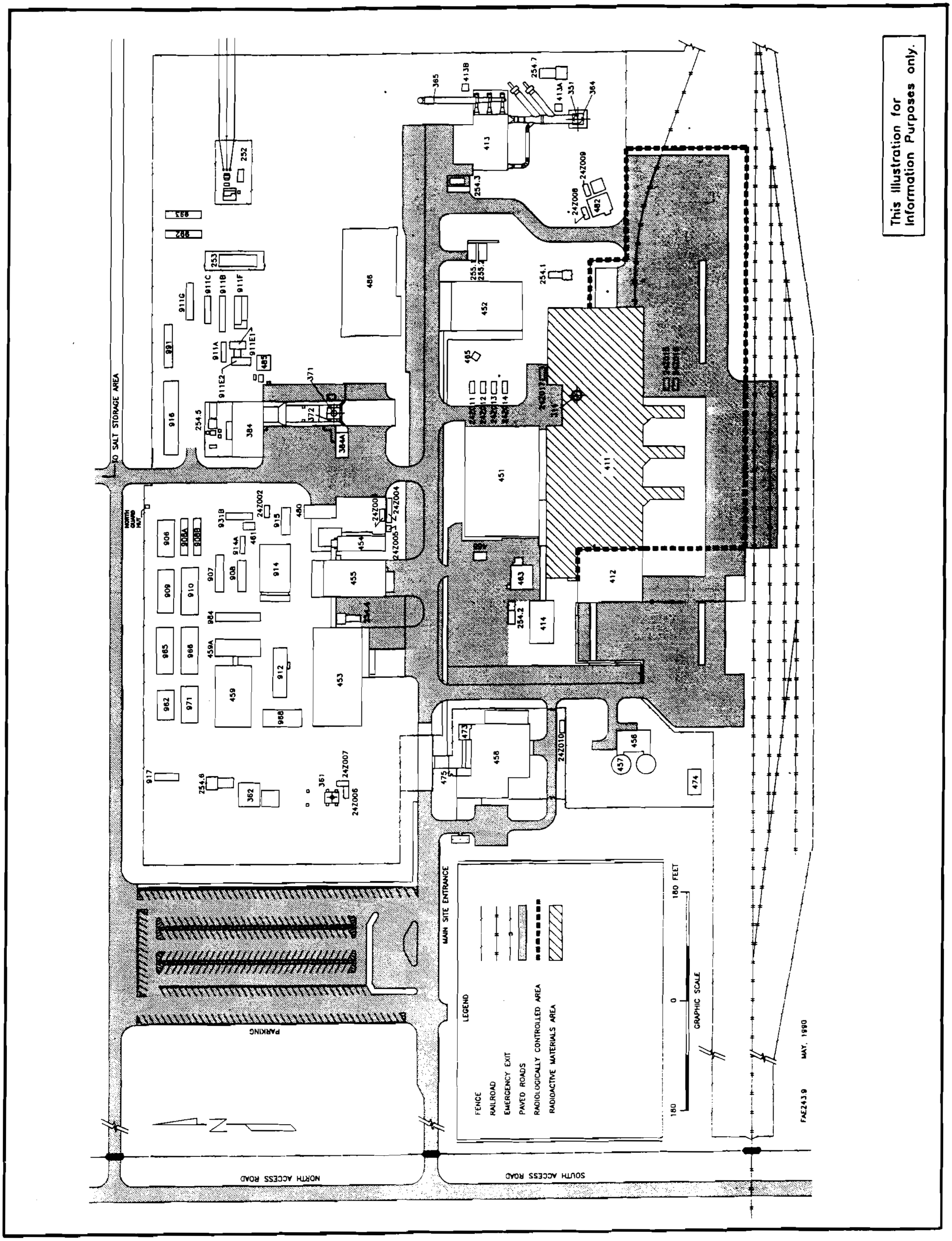


FIGURE 2.1-2
WIPP Surface Structures

Explanation to Figure 2.1-2

FACILITIES, USAGE AND STRUCTURE NUMBERS (FY 1990)

SPS UTILITY SUBSTATION	FAC 252
13.8 KV SWITCHGEAR 25P-SWG15/1	FAC 253
AREA SUBSTATION NO.1 25P-SW15.1	FAC 254.1
AREA SUBSTATION NO.2 25P-SW15.2	FAC 254.2
AREA SUBSTATION NO.3 25P-SW15.3	FAC 254.3
AREA SUBSTATION NO.4 25P-SW15.4	FAC 254.4
AREA SUBSTATION NO.5 25P-SW15.5	FAC 254.5
AREA SUBSTATION NO.6 25P-SW15.6	FAC 254.6
AREA SUBSTATION NO.7 25P-SW15.7	FAC 254.7
ON-SITE GENERATOR #1 25-PE 503	FAC 255.1
ON-SITE GENERATOR #2 25-PE 504	FAC 255.2
WASTE SHAFT	FAC 311
EXHAUST SHAFT	FAC 351
AIR INTAKE SHAFT	FAC 361
AIR INTAKE SHAFT/WINCH HOUSE	FAC 362
EFFLUENT MONITORING INSTRUMENT SHED - "A"	FAC 364
EFFLUENT MONITORING INSTRUMENT SHED - "B"	FAC 365
SALT HANDLING SHAFT	FAC 371
SALT HANDLING SHAFT HEADFRAME	FAC 372
SALT HANDLING SHAFT HOISTHOUSE	FAC 384
UNDERGROUND SERVICES OFFICE	FAC 384A
WASTE HANDLING BUILDING	BLD 411
TRUPACT MAINTENANCE BUILDING	BLD 412
EXHAUST SHAFT FILTER BUILDING	BLD 413
MONITORING STATION A	BLD 413A
MONITORING STATION B	BLD 413B
WATER CHILLER FACILITY	FAC 414
SUPPORT BUILDING - OFFICES, ETC.	BLD 451
SAFETY & EMERGENCY SERVICES FACILITIES	BLD 452
WAREHOUSE/SHOPS BUILDING	BLD 453
VEHICLE SERVICE BUILDING	BLD 454
AUXILIARY WAREHOUSE BUILDING - MAINTENANCE	BLD 455
WATER PUMPHOUSE	BLD 456
WATER TANKS (2)	FAC 457
GUARD AND SECURITY BUILDING	BLD 458
CORE STORAGE BUILDING	BLD 459
DBL WIDE TRAILER - OFFICE	BLD 459A
MAINTENANCE STORAGE	BLD 461
COMPRESSOR BUILDING	BLD 463
AUXILIARY AIR INTAKE	FAC 465
TELEPHONE HUT	BLD 468
ARMORY BUILDING - ARMORY AND LOCK SHOP	BLD 473
HAZARDOUS WASTE STORAGE BUILDING	BLD 474
GATEHOUSE - MAIN SITE ENTRANCE/EXIT	BLD 475
VEHICLE FUEL STATION	FAC 480
EXHAUST SHAFT HOIST EQUIPMENT WAREHOUSE	BLD 482
SULLAIR COMPRESSOR BUILDING	BLD 485
ADMINISTRATION BUILDING	BLD 486
DBL WIDE TRAILER	TRL 906
SINGLE WIDE TRAILER - OFFICE	TRL 907
SINGLE WIDE TRAILER - OFFICE	TRL 908
SINGLE WIDE TRAILER - CABLE FABRICATION	TRL 908A
SINGLE WIDE TRAILER - LAB AND CABLE FABRICATION	TRL 908B
DBL WIDE TRAILER - OFFICE	TRL 909
DBL WIDE TRAILER - OFFICE AND LAB	TRL 910
SINGLE WIDE TRAILER - VACANT - TO BE EXCESSED	TRL 911A
SINGLE WIDE TRAILER - OFFICE	TRL 911B
SINGLE WIDE TRAILER - OFFICE	TRL 911C
SINGLE WIDE TRAILER - AIS STAGING	TRL 911E1
SINGLE WIDE TRAILER - VACANT - TO BE EXCESSED	TRL 911E2
DBL WIDE TRAILER - COMPUTER CENTER	TRL 911F
SINGLE WIDE TRAILER - CABLE FABRICATION	TRL 911G
DBL. WIDE TRAILER - OFFICE AND CLASSROOMS	TRL 912
TRAILER COMPLEX (7) - OFFICE	TRL 914
SINGLE WIDE TRAILER - OFFICE	TRL 914A
SINGLE WIDE TRAILER - OFFICE	TRL 915
TRAILER COMPLEX (4) - OFFICE	TRL 916
SINGLE WIDE TRAILER - AIS DATA AQUISITION	TRL 917
SINGLE WIDE TRAILER - CHANGE ROOM	TRL 931B
DBL WIDE TRAILER - OFFICE	TRL 971
DBL WIDE TRAILER - OFFICE	TRL 982
SINGLE WIDE TRAILER - OFFICE	TRL 984
DBL WIDE TRAILER - OFFICE	TRL 985
DBL WIDE TRAILER - OFFICE	TRL 986
DBL WIDE TRAILER - OFFICE	TRL 988
SINGLE WIDE TRAILER - OFFICE	TRL 991
SINGLE WIDE TRAILER - LAB	TRL 992
SINGLE WIDE TRAILER - LAB	TRL 993
MOBILE STORAGE BUILDINGS	24Z002 THRU 24Z017

FAE259.9-1 CURRENT AS OF MAY, 1990

This illustration for Information Purposes only.

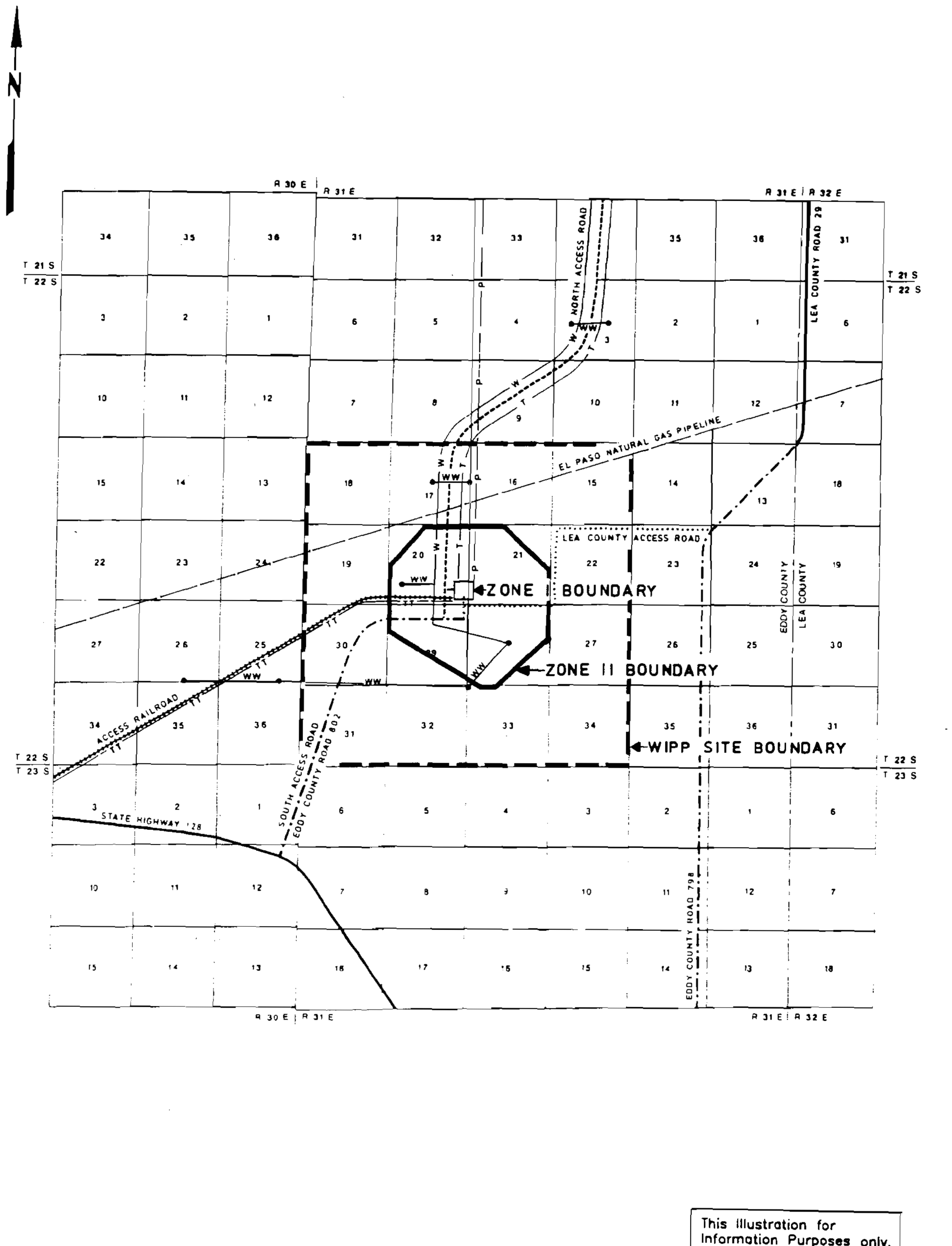
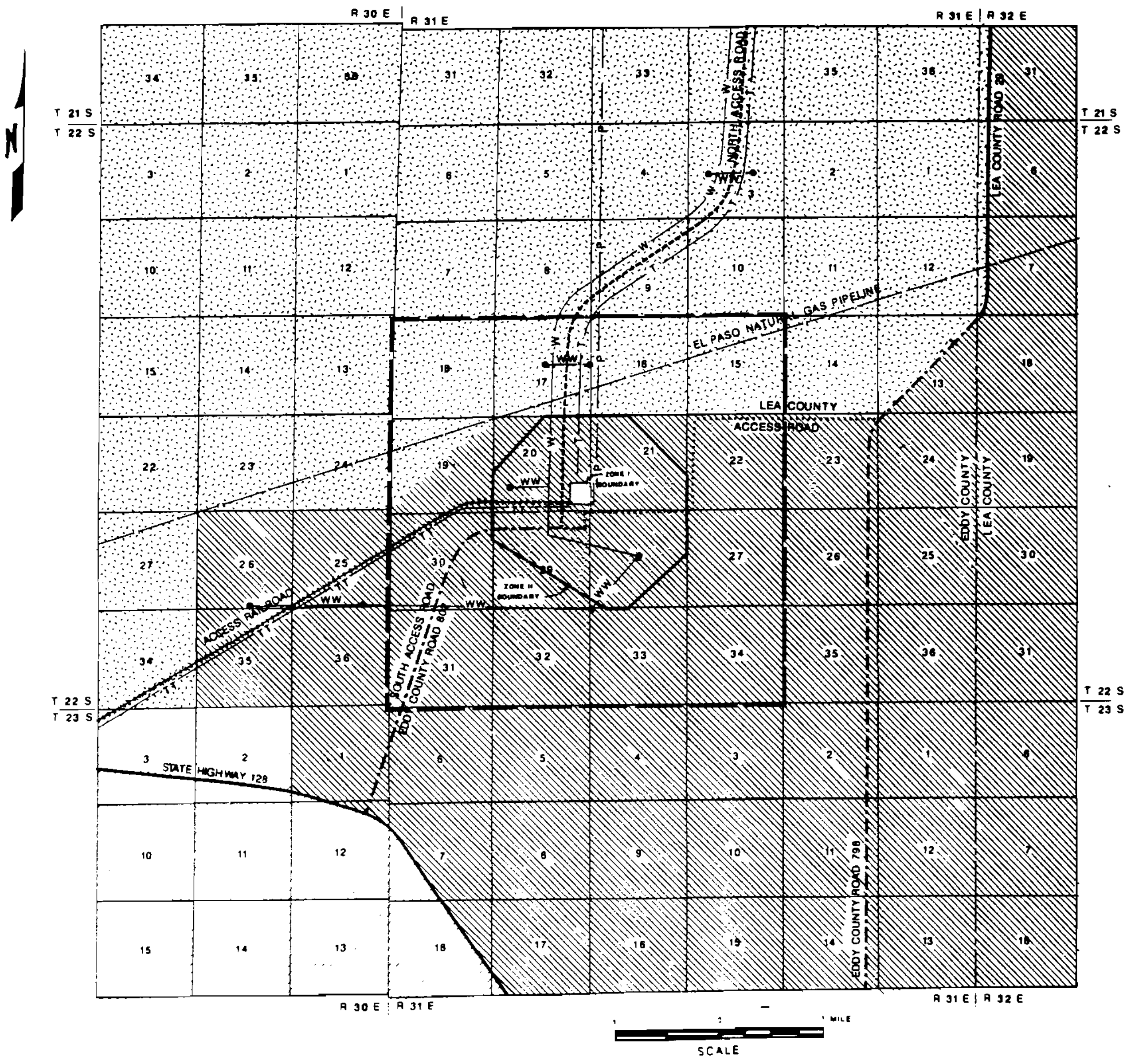


FIGURE 2.1-3
WIPP Facility Boundaries



This illustration for Information Purposes only.

FIGURE 2.1-4

Grazing Leases Within the WIPP Site Boundry

LEGEND

WIPP SITE BOUNDARY 10,240 ACRES.

—W— U.S. DOE RIGHT OF WAY NUMBER NM-53809, FOR WATERLINE, 50 FEET WIDE. THE DOE HAD AGREED WITH THE CITY OF CARLSBAD TO ALLOW THE INDIVIDUALS TO TAP THIS LINE LOCATED WITHIN THE NORTH ACCESS ROAD RIGHT OF WAY.

—WW— STOCK WATER TANKS AND TAP LINES CONNECTED TO THE MAIN WIPP WATERLINE.

—P— SOUTHWESTERN PUBLIC SERVICE COMPANY RIGHT OF WAY NUMBER NM-43203 FOR POWERLINE 60 FEET WIDE.

—T— GENERAL TELEPHONE OF THE SOUTHWEST RIGHT OF WAY FOR TELEPHONE LINE, 30 FEET WIDE, LOCATED WITHIN THE NORTH ACCESS ROAD RIGHT OF WAY.

—TT— GENERAL TELEPHONE OF THE SOUTHWEST RIGHT OF WAY NUMBER NM-60174 FOR TELEPHONE LINE, 30 FEET WIDE, LOCATED WITHIN THE RAILROAD RIGHT OF WAY.

U.S. DOE RIGHT OF WAY NUMBER NM-55675 FOR NORTH ACCESS ROAD, 170 FEET WIDE.

EL PASO NATURAL GAS COMPANY RIGHT OF WAY FOR GAS PIPELINE, 30 FEET WIDE IN SECTION 16, 50 FEET WIDE ELSEWHERE.

U.S. DOE RIGHT OF WAY NUMBER NM-55699 FOR ACCESS RAILROAD, 150 FEET WIDE.

EDDY COUNTY RIGHT OF WAY FOR ACCESS ROADS INCLUDES RIGHT OF WAY NUMBER NM-4130 FOR THE SOUTH ACCESS ROAD WHICH IS 150 FEET WIDE.

J.C. MILLS, ABERNATHY, TEXAS. GRAZING LEASE.

KENNETH SMITH, CARLSBAD, NEW MEXICO. GRAZING LEASE.

W.L. MOBLEY, CARLSBAD, NEW MEXICO. GRAZING LEASE.

NOTES

1. ZONE I IS A FENCED AREA OF APPROXIMATELY 35 ACRES. IT CONTAINS ALL SURFACE FACILITIES WITH THE EXCEPTION OF SALT STORAGE PILES, PARKING LOT, LANDFILL AND WASTE WATER STABILIZATION LAGOONS.
2. ZONE II OVERLIES THE MAXIMUM EXTENT OF THE AREA AVAILABLE FOR UNDERGROUND DEVELOPMENT. THE PORTION OF ZONE II LOCATED OUTSIDE THE DOE EXCLUSIVE USE AREA IS PRESENTLY MANAGED BY THE BLM.
3. WIPP SITE BOUNDARY (WSB) PROVIDES A ONE MILE BUFFER AREA AROUND THE AREA AVAILABLE FOR UNDERGROUND DEVELOPMENT. PORTIONS OF WSB ARE PRESENTLY MANAGED BY THE BLM.

This Illustration for Information Purposes only.

Explanation To Figure 2.1-4

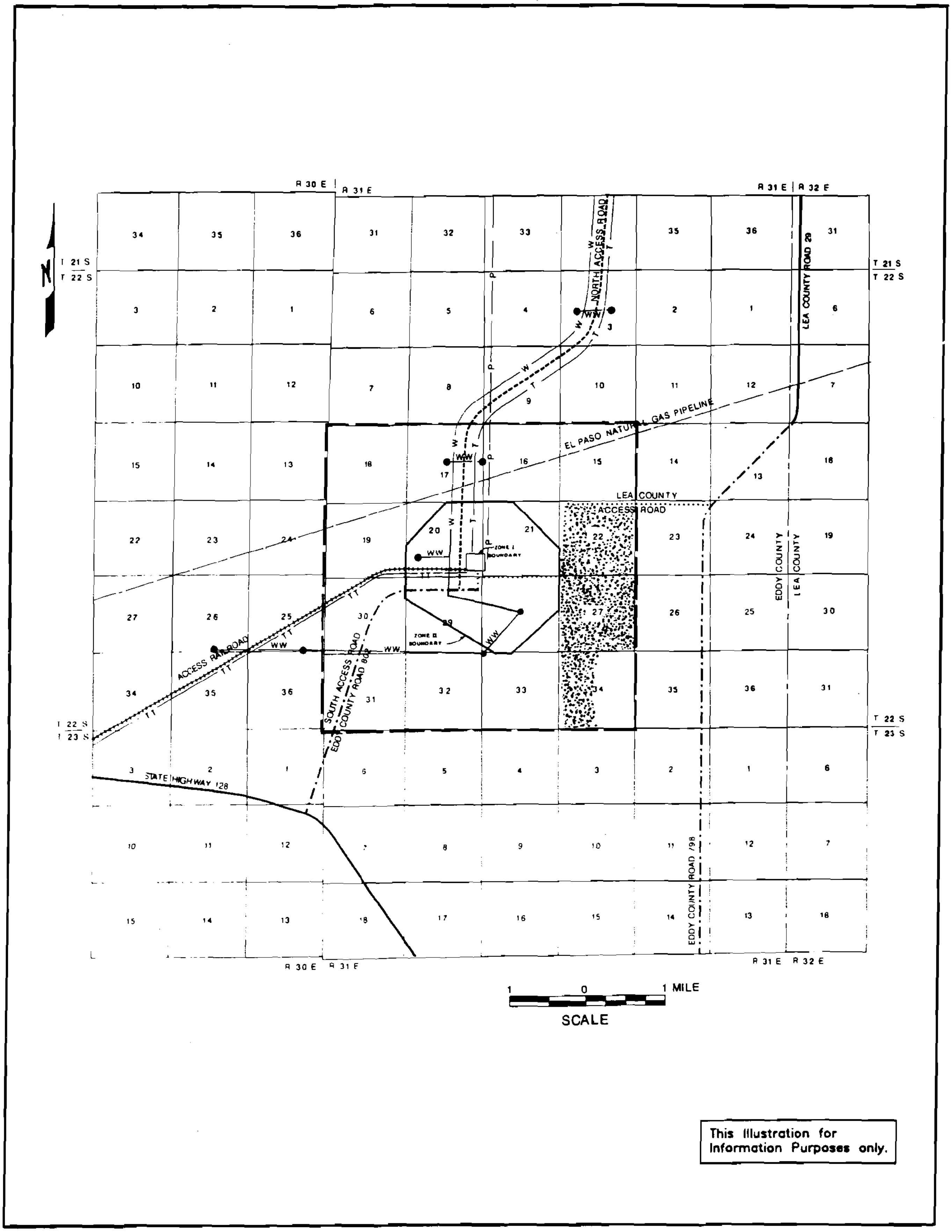


FIGURE 2.1-5
Potash Leases Within the WIPP Site Boundary

LEGEND

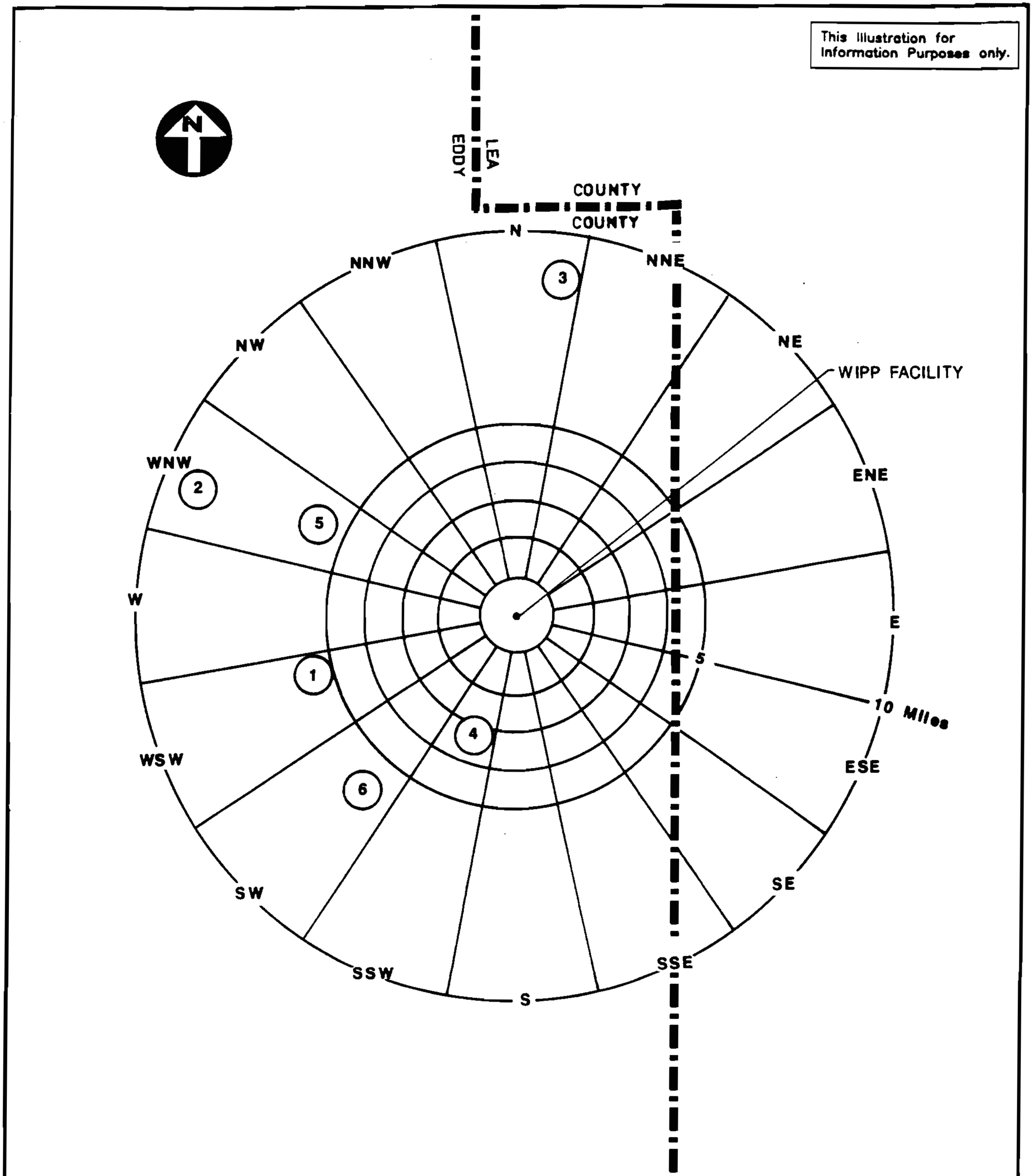
Symbol	Description
▬▬ ▬▬	WIPP SITE BOUNDARY
——W——	U.S. DOE RIGHT OF WAY NUMBER NM-53809, FOR WATERLINE, 50 FEET WIDE. THE DOE HAD AGREED WITH THE CITY OF CARLSBAD TO ALLOW INDIVIDUALS TO TAP THIS LINE LOCATED WITHIN THE NORTH ACCESS ROAD RIGHT OF WAY
——WW——	STOCK WATER TANKS AND TAP LINES CONNECTED TO THE MAIN WIPP WATERLINE
——P——	SOUTHWESTERN PUBLIC SERVICE COMPANY RIGHT OF WAY NUMBER NM-43203 FOR POWERLINE, 60 FEET WIDE
——T——	GENERAL TELEPHONE OF THE SOUTHWEST RIGHT OF WAY FOR TELEPHONE LINE, 30 FEET WIDE, LOCATED WITHIN THE NORTH ACCESS ROAD RIGHT OF WAY
——TT——	GENERAL TELEPHONE OF THE SOUTHWEST RIGHT OF WAY NUMBER NM-60174 FOR TELEPHONE LINE, 30 FEET WIDE, LOCATED WITHIN THE RAILROAD RIGHT OF WAY
- - - - - - -	U.S. DOE RIGHT OF WAY NUMBER NM-55675 FOR NORTH ACCESS ROAD, 170 FEET WIDE
——┤ ├——	EL PASO NATURAL GAS COMPANY RIGHT OF WAY FOR GAS PIPELINE, 30 FEET WIDE IN SECTION 16, 50 FEET WIDE ELSEWHERE
++++++++	U.S. DOE RIGHT OF WAY NUMBER NM-55699 FOR ACCESS RAILROAD, 150 FEET WIDE
·—·—·—·	EDDY COUNTY RIGHT OF WAY FOR ACCESS ROADS INCLUDES RIGHT OF WAY NUMBER NM-4130 FOR THE SOUTH ACCESS ROAD WHICH IS 150 FEET WIDE
(stippled box)	**INTERNATIONAL MINERALS AND CHEMICALS CORPORATION, POTASH LEASES M3671 AND NM0384571**

NOTES

1. ZONE I IS A FENCED AREA OF APPROXIMATELY 35 ACRES. IT CONTAINS ALL SURFACE FACILITIES WITH THE EXCEPTION OF SALT STORAGE PILES, PARKING LOT, LANDFILL AND WASTE WATER STABILIZATION LAGOONS.
2. ZONE II OVERLIES THE MAXIMUM EXTENT OF THE AREA AVAILABLE FOR UNDERGROUND DEVELOPMENT. THE PORTION OF ZONE II LOCATED OUTSIDE THE DOE EXCLUSIVE USE AREA IS PRESENTLY MANAGED BY THE BLM.
3. WIPP SITE BOUNDARY (WSB) PROVIDES A ONE MILE BUFFER AREA AROUND THE AREA AVAILABLE FOR UNDERGROUND DEVELOPMENT. PORTIONS OF WSB ARE PRESENTLY MANAGED BY THE BLM.

This Illustration for Information Purposes only.

Explanation to Figure 2.1-5



1. NASH DRAW MINE (WESTERN AG-MINERALS)
2. INTERNATIONAL MINERALS AND CHEMICAL CORP. MINE AND PLANT
3. NEW MEXICO POTASH CORP. MINE AND PLANT
4. MILLS RANCH
5. SMITH RANCH
6. MOBLEY RANCH

FIGURE 2.1-6
Mines and Ranches Within 10 Mile Radius of the WIPP Facility

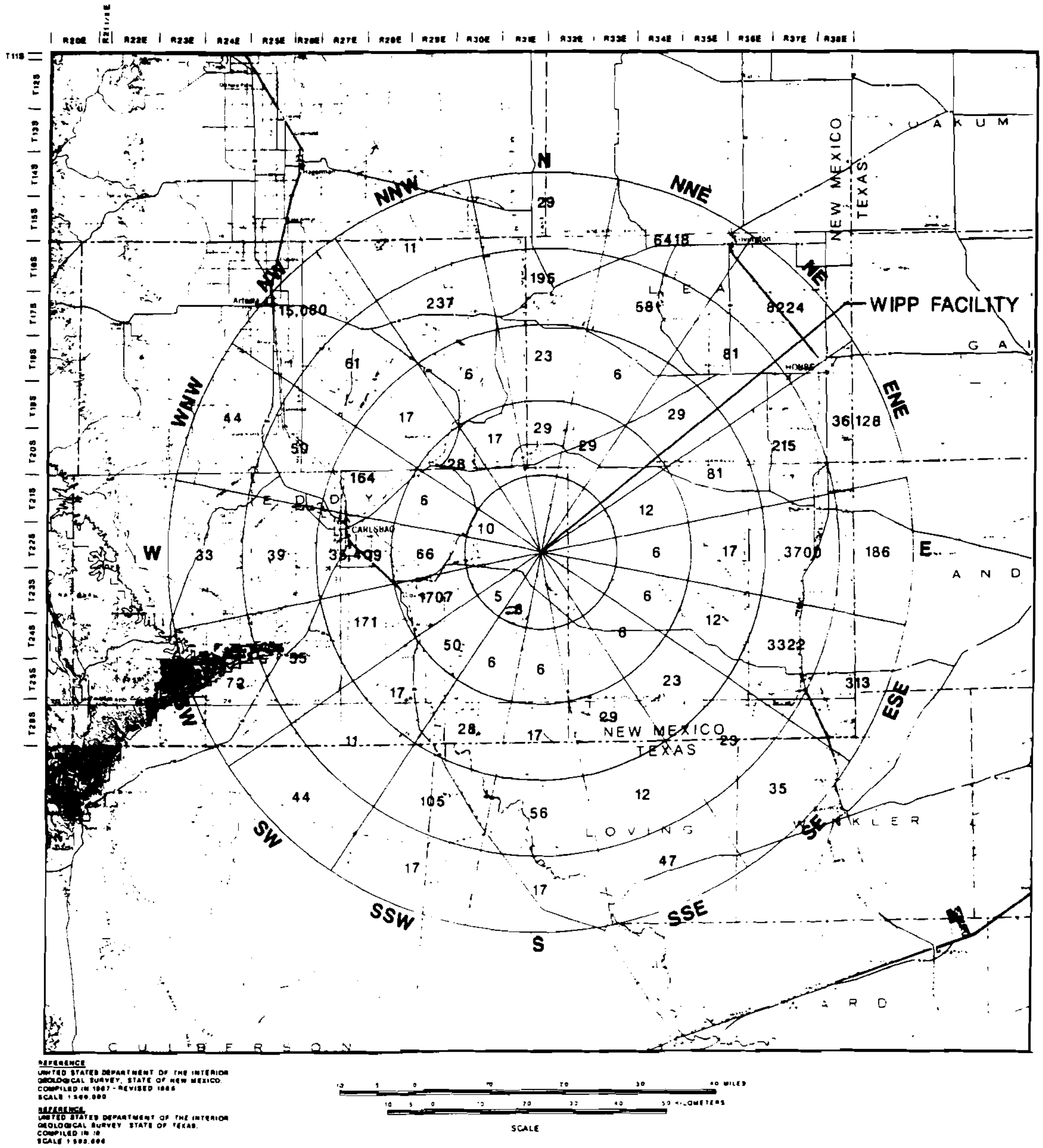


FIGURE 2.1-7
1985 Population Within 50 Mile Radius
of the WIPP Facility

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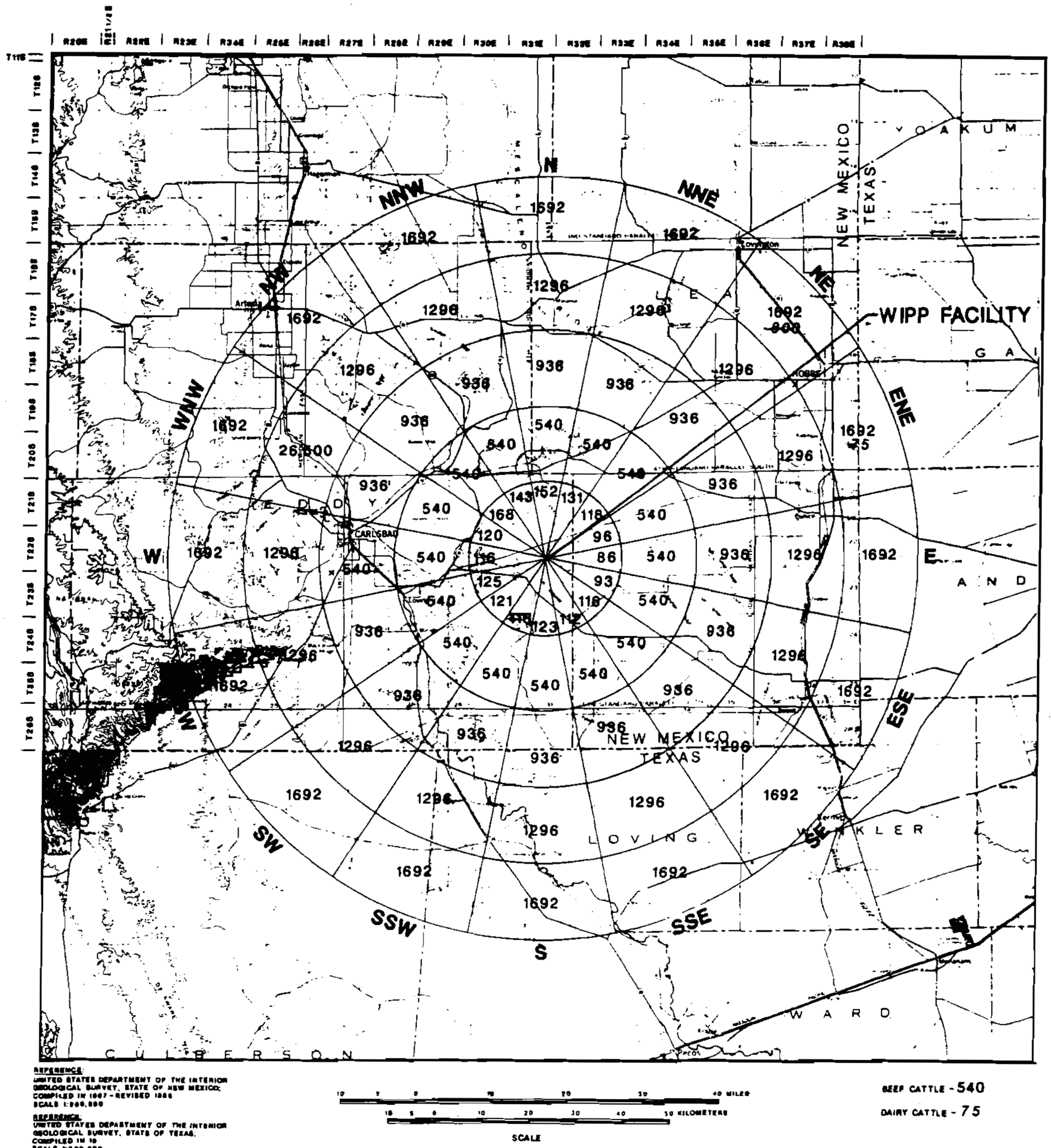


FIGURE 2.1-8
1985 Average Yearly Cattle Density
Within 50 Miles of the WIPP Facility

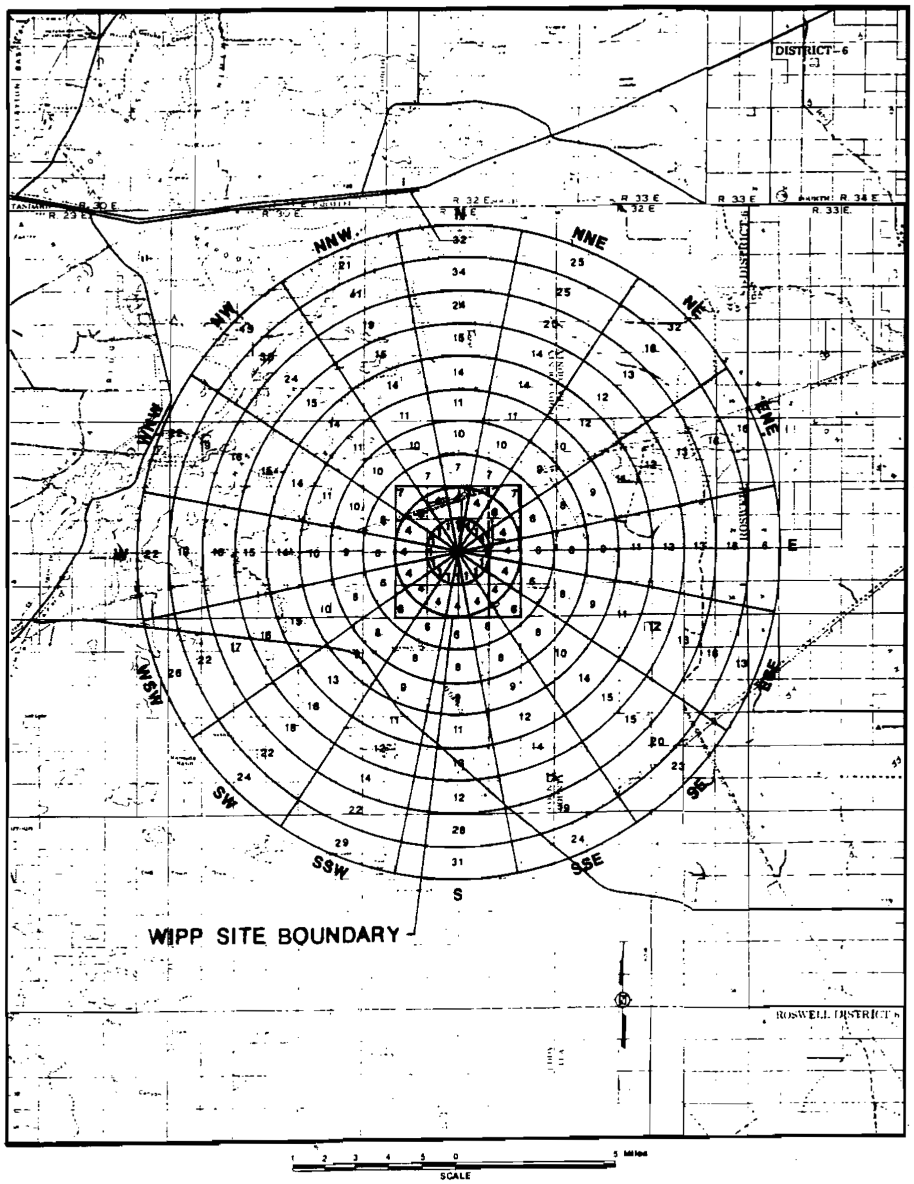


FIGURE 2.1-9
1985 Average Yearly Cattle Density
Within 10 Miles of the WIPP Facility

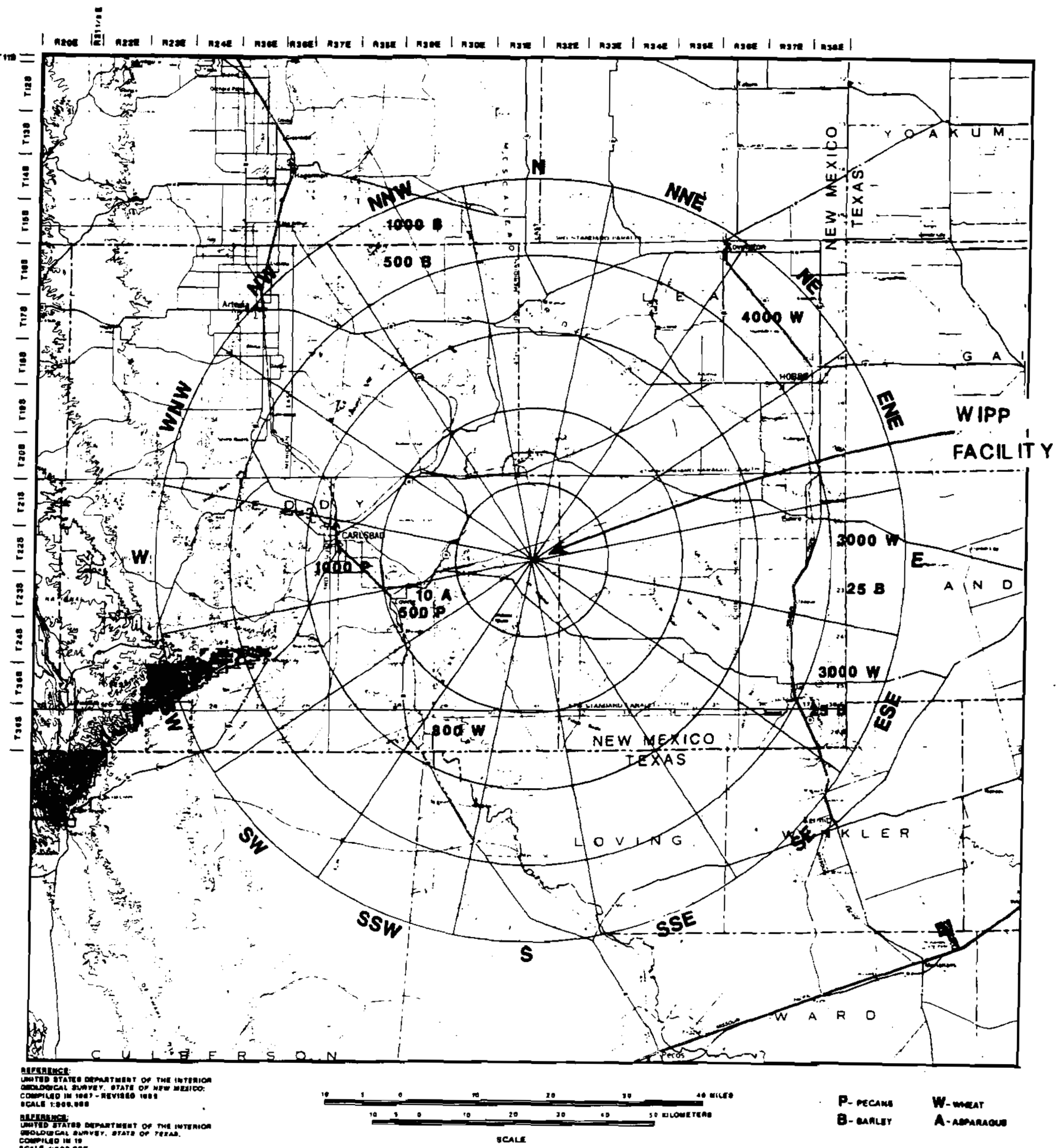


FIGURE 2.1-10
1985 Acres Planted in Edible Agriculture and Commercial Crops Within 50 Miles of the WIPP Facility

2.2 NEARBY INDUSTRIAL, TRANSPORTATION AND MILITARY FACILITIES

The extractive activities, transportation routes, and military operations that may have a potential affect on operations at the WIPP facility are discussed in this section.

2.2.1 INDUSTRIAL AND COMMERCIAL FACILITIES

There are no industrial facilities within a five-mile radius of the WIPP facility. Ranching is the only commercial operation within five miles of the facility. The five-mile radius encompasses grazing allotments of three separate ranches; however, only one ranch house is located in the area. It is about 3.5 miles from the center of the WIPP facility in the south southwest sector. There are three potash mines and two chemical processing plants (adjacent to the mines) between five and 10 miles of the WIPP facility.

2.2.2 EXTRACTIVE ACTIVITIES

Within a five-mile radius of the center of the WIPP facility there are 14 gas wells which were active as of 1987. They generally tap Pennsylvanian strata which is about 14,000 ft deep in the vicinity of the WIPP facility. The locations of these wells can be divided into three groups (Figure 2.2-1). Three wells are located northwest of the center of the WIPP facility at a distance of about four or five miles. At approximately four or five miles ESE of the center of the WIPP facility, there are two single wells, two more four or five miles to the south, and seven wells are located to the southwest. The nearest is approximately three miles SSW of the center of the facility.

Outside of the five-mile radius, but within 10 miles of the center of the WIPP facility, there are 20 more gas wells.

Seven of the gas wells located within the five-mile radius also produce some oil and there are 42 oil and gas wells located five or ten miles from the WIPP facility (Figure 2.2-1). All wells are designated as operational in the New Mexico Oil and Gas Commission files. The wells not necessarily currently producing.

2.2.3 MILITARY FACILITIES

There are no military facilities within a five-mile radius of the WIPP facility; however, some military installations in New Mexico and Texas have missions that might affect the region including the WIPP facility. The location of these military facilities is shown in Figure 2.2-2.

2.2.3.1 Fort Bliss/Biggs AAF, Texas

Biggs Army Air Field, located at Fort Bliss about 156 miles southwest of the WIPP facility, currently has aircraft operations within five miles of the WIPP facility. These aircraft operations are summarized in Table 2.2-1.

2.2.3.2 Holloman Air Force Base, New Mexico

The Air Force Geophysics Laboratory, located at Holloman Air Force Base about 138 miles northwest of the WIPP facility, launches instrumented balloons in the conduct of its mission. The payload of these balloons range up to 1200 pounds. Parachutes are used for payload recovery. Data on the balloon flights are given in Table 2.2-1.

2.2.3.3 White Sands Missile Range

The main facilities of White Sands Missile Range (WSMR) are located about 160 miles west of the WIPP facility (see Figure 2.2-2). The nearest restricted zone associated with WSMR is the McGregor Range which is about 102 miles west of the WIPP facility. About six aircraft from WSMR fly over the WIPP facility in a year (Table 2.2-1).

Several missile and drone test activities are conducted at WSMR. None of these missiles or drones is tested with live warheads or overfly the WIPP facility. A preliminary review of known missile and drone impact points shows that none has occurred within 100 miles of Carlsbad, New Mexico, which is 26 miles west of the site.

All missiles and drones flown at WSMR are equipped with fail safe devices or flight safety systems that are initiated either automatically, by the test conductor, or by a flight safety officer. Almost all of the missiles and drones discussed herein are monitored by a real-time computer system, which provides a continuous update of the test vehicles' impact point. This minimizes the potential that a malfunction during testing may affect the WIPP facility.

The WSMR occasionally uses off-range overflight corridors where missiles are launched from Fort Wingate, New Mexico (270 miles north northwest from the southern end of WSMR and 350 miles northwest of the WIPP facility); Green River, Utah (530 miles north northwest from the southern end of the WSMR and 580 miles northwest of the WIPP facility); and Blanding, Utah (420 miles north northwest from the southern end of WSMR and 490 miles northwest of the WIPP facility). These corridors have not been used in recent years. The locations of these off-range launch sites are shown in Figure 2.2-3. Because of the above considerations, operations at the WSMR do not pose a threat to the WIPP facility.

2.2.4 OIL AND GAS PIPELINES

There are no crude oil pipelines within five miles of the WIPP facility. There are, however, 16 natural gas pipelines located within a five-mile radius of the WIPP facility (Figure 2.2-4). Thirteen of these pipelines have right-of-way lease permits issued by the U.S. Department of the Interior(DOI), Bureau of Land Management (BLM) for access to federal land, while four have permits issued by the State of New Mexico, State Land Office, for access to state lands. Two pipelines require both federal and state right-of-way lease permits. There is one pipeline located on federal land for which no right-of-way lease permit information is available.

The natural gas pipelines are owned and operated by three companies:

- El Paso Natural Gas Company, El Paso, Texas;
- Natural Gas Pipeline Company of America, Chicago, Illinois;
- Transwestern Pipeline Company, Roswell, New Mexico.

Figure 2.2-4 shows the location of each pipeline within five miles of the WIPP facility, along with pertinent information regarding each pipeline.

The State of New Mexico requires that all natural gas pipelines be buried not less than 20 inches deep, except if hard rock is encountered, which would require blasting. The pipelines are then buried to the greatest depth possible without blasting, but in no such event less than eight inches. Pipelines laid on lands subject to cultivation must have a minimum of 20 inches of cover.

An on-site inspection of the immediate areas surrounding the WIPP facility revealed that sections of the 12-3/4-inch Eunice to Carlsbad Line (Figure 2.2-4) are completely void of overburden. It is not apparent whether exposed sections of the pipeline were caused by natural forces of erosion, i.e., wind, water, etc., or whether the pipelines were uncovered during various types of exploration and construction work that have been conducted in the area. Since on-site inspection did not include all pipelines in the area, sections of other pipelines may also be exposed.

The U.S. Department of Transportation (DOT) requires natural gas pipelines to be constructed with isolation valves located at points that are not more than 20 miles from each other throughout the total span of the pipeline. An isolation valve is also located at the site of each natural gas well and each natural gas pipeline. Eight pipelines extend beyond the boundaries of the five-mile radius area (Figure 2.2-4). The locations of the isolation valves that control the flow of the natural gas within a five-mile radius of the WIPP facility are shown in Figure 2.2-4.

Natural gas pipelines are regulated by the National Transportation Safety Board (NTSB) in 49 CFR 192. The NTSB establishes safety zones for habitation near high-pressure gas lines. This has been established as 220 yards on each side for pipelines similar to the one that crosses the WIPP Site Boundary. In addition, the Nuclear Regulatory Commission, in NUREG-0625 has established a standoff distance of 0.5 miles.[1] Therefore, this pipeline poses no risk to the WIPP facility.

One major non-oil or gas pipeline lies within the WIPP Site Boundary. This is a 24 inch City of Carlsbad water pipeline that provides the WIPP facility with potable water. This line is described in greater detail in Section 4.4.4.1.

2.2.5 WATERWAYS

There are no navigable waterways within a five-mile radius of the WIPP facility. The nearest river is the Pecos River which is 14 miles west of the WIPP facility.

2.2.6 AIRPORTS AND AVIATION ROUTES

There are no airports within a five-miles radius of the site. The nearest airstrip, 12 miles north of the WIPP facility, is privately operated by Transwestern Pipeline Company. The nearest commercial airport is Cavern City, 28 miles west of the WIPP facility near Carlsbad. Other major airports in the area are Eunice (32 miles east of the WIPP facility), Carlsbad Caverns (42 miles southwest of the site), Hobbs Industrial Airpark (42 miles northeast of the WIPP facility), Jal (40 miles southwest of the WIPP facility), Lovington (45 miles northeast of the WIPP facility), and Artesia (51 miles northwest of the WIPP facility). The relationship of these airports to the WIPP facility is shown in Figure 2.2-5.

Portions of two federal airways are within five miles of the WIPP facility. Each airway is 10 miles wide. The centerline of low altitude airway V-102 is three miles northwest of the WIPP facility and high altitude airway J-15 is four miles northeast of the WIPP facility at their nearest points. These airways are shown in Figure 2.2-5. Traffic data for these airways are given in Table 2.2-2. The combined traffic on both routes is about 28 Instrument Flight Rule (IFR) flights per peak day. There are no approach or landing zones within five miles of the WIPP facility.

J-15 is a major northwest southeast airway that is also used by military aircraft. It can be assumed that from time to time military aircraft carrying ordnance will fly this airway. The ordnance could be carried by either military cargo or combat aircraft. The exact number of military flights carrying ordnance on this airway is unavailable.

2.2.7 LAND TRANSPORTATION

2.2.7.1 Roads and Highways

Other than the highways that provide north or south access, only one other highway lies within a five-mile radius. This is New Mexico Highway 128, which is between four and five miles southwest of the WIPP facility (Figure 1.1-1). It connects the small community of Jal with NM 31, which leads into Loving and it provides access to Carlsbad. New Mexico Highway 128 is used by ranchers, school buses, potash miners, and by oil and gas company vehicles occasionally transporting drilling rigs (wide loads) to sites in the area. In 1985, it had an average daily traffic flow of about 400 vehicles. Several dirt roads in the area are maintained for ranching, pipeline maintenance, and access to drilling sites. The north and south access roads to the WIPP facility are described in Section 4.4.7.1.

2.2.7.2 Railroads

Except for the rail spur that serves the WIPP facility (see Section 4.4.7.2), there are no railroad lines within the five-mile radius of the WIPP facility. Rail lines to Western Ag-Minerals Corp. Nash Draw operation, International Minerals and Chemical Corp., and the New Mexico Potash Corp. plant, all potash mining operations, are located between six and 10 miles of the WIPP facility. The Nash Draw mine line has a spur that connects with the Atchison, Topeka & Santa Fe Railroad. All railroad lines within the general vicinity of the WIPP facility are used specifically to transport potash ore.

2.2.8 PROJECTED INDUSTRIAL GROWTH

At present, there is no industrial activity within five mile of the WIPP facility nor is any projected for the future; however, there are extractive activities within this area. Present activity includes gas wells (potash leases in the area are not active); but, no new extractive activity within the WIPP Site Boundary will be permitted.

Three potash mining operations located around the WIPP facility were contacted concerning their anticipated growth; i.e., the Western Ag-Minerals Corp. operation at Nash Draw, International Minerals and Chemical Corp. along NM 31, and the Kerr-McGee operation (now New Mexico Potash Corp.) to the north of the WIPP facility along U.S. 62-180. At least two of these operations reported the distinct possibility of expanding into a two to five mile annulus around the WIPP facility at some later date; one of the operations, Western Ag-Minerals, is almost within the annulus at the present time and its main ore body lay within the annulus. If these operations expand, there is a high probability that at least two new shafts will be sunk in the approximate two to five miles radius. Plans for expansion are not firm because they are dictated in most cases by the market conditions for potash. Even if this expansion were to occur, it would not pose a safety risk for the WIPP facility since development would be restricted to areas outside the WIPP Site Boundary.

Except for the possible potash mining expansion discussed above, no significant increase in economic activity is forecast for the future within five miles of the WIPP facility. No significant change is forecast for the one highway within five miles of the WIPP facility; however, the construction of WIPP necessitated two new paved access roads to both NM Highway 128 and U.S. Highway 62-180 (Figure 1.1-1) and the extension of the Western Ag-Minerals mine rail spur six miles to the WIPP facility. There are no aircraft landing strips within five miles of the WIPP facility.

2.2.9 EVALUATION OF POTENTIAL ACCIDENTS

Most of the nearby industrial, transportation and military activities are sufficiently removed from the WIPP facility so that the potential risk to the facilities is small. There are no industrial sites, military sites, water transport routes or railroad routes within five miles of the WIPP facility and the nearest highway is more than four miles from the facility. The risk to the WIPP facility from these activities can be considered insignificant.

The activities that may present a potential risk to the WIPP facility are existing gas wells, gas pipelines and air travel. The nearest gas well is approximately three miles from the center of the WIPP facility while the nearest gas pipeline is slightly more than one mile. The greatest risk from the gas would be an explosion; however, at a distance of more than one mile, damage to WIPP facility surface structures from an explosion would be expected to be very small and would not cause any release of radioactive material.

Air travel presents the only other potential risk of any importance to the WIPP facility since two airways pass within five miles of the WIPP facility. Nevertheless, considering the number of flights per year on the two airways, the probabilities of commercial or military airplane crash per mile of flight and the small area covered by the WIPP facility surface structures, the probabilities of an air disaster at the WIPP facility are very small.

Federal Aviation Administration regulations do not allow commercial or private aircraft to fly within 1000 feet of buildings. Whenever it appears that this rule has been violated by any aircraft, including military aircraft, an Unusual Occurance Report (UOR) is prepared on the incident and submitted to the DOE in accordance with Order DOE 5000.3.

References for Section 2.2

1. U.S. Nuclear Regulatory Commission, Report of the Siting Policy Task Force, NUREG-0625, September 1979.

Table 2.2-1

MILITARY AIRCRAFT OPERATIONS IN THE VICINITY OF THE WIPP FACILITY

Military Facility	Aircraft Type	Flights/Yr	Minimum Alt., Ft.	Ordnance Carried
Fort Bliss, Texas	U-8, U-21	24	8,000 MSL	None
Biggs AAF	UH-1H	14	500 AGL	None
Air Force Geophysics Laboratory	Balloons	60	NA*	Squibs, six grains maximum
White Sands Missile Range	B-52, FB-111	1	15,000 AGL	Short-range attack missiles

*Not Applicable

Table 2.2-2

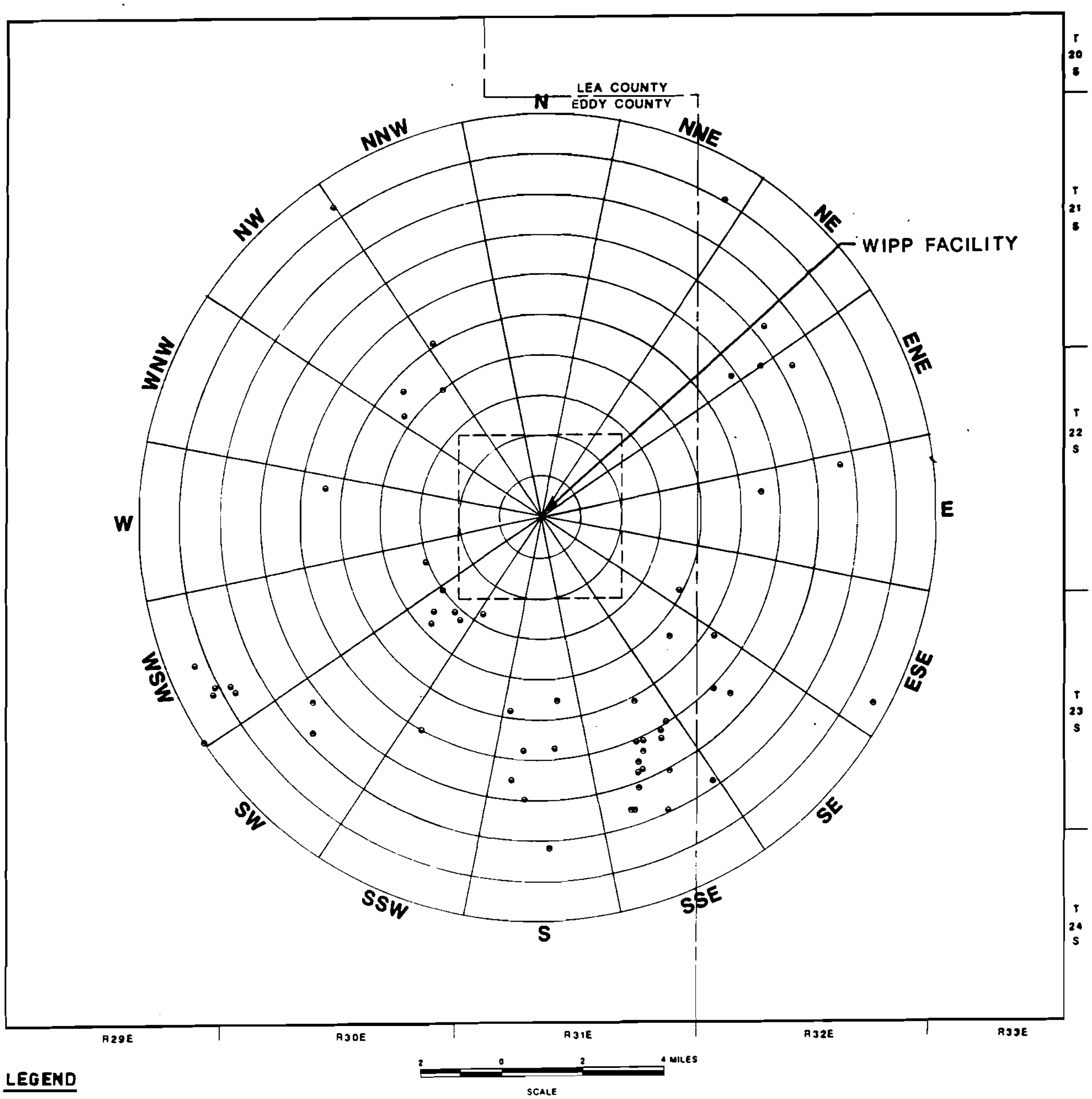
AVIATION ROUTES WITHIN 5 MILES OF THE WIPP FACILITY*

Name of Route	Minimum Altitude	Origin and Destination	Aircraft Type	Flights/Day	Flight Rule
FAA V-102	3,000 ft AGL	Carlsbad VORTAC Hobbs VORTAC	Commercial, military, and private	5**	IFR
FAA J-15	18,000 ft MSL	Wink VORTAC Roswell VORTAC	Commercial, military, and private	23	IFR

*U.S. Department of Transportation, Federal Aviation Administration, Air Traffic Service, "En Route IFR Peak Day Charts, FY 1976."

**Flights per day on V-102 does not include aircraft operating under Visual Flight Rules.

NOTE: 1976 was the last year day charts were logged by FAA. Local airfield does not monitor this information.



LEGEND

Gas Well
Oil Well
Oil and Gas Well

This Illustration for Information Purposes only.

FIGURE 2.2-1
1986 Operable Natural Gas and Oil Wells, 10 Mile Radius

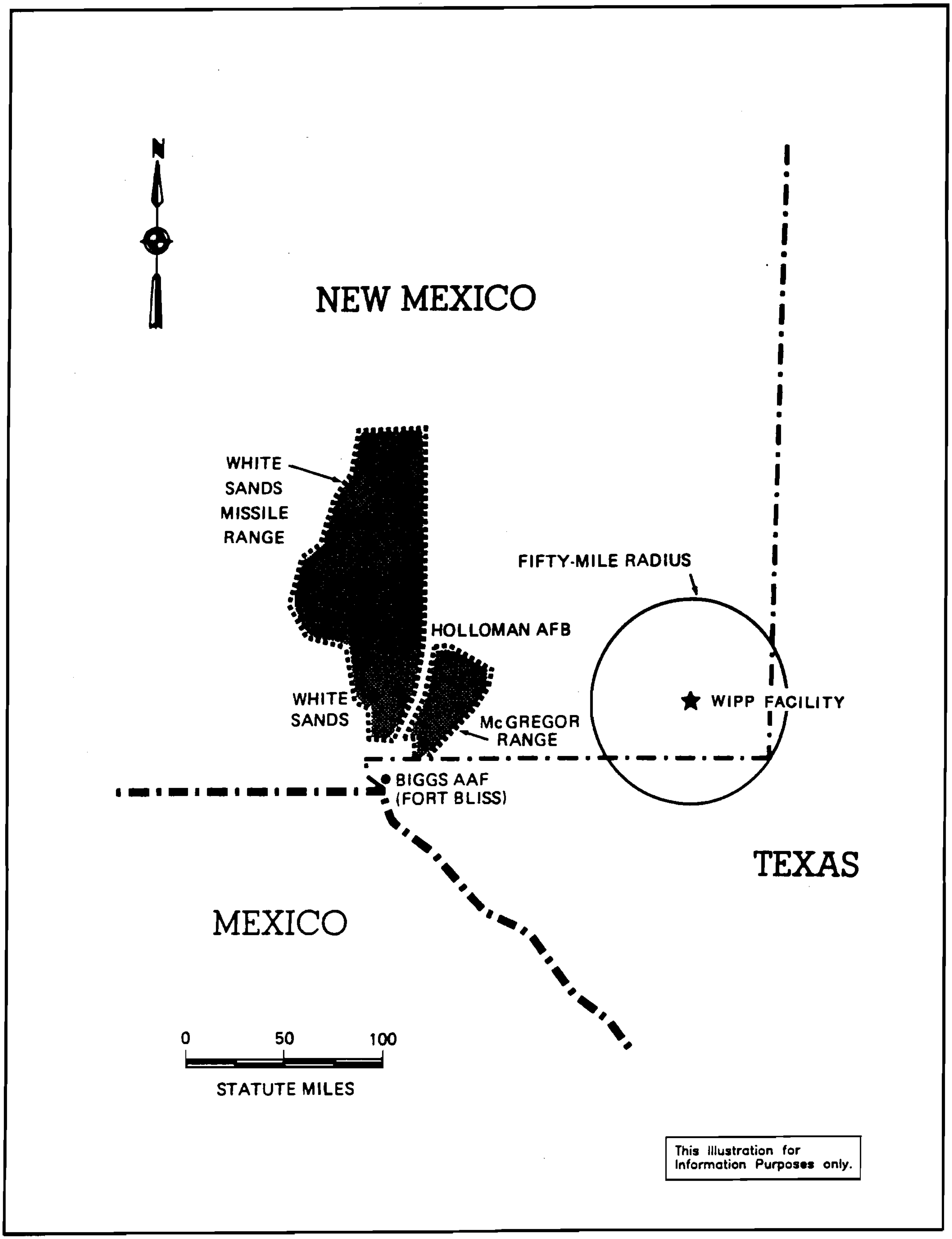


FIGURE 2.2-2
Military Facilities in the Area of the WIPP Facility

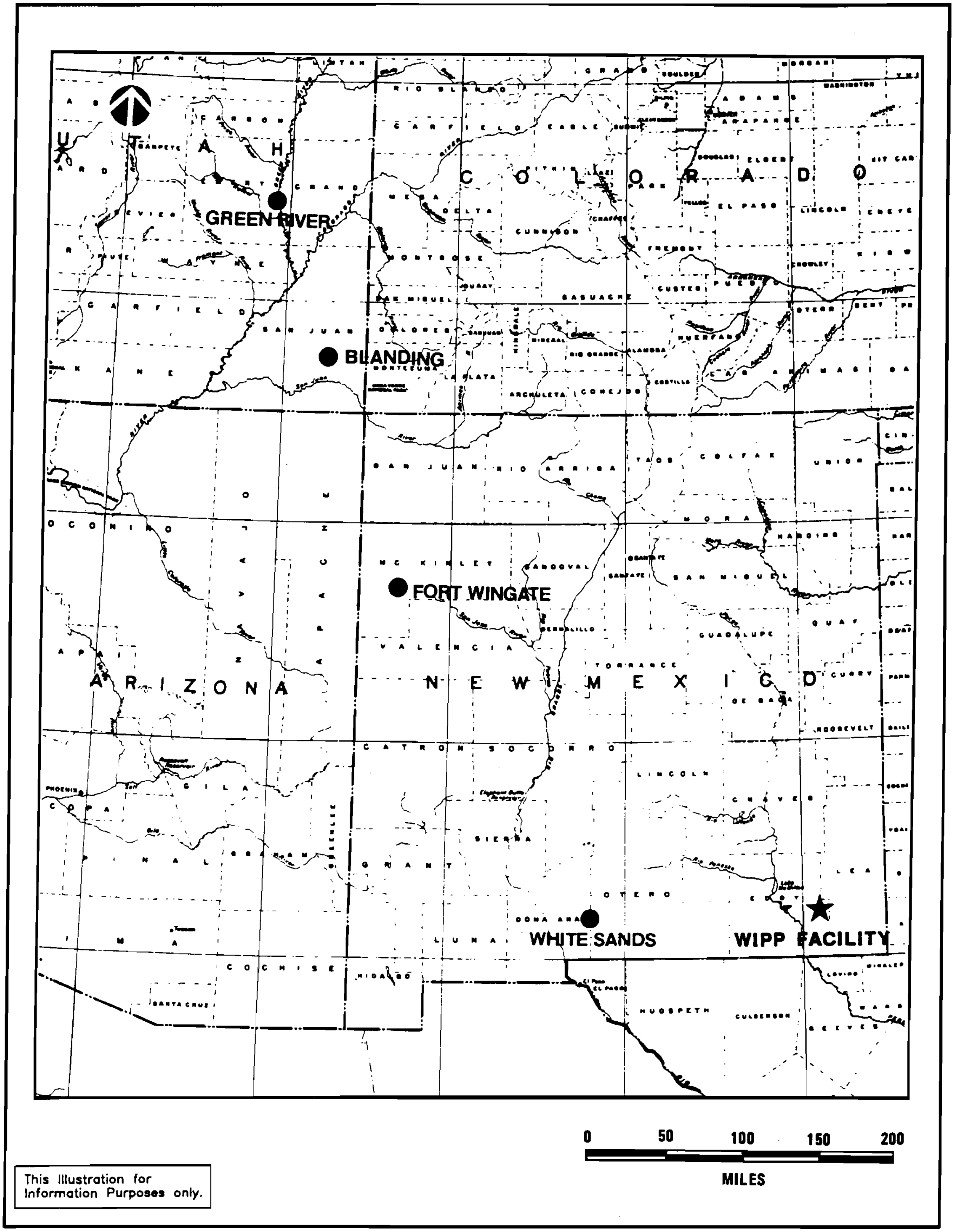


FIGURE 2.2-3
Missile Launch Sites in New Mexico and Utah

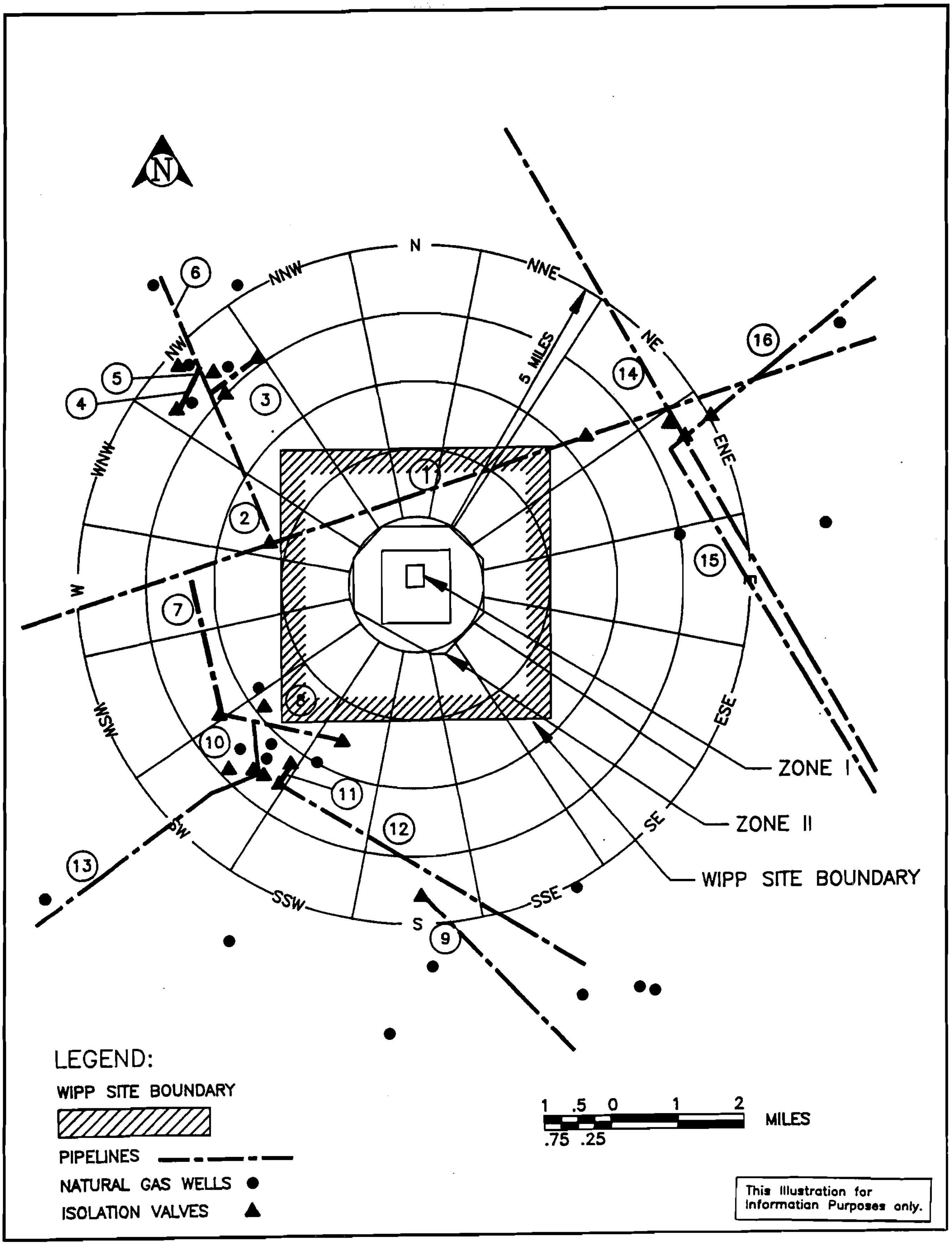


FIGURE 2.2-4
Natural Gas Pipelines and Wells, 5 Mile Radius

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(1) El Paso Natural Gas Co, Eunice-Carlsbad Line (LC060762) 12.75" Dia. Gas Line, Built 1942, Located 1.125 miles NNW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

(2) El Paso Natural Gas Co, James "A" No. 1 (NM17321) 4.5"/8.625" Dia. Gas Line, Built 1974, Located 2.375 Miles WNW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

(3) El Paso Natural Gas Co, Cabana No. 1 (NM18432) 4.5" Dia Gas Line, Built 1974, Located 4.25 Miles NW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

(4) El Paso Natural Gas Co, James "E" No. 1 (NM19974) 4.5" Dia Gas Line, Built 1974, Located 4.25 Miles NW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

(5) El Paso Natural Gas Co, El Paso "201" Spur Line (NM20125) 4.5" Dia Gas Line, Built 1974, Located 4.625 Miles NW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

(6) El Paso Natural Gas Co, James "C" No. 1 (RW18344) 6.625" Dia Gas Line, Built 1974, Located 4.625 Miles NW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

(7) El Paso Natural Gas Co, James Ranch Unit No. 1 (NM046228) (RW14190) 4.5" Dia Gas Line Built 1958, Located 3.06125 Miles WSW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

(8) El Paso Natural Gas Co, James Ranch Unit No. 7 (NM26987) 4.5" Dia Gas Line Built 1976, Located 2.625 Miles SW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

(9) El Paso Natural Gas Co, Arco State No. 1 (RW17822) 6.625" Dia Gas Line, Built 1971, Located 4.625 Miles S of WIPP. Operation Pressure 837, Burial Depth 24".

(10) El Paso Natural Gas Co, Lateral EE-4 (NM16959/(RW18065) 4.5" Dia Gas Line, Built 1973, Located 3.125 SW of WIPP. Operating Pressure 1200 PSIG, Burial Depth 36".

(11) Natural Gas Pipeline Co of America, Lateral EE-6 Built 1974, 4.5" Dia Gas Line, Built 1974, Located 3.2 Miles SSW of WIPP. Operating Pressure 1200 PSIG, Burial Depth 36".

(12) Natural Gas Pipeline Co of America, Lateral EE-3 (NM16029) 8.625" Dia Gas Line, Built 1972, Located 3.4 Miles SSW of WIPP. Operating Pressure 1200 PSIG, Burial Depth 36".

(13) Natural Gas Pipeline Co of America, Lateral EE-7 (NM22471), 4.5" Dia Gas Line, Built 1974 Located 4.7 miles SW of WIPP. Operating Pressure 1200 PSIG, Burial Depth 36".

(14) Transwestern Pipeline Co, West Texas Lateral (NM070224) 24" Dia Gas Line, Built 1960, Located 4.5 ENE of WIPP. Operating Pressure 930 PSIG, Burial Depth 30".

(15) Transwestern Pipeline Co, West Texas Lateral (NM8722) 30" Dia Gas Line, Built 1969, Located 4.25 Miles ENE of WIPP. Operating Pressure 930 PSIG, Burial Depth 30".

(16) Transwestern Pipeline Co, Monument Lateral (NM073482) 10" Dia Gas Line, Built 1960, Located 4.5 Miles ENE of WIPP. Operating Pressure 930 PSIG, Burial Depth 30".

This Illustration for Information Purposes only.

Explanation to Figure 2.2-4

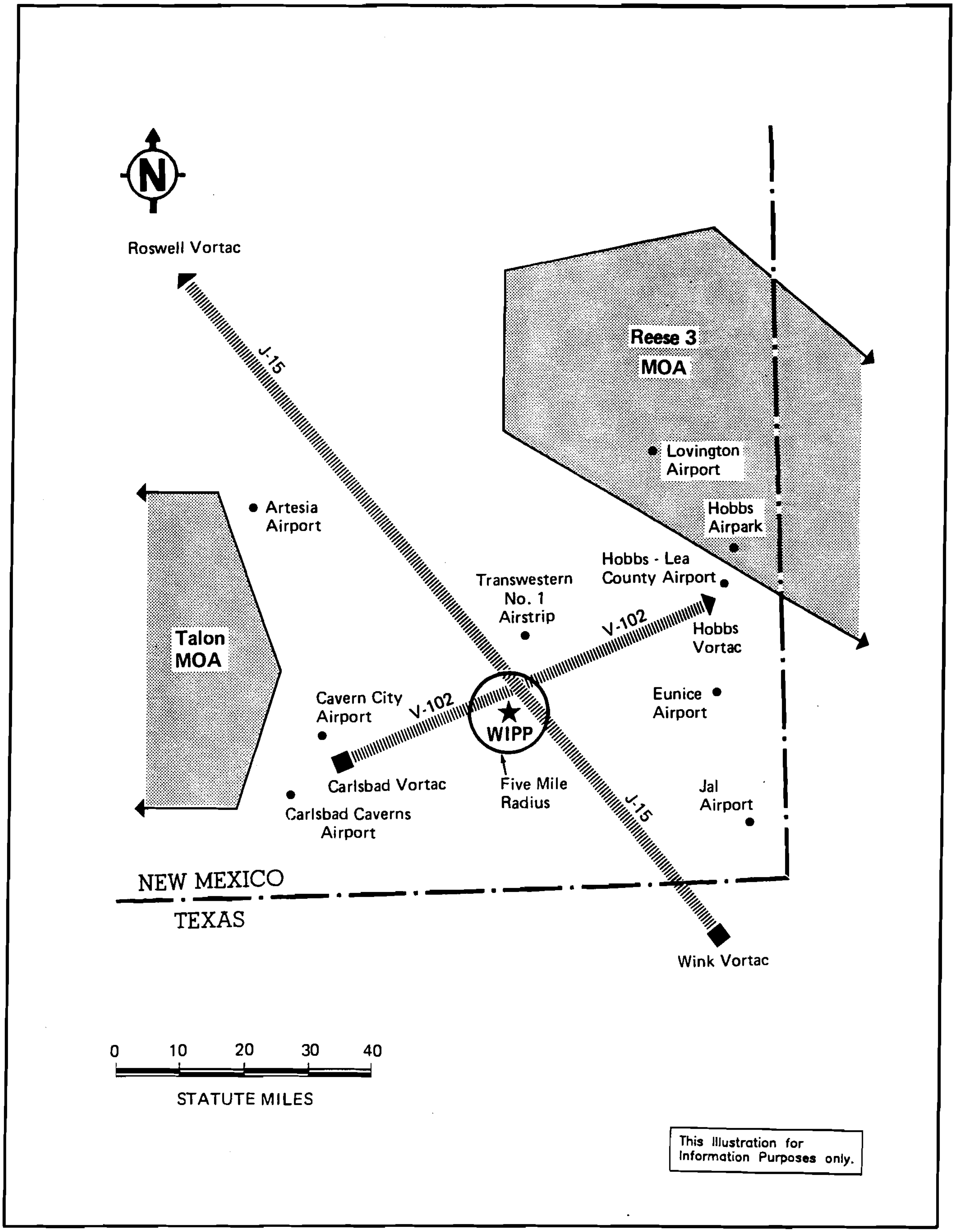

FIGURE 2.2-5
Airports and Aviation Routes
Adjacent to the WIPP Facility

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2.3 METEOROLOGY

2.3.1 REGIONAL CLIMATOLOGY

Information used to evaluate the climate of the area surrounding the WIPP facility consists of climatological data summaries from recording stations in New Mexico, local climatological data summaries from Roswell, New Mexico, and a wind summary from Midland-Odessa, Texas. The climatological data were obtained from the Environmental Data and Information Service of the National Oceanic and Atmospheric Administration, Asheville, North Carolina. Precipitation summaries from stations at Carlsbad, the Western Ag-Mineral Mine (formerly Duval potash mine), Jal, Pearl, and Ochoa were also included because of their proximity to the WIPP facility (Figure 2.3-1). The local climatological data summaries provide extreme and normal values of meteorological parameters for the period of record at Roswell (about 80 miles from the WIPP facility), which were used to characterize the regional climatology. Most of the data used in this report is historical. However; where possible, tables were updated. Section 2.3.3 contains data collected at the WIPP facility for 1985 and 1986.

2.3.1.1 General Climate

The climate of the region is semi-arid, with generally mild temperatures, low precipitation and humidity, and a high evaporation rate. Winds are moderate and most commonly from the southeast. During the winter months, the weather is dominated by a high-pressure system often situated in the central portion of the western United States and a low-pressure system commonly located in north central Mexico. During the summer, the region is affected by a low-pressure system normally situated over Arizona. The regional climate is significantly affected by these large-scale pressure systems and their seasonal variations.[1-3] These low-pressure systems set up the moist southerly flow that produces afternoon thunderstorms that characterize summer weather. The high-pressure systems are responsible for the clear dry weather common throughout the fall and winter months.

The region, meteorologically referred to in New Mexico as the Southeastern Plains, is an area of over 30,000 mi^2. It marks the western extremity of the Great Plains, which end at the Sacramento and Guadalupe Mountains, about 60 miles west of the site. It is bounded on the east and south by an erosional escarpment in central Texas. Elevations range from less than 3,000 feet in the south and east to more than 4,000 feet in the north. The downslope to the east and south averages 600 ft/100 mi. The terrain is characterized by gently rolling hills of moderate relief that are dissected by many small dry stream valleys.

Although seasonal changes are distinct, moderate temperatures are typical throughout the year. Mean annual temperatures in southeastern New Mexico are near 60°F.[4] Temperatures in December through February show a large diurnal variation that averages 35°F at Roswell (the nearest National Weather Service station with appropriate data and an adequate period of record). Although about 75 percent of the winter days have morning temperatures below freezing, afternoon maximum temperatures average well up in the fifties and afternoon winter temperatures of 70°F or more are not uncommon. Nighttime lows average near 22°F and occasionally fall as low as 10°F. There are typically only two or three winter days when the temperature fails to rise above freezing. The lowest recorded temperature at Roswell was -29°F, in February 1905. During June through August, the temperature is about 90°F or above about 75 percent of the time, with readings of 100°F or higher occurring on a number of afternoons. However, even the hottest month, July, with average daily temperatures in the upper seventies, has morning lows below 64°F. The highest recorded temperature at Roswell was 110°F in July 1958. Temperature extremes for Roswell are summarized in Table 2.3-1.[1,6]

Precipitation in the WIPP facility region is light and unevenly distributed through the year, averaging 11 to 13 inches (Table 2.3-2).[5] Table 2.3-2 contains data for other sites near the WIPP facility for 1972-1976. Table 2.3-3 contains annual summaries for 1977-1985. 1981 and 1984 had unusually heavy rainfall, departing from the average by as much as 8 inches.[6] The location of those sites is shown in Figure 2.3-1. Winter is the season of least precipitation, averaging about 0.4 inches of rainfall a month. Snow averages about 10.6 inches a year at Roswell and seldom remains on the ground for more than one day at a time because of the typical above freezing temperatures in the afternoon.[2] About half the annual precipitation is from the frequent thunderstorms in June through September. Rains are usually brief but occasionally intense when moisture from the Gulf of Mexico spreads over the region. The minimum annual precipitation measured during the last 40 years at Roswell was 4.35 inches in 1956; the maximum recorded was 32.92 inches 1941. The maximum monthly precipitation was 9.56 inches in August 1916; the maximum 24-hour rainfall was 5.65 inches in November 1901.[1]

Prevailing winds for the Region, based on data from Roswell and Midland/Odessa are from the south, as shown in Figure 2.3-2. The normal mean wind speed at Roswell is 8.7 mi/h (see Table 2.3-4 for monthly values).[6]

2.3.1.2 Regional Meteorological Conditions for Design and Operating Bases

2.3.1.2.1 Heavy Precipitation

The maximum point rainfall at Roswell is shown in Table 2.3-5.[7] The maximum 24-hour snowfall in Roswell was 15.3 inches in December 1960. The greatest snowfall during a one-month period was 23.3 inches in February 1905.[1]

2.3.1.2.2 Thunderstorms and Hail

The region has about 40 thunderstorm days annually. About 87.5 percent of these occur from May to September.[1] A thunderstorm day is recorded if thunder is heard; but, the thunderstorm record is not related to observations of rain or lightning and does not indicate the severity of storms in the region.

Hail usually occurs in April through June and is not likely to develop more than three times a year. During a 39-year period at Roswell, hail was observed 97 times (about 2.5 times a year), occurring nearly two thirds of the time between April and June.[8] For the one square mile (32 to 33 N by 103 to 104W) surrounding the WIPP facility, hailstones 0.75 inches and larger were reported eight times from 1955 to 1967 (slightly less than once a year).

2.3.1.2.3 Tornadoes

For the period 1916-1958, 75 tornadoes were reported in New Mexico on 58 tornado days.[9] Data for 1953 through 1976 indicate a state-wide total of 205 tornadoes on 152 tornado days,[5] or an average of nine tornadoes a year on 6 tornado days. The greatest number of tornadoes in one year was 18 in 1972; the least was zero in 1953. The average tornado density in New Mexico during this period was 0.7 per 1,000 mi^2. Most tornadoes occur in May and June.[10] From 1955 through 1967, 15 tornadoes were reported in the one square mile containing the WIPP facility.[11]

H.C.S. Thom has developed a procedure for estimating the probability of a tornado striking a given point.[12] The method uses a mean tornado path length and width and a site-specific frequency. Applying Thom's method to the WIPP facility yields a point probability of 0.00081 on an annual basis, or a recurrence interval of 1,235 years. An analysis by Fujita yields a point tornado recurrence interval of 2,832 years in the Pecos River Valley.[13]

According to Fujita, the WIPP design basis tornado with a million year return period has a maximum wind speed of 183 mi/h, a rotational speed of 146 mi/h, a maximum translational speed of 37 mi/h, a minimum translational speed of five mi/h, a maximum rotational speed radius of 150 feet, a pressure drop of 0.69 lb/in^2, and a pressure drop rate of 0.08 $lb/in^2/s$.

2.3.1.2.4 Freezing Precipitation

The region of the WIPP facility has about one day of freezing rain or drizzle a year.[8] An ice accumulation of more than 0.25 inches has not been observed. Any ice accumulation that does occur is thin because of the scarcity of precipitation during the winter months and because daytime temperatures rise well above freezing.

2.3.1.2.5 Strong Winds

The maximum one-minute wind speeds recorded at Roswell are shown in Table 2.3-6. The fastest one-minute wind ever recorded at Roswell was 75 mi/h from the west in April 1953.[3] Windstorms with speeds of 50 knots or more occurred ten times (during the period between 1955 and 1967), about one a year.[10] The mean recurrence interval for annual extreme fastest mile wind speeds at 30 feet above the ground in southeastern New Mexico is shown in Table 2.3-7.[12,14] The 100-year recurrence 30-foot level wind speed in southeastern New Mexico is 82 mi/h. Based on a gust factor of 1.3,[15] the highest instantaneous gust expected once in 100 years at 30 feet above grade is 107 mi/h. The vertical wind profile for two 100-year recurrence intervals has been estimated from the 30-foot values using the 1/7 power law and is presented in Table 2.3-7. Reference 16 was used for the power law.

2.3.1.2.6 Restrictive Dispersion Conditions

Hosler[17] and Holzworth[18] analyze records from several National Weather Service stations with the objectives of characterizing atmospheric dispersion potential. Seasonal and annual frequencies of inversions based at or below 500 feet for the WIPP facility region are shown in Table 2.3-8. Most of these inversions are diurnal (radiation-induced) and occur because the radiation cooling at the earth's surface is increased by conditions that frequently exist at the WIPP facility. The conditions are lack of moisture, clear skies and low air density. When these conditions exist in the early morning, radiation lost from the surface is not adequately absorbed and reradiated by upper-level air to heat the air at the surface sufficiently. Consequently, the air at the surface quickly becomes cooler than the upper level air and the colder surface air becomes trapped.

Holzworth gives estimates of the average depth of vertical mixing, which indicates the thickness of the atmospheric layer available for the mixing and dispersion of effluents.[18] The seasonal afternoon mixing heights for the region (Table 2.3-9) range from 1,320 meters in winter to 3,050 meters in summer. Seasonal morning mixing heights in the region range from 300 meters in winter to 680 meters in summer.

2.3.1.2.7 Sandstorms

Blowing dust or sand may occur occasionally in the region due to the combination of strong winds, sparse vegetation and the semiarid climate. High winds associated with thunderstorms are frequently a source of localized blowing dust. Dust storms covering an extensive area are rare, and those that reduce visibility to less than one mile occur only with the strongest pressure gradients such as those associated with intense extratropical cyclones that occasionally form in the region during winter and early spring. Winds of 50 to 60 mi/h and higher may persist for several days if these pressure systems become stationary.[1] Ten windstorms of 58 mi/h and greater were reported during 1955-1967 within the one square mile in which the WIPP facility is located.[10] Blowing dust or sand may reduce visibility to less than five miles over an area of thousands of square miles. However, restrictions of less than one mile are quite localized and depend on soil type, conditions, cultivation practices and vegetation in the immediate area.[1]

2.3.1.2.8 Snow

The 100-year recurrence maximum snowpack for the WIPP facility region is 10 lb/ft^2.[14] The probable maximum winter precipitation (PMWP) in the WIPP facility region is taken to be the probable maximum 48-hour precipitation during the winter months of December through February. The PMWP for the WIPP facility is estimated to be 12.8 inches of rain (i.e., 66 lb/ft^2).[21,22] The snowload for the WIPP facility is calculated in Section 2.4.2. This calculation yielded a snowload value (ground level equivalent) of 27 lb/ft^2. Specific roof loads are estimated based on ANSI's methodology.[14]

2.3.2 LOCAL METEOROLOGY

2.3.2.1 Data Sources

On-site meteorological data (hourly) are used to characterize the local meteorology of the WIPP facility. Available summary on-site meteorological data presented in this document include temperature and precipitation data for the period of May 1976 through April 1977, barometric pressure, humidity, and solar radiation for the period of June to August, 1976, as well as wind and stability data for June 1977 through May 1979. Annual wind roses (1973-1976) were also obtained from the National Climatic Center for Roswell, New Mexico and Midland/Odessa, Texas.

2.3.2.2 Normal and Extreme Values of Meteorological Parameters

2.3.2.2.1 Wind Summaries

Wind direction and wind speed measurements were obtained from the two-year site data collected at the 10-meter level. Annual wind roses for the site and for Roswell, New Mexico, for the period of June 1, 1977 to May 31, 1979 are shown in Figure 2.3-2. Long-term (1973-1976) annual wind roses for Roswell, New Mexico and Midland-Odessa, Texas (the next nearest National Weather Station with suitable data) are shown in this figure.

The two year WIPP facility wind record (Table 2.3-10 and Table 2A-20 of Appendix 2A) shows that southeast, south southeast, and east southeast winds occur most frequently (18.8, 15.1, and 8.5 percent of the time, respectively). Other directions are represented from 2.7 to 9.0 percent of the time. Monthly wind rose data are presented in Appendix 2A (Tables 2A-1 through 2A-12).

2.3.2.2.2 Temperatures

Average monthly, average daily maximum, and average daily minimum temperatures for May 1, 1976 through May 20, 1979 are presented in Table 2.3-11, which also shows corresponding data for the WIPP facility. The normal values for Roswell have been updated.[6] Table 2.3-11 is also updated with average monthly, average daily maximum, and average daily minimum temperatures for 1980-1985 for Roswell.[6] Average temperatures show large seasonal differences, ranging from 37.2°F in winter to 82.6°F in summer.

The highest and lowest temperatures recorded at Roswell between May 1, 1976 and April 30, 1977 were 104° and 3°F, respectively; the highest and lowest temperatures recorded at the WIPP facility between May 1, 1976 and May 31, 1979 were 103.1° and 0.7°F, respectively. At the WIPP facility, the average winter minimum temperatures are consistently higher than those in Roswell and the summer maximum temperatures are lower.

2.3.2.2.3 Precipitation and Atmospheric Moisture

Precipitation data for the WIPP facility are available for May 1, 1976 through May 31, 1979. Table 2.3-12 shows the monthly totals for the WIPP facility, the corresponding totals for Roswell and the monthly normals for Roswell, which have been updated.[6] Precipitation at the WIPP facility ranged from 0.07 inches in February 1977 to 5.19 inches in September 1978. At Roswell precipitation ranged from 0.0 inches in December 1976 to 4.45 inches in August 1977 for that particular time period. The differences between Roswell and the WIPP facility data and between Roswell two-year data and normals are typical of precipitation spatial variations in the region. Table 2.3-13 contains data for Roswell (but none for the WIPP facility) for 1980 through 1985. This table shows that on four different occasions (September 1980 and June, July, and August 1981) rainfall exceeded the previous observation of 4.45 inches in August 1977. The annual rainfall at Roswell for 1981 was 24.33 inches, which was 6.73 inches more than the previously reported 17.60 in Table 2.3-12.

Dew point temperature data for Roswell are available from January 1, 1973 to December 31, 1976. The dew point temperature is the temperature to which the air must be cooled to become saturated with water vapor (pressure and water vapor content remaining constant). It is lower than the free air temperature except when the free air is saturated. In the latter case, the two temperatures are the same. Thus, the difference between the free air and dew point temperatures (the dew point spread) is a measure of the atmospheric moisture content. The average and dew point temperatures at Roswell are shown in Table 2.3-14.[20] At Roswell, the dew point spread is less than 7.9°F only 20 percent of the time. Relative humidity normals for Roswell are presented in Table 2.3-15,[6] while the relative humidity for the WIPP facility is given in Table 2.3-16. The barometric pressure and solar radiation data are also presented in Table 2.3-16 as additional information that may be useful in determining atmospheric stability and evaporation rates. The data available at this time do not allow generalizations to be made.

Heavy fog (defined as reducing visibility to 0.25 miles or less) occurs in the region on the average of 16 days per year. The monthly distribution of heavy fog is shown in Table 2.3-17.[6]

2.3.2.2.4 Atmospheric Stability

Estimates of the average dispersion of effluents over extended periods are generally based on the joint probability of wind speed, wind direction, and atmospheric stability frequencies. These frequencies have been taken (Table 2.3-18) from data collected at the WIPP facility by the temperature difference method outlined in NRC Regulatory Guide 1.23. The period of data collection range from June 1977 through May 1978 (Tables 2A-1 through 2A-12).

The joint frequencies of these stability categories with wind (Tables 2A-13 through 2A-20 of Appendix 2A) show two dominant trends. The first is the very unstable category (category A), where southeast to south winds in the 6.9 to 11.2 mi/h range are most frequent. The second is the slightly stable (E) and extremely stable (G) categories (and, to a lesser degree, categories D and F), where the southeast wind in the 3.4 to 11.2 mi/h range predominates.

Available stability frequency information for Roswell and the WIPP facility are presented in Table 2.3-19. The apparent differences in the stability distributions between Roswell and the WIPP facility are primarily due to the different computational methods used to characterize the available data. The National Climatic Center data for Roswell did not contain information necessary to use either the temperature difference (T) or standard deviation of horizontal wind direction (Sp) computational methods. The WIPP facility data used the T method for calculation of stability frequency. The Turner method,[23] which essentially uses surface wind speed and net solar radiation, was used to calculate the Roswell stability frequencies presented in Table 2.3-19.

Figure 2.3-2, Annual Wind Roses, demonstrates that the meteorological data collected at the WIPP facility during the indicated time period are representative of the long-term regional conditions.

2.3.2.3 Topography

The land surface in the vicinity of the WIPP facility is a semiarid, windblown plain sloping gently to the west and southwest. Its surface is made somewhat hummocky by an abundance of sand ridges and dunes. The average slope within a 3-mile radius is about 50 ft/mi from the east to west.

A plot of terrain profiles from the center of the WIPP facility out to five miles is presented in Figure 2.3-3 for each of the 16 direction sectors.

2.3.3 ON-SITE METEOROLOGICAL MEASUREMENT PROGRAM

2.3.3.1 Measurements Through 1981

On-site meteorological data were used to characterize the local meteorology of the region around the WIPP facility. These data have been presented, and their representation is discussed in Section 2.3.2. The meteorology station was located in T22S, R31E, Section 11, from January to June 1976, in Section 15 from June 1976 to May 1977, and in section 21 from May 1977, until it was dismantled in 1981. These locations are shown in Figure 2.3-4 and are representative of local terrain conditions.

Until May 1977 the monitoring system consisted of the following seven sensors at the indicated heights aboveground:

Sensor	Height Aboveground (m)
Average wind speed	10
Wind direction	10
Humidity	10
Pressure	1
Precipitation	1
Sky radiation	3
Temperature	10

The meteorological system, as of November 1977, provided data as described in Table 2.3-20. The sensors are described in Table 2.3-21.

2.3.3.2 Measurements From 1984 Through Present

In 1981 the meteorological measuring system was dismantled except for the tower. In September 1984, an interim weather station was established with the installation of a 10-meter tower at the northwest corner of Zone I on which wind speed, wind direction, and temperature sensors were placed. In October, 1988 this station was relocated to the far field monitoring site, 1000 meters northwest of the Exhaust Shaft. This relocation was necessitated by construction of the Air Intake Shaft (AIS). Up until March 1986, the analog signals from the 10-meter tower were continuously recorded on strip-chart recorders. After March 1986, the recorders were hooked up to the Sum-X Data Acquisition System, which is now the primary data logger. Strip chart recorders are being used as backup. Monthly precipitation has been recorded since June 1985.[24]

Temperatures for the WIPP facility for 1985 and 1986 are presented in Table 2.3-22.[24,25] Monthly precipitation is presented in Table 2.3-23.[24] Figures 2.3-5 through 2.3-7 are annual windroses for 1985 through 1986.[24,25] Appendix 2B presents wind rose data for 1985 and 1986. (Note: Data for subsequent years are reported in the WIPP Annual Site Environmental Reports, published in June of each year.)

2.3.3.3 Operational Meteorological Monitoring

A multilevel weather monitoring station has been built and is currently providing weather data to the Central Monitoring System. This equipment is mounted on a 40 meter tower located northeast of the exhaust shaft. (See Final Station location in Figure 2.3-4).

To obtain the required inputs for calculation of atmospheric diffusion at the WIPP facility, the meteorological monitoring system continously monitors and records data from four elevations, as follows:

1st elevation; on ground surface - barometric pressure, background radiation, and precipitation.

2nd elevation; mounted three meters above the surface on an existing structure - dew point, solar radiation, ambient air temperature, wind speed, and wind direction.

3rd elevation; mounted 10 meters above the surface - wind speed, wind direction, and ambient air temperature.

4th elevation; mounted 40 meters above the surface - wind speed, wind direction, and ambient air temperature.

Wind speed, wind direction, ambient air temperature, quantity of precipitation, barometric pressure, and solar radiation are monitored with individual sensors. Local, analog strip chart recorders are provided for wind speed, wind direction, and ambient air temperature. A continuous analog signal from each parameter measurement channel is transmitted to a local panel which then provides output signals to an LPU for transmission to and subsequent monitoring and storage in the CMS. The system's maintenance and calibration programs assure at least 90 percent data recovery.

This station has been designed to operate in compliance with applicable DOE orders and guidance including DOE/EP-0096[45]. This station and its operation will also comply with Order DOE 5400.1,[46] when issued in final form. The design life of each measurement system is 25 years, with proper maintenance and replacement of malfunctioning components.

2.3.4 PALEOCLIMATOLOGY

2.3.4.1 Pleistocene

The range of climates that has occurred in the past indicates the long-term variabilities of the climate in a region and provides a basis for postulating the bounds of future climatic changes that may affect the long-term impact of the WIPP facility. In order to predict the climate for the next 10,000 to 100,000 years, the climatological history must be well characterized for at least the same length of time. Qualitative estimates of temperature and precipitation regimes have been made for this historical period, and the extent of glaciation and flooding (which are the long-term climatological phenomena that may impact a waste repository) can be fairly accurately estimated from geologic evidence. Much of the available paleoclimatological information refers to large geographical areas (continents, hemispheres, etc.), and specific climatic conditions for the WIPP facility region must be inferred from these generic descriptions. However, geologic investigations provide some information that is directly applicable to the WIPP facility.

Periodically, at intervals of about 250 million years (m.y.), there have been major glacier advances from the polar regions lasting on the order of millions of years.[26] The Pleistocene epoch, which began about one to two m.y. ago, is the latest glacial period.[26-29] Within the Pleistocene there have been several glacier advances (glacials) and retreats (interglacials), as illustrated by worldwide temperature variations in Figure 2.3-8.

Continental ice sheets of the Pleistocene epoch did not advance south of Colorado (latitude 37°N) but during these glaciations individual mountain glaciers were widespread throughout the Rocky Mountains from Canada to central New Mexico, and local ice caps existed in a number of ranges.[30] Glaciers developed as far south as latitude 3322' N (Sierra Blanca, peak elevation 12,003 feet, west of Roswell) during the glaciations of late Pleistocene time. The average end moraines of late Pleistocene glaciers are at elevations of between 10,200 and 11,400 feet at this latitude.[30] Summer temperatures were about 7° to 16°F colder than at present, but winter temperatures were much the same as at present.[30]

The advance of glaciers was initially associated with a cold, damp climate, followed by a cold, dry climate that developed over the contiguous ice sheet itself.[31] Precipitation over this area was probably less than that over the same region at present. During these periods, the climate was much more variable than at present. Winters were longer; spring, fall, and summer were shorter; and diurnal and day-to-day variations were greater.[29]

During glaciation periods in North America, the westerly wind belt was displaced toward the equator.[31,32] This change resulted in some areas south of the continental glacier receiving increased precipitation.[31] In the United States, pluvial effects occurred in the central region. Several lakes were formed or expanded during the pluvial, especially in the western United States in areas that are now deserts.[31,33] The climate of New Mexico during this period was characterized by more precipitation (about 60 percent more than at present), less evaporation (only about 70 percent of present), and a mean June - September temperature about 18°F lower than at present.[34]

In summary, it can be inferred that the climate of the region during the glacial/pluvial periods of the Pleistocene was probably cooler and wetter than at present.

2.3.4.2 Holocene

Major glacial epochs have been alternating with interglacials on an approximate 100,000-year cycle.[32] These interglacials previously lasted 11,000 to 15,000 years (during the Pleistocene). The present global climate is considered interglacial and has lasted about 10,000 to 12,000 years,[26,30] although this has varied by region, and glacial advances have at times occurred. The interglacials of the Pleistocene were typically free of ice and were drier than the present.[26] Moreover, temperatures were similar or at times slightly warmer than at present.[26] In the Rocky Mountain region, the present interglacial has been less arid and colder than previous interglacials.[35] A brief summary of the climate of the current epoch is presented in Table 2.3-24. The most significant events are the Cochrane Glacial Re-advance (6800 to 5600 B.C.), the Climate Optimum (5600 to 2500 B.C.), and the Little Ice Age (1500 to 1900 A.D.). However, these oscillations of the interglacial climate in the United States during the Holocene have been less severe than those experienced during the Pleistocene, when conditions varied between glacial and interglacial.[36] There are indications that a long-term global cooling trend is still under way, although there has been a relatively recent short-term period (about 40 to 100 years ending in about 1950) of global warming.

2.3.5 CLIMATIC CHANGES

A recent survey of expert opinion indicates that the climate for the next several decades is expected to resemble the average of the last 30 years.[37] The likelihood of a catastrophic climatic change by the year 2000 is assessed as being small (because of the balancing of the warming effect of carbon dioxide produced by the hydrocarbon economy and other human activities with the cooling effect of a natural climatic cycle). Specifically, the survey suggests only one chance in ten that the average global temperature will increase by more than 1°F relative to the early 1970s in the next 25 years. However, it is equally probable that there will be a 0.5°F drop in temperature.[37]

Future climatic changes within the next few millennia or even centuries are expected to be associated with global cooling (without the impact of man).[29] The global environments of the last several millennia have been relatively warm in comparison with the climate of the last million years. Warm intervals such as the present interglacial have been short-lived. Considering that the most recent glacial period was at a maximum of 18,000 years ago, the present interglacial can be expected to end within the next several thousand years. At times, transitions from one major temperature regime to another have occurred within a century or so.[29] However, transitions from interglacial to glacial regimes are usually gradual.[38]

Comparison of the Holocene history of the Rocky Mountains suggests that the regional climate may become first warmer and more arid and subsequently wetter before the end of the present interglacial.[35] In fact, the regional trend during the last 2,500 years has been toward increasing warmth interspersed by cooler times of advances of cirque glaciers in the Rocky Mountains.[35]

The prediction of the future climate is complicated by natural variables, such as volcanic eruptions and human activities.[29,39] Volcanic eruptions inject huge quantities of dust into the stratosphere and diminish the amount of sunlight reaching the surface of the earth. Many of the dust particles remain in the stratosphere for months or years. Climatologists generally agree that diminution of the sunlight by as little as one percent could initiate a cool period and even major glaciations. Historical short-term (decades or centuries) cooling trends have been associated with major volcanic eruptions.[40] However, the dust loading in the atmosphere has also been increased by the following human activities: the burning of fossil fuels, mechanized agricultural operations, overgrazing of arid land (resulting in windblown dust), industrial pollution and slash and burn land clearing methods that are widely used in the tropics. One school of thought is that the increased dust loading will result in global cooling.[29]

Another major pollutant is carbon dioxide from the burning of fossil fuels. Although it does not significantly impede incoming solar radiation, it attenuates outgoing long wave radiation from the earth's atmosphere to space. The net result of increased carbon dioxide concentrations is an increase in the atmospheric temperature near the earth's surface.[41]

Carbon dioxide concentrations measured in 1958-1972 at Mauna Loa, Hawaii (and other locations) show a steady increase in the annual average by 4 percent a year.[27] Current projections indicate that the present carbon dioxide concentrations of the atmosphere may double by 2040 and be five to 10 times the preindustrial level during the twenty second century.[42] Once reached, these levels will decrease only slowly, remaining well above the preindustrial level for at least a thousand years. They are expected to result in a global warming of about 4.5° to 13°F.[42] As a consequence, arid and semiarid regions in the western United States are expected to become even drier.

Other man caused events that may affect future climates are thermal pollution, cloud enhancement, changes in surface land use, and industrial pollution. The discharge of waste heat is not yet significant on a global scale. However, waste heat may become an appreciable fraction (1 percent or more) of the effective solar radiation absorbed at the earth's surface by the middle of the next century. In industrial areas, it may be even more significant.[27] The artificial creation of clouds by aircraft exhaust and by other activities may induce climatic variations.[27] Widespread changes in land use (e.g., urbanization), the creation of man-made artificial lakes and ponds, and attempts to modify the environment on a large scale (e.g., removal of ice cover in polar regions, diversions of ocean currents, etc.) may alter the climate significantly.[27] Discharged industrial gases (methane, ammonia, nitric acid, acetylene, nitrous oxide, and chlorofluorocarbons) tend to warm the lower atmosphere. The combined effect of these pollutants is likely to be considerably greater than that of carbon dioxide alone.[42] The most widely accepted theory of future climates holds that the total effect of human activities will be a sharp rise in worldwide temperatures within the next couple of centuries. Moreover, these disturbances may result in greater variability of future climates as well as long-term temperature increases.[43]

In summary, future climatic changes cannot be predicted with certainty at this time because of the complexity of atmospheric oceanic terrestrial interactions that are complicated by the impact of human activities.[44] Although climatology experts have varying opinions, there appears to be a consensus that there will not be a catastrophic change in climate during the next couple of decades. The long-term (thousands of years) natural trend is toward another ice age. However, man's effect on the climate may counterbalance this trend or result in a warming trend (possibly a global warming of 4.5° to 13°F or more, with greater aridity in the western United States starting in the next century). The possible variability in the next 10,000 to 20,000 years of the climate in the vicinity of the WIPP facility region is similar to that experienced during the latter portion of the Pleistocene and the Holocene, that is, the climate of New Mexico ranging from that associated with glaciers to the north (rainfall about 60-70 percent greater than at present and summer temperatures about 20°F less than at present) to that associated with interglacial periods (global temperatures about 3°F warmer and greater aridity in the Southwest than at present).

If continental glaciation returns, judging from the Pleistocene record, there is virtually no possibility that the region around the WIPP facility itself will be glaciated. The increased rainfall, however, will increase the amount of water in the Pecos River, increase the amount of vegetation in the regions, and cause the composition of the vegetation to shift toward prairie grasslands. If, on the other hand, man's influence causes a global warming, flow in the Pecos will decrease, and the region will shift more toward the flora of the Chihuahuan desert.

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Table 2.3-1

MONTHLY EXTREME TEMPERATURES FOR ROSWELL, NEW MEXICO*

	Max., °F	Year	Min., °F	Year
January	83	1972	-9	1979
February	84**	1979	-8	1951
March	95	1971	9	1971
April	97**	1972	21	1970
May	103	1951	33	1970**
June	108	1957	40	1970**
July	110	1958	55	1952
August	105	1969	54	1970**
September	102	1959	33	1971
October	95	1979	22	1970
November	86	1980**	4	1976
December	84	1958	-8	1978
Annual	**110**	**July 1958**	**-8**	**Feb 1951**

*Climates of the States, Vol. 2 - Western States, Roswell, NM, U.S. National Oceanic and Atmospheric Administration (NOAA), Water Information Center, Inc., Port Washington, NY, 1974, p. 804.

(Period of record: June 1950 through August 1960 and February 1969 through December 1977.) Local Climatological Data, Annual Summaries for 1973 through 1985 for Roswell, NM, NOAA-EDS.

**Also on earlier dates.

The temperatures above are for existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: lowest temperature recorded was 29°F in February 1905.

Table 2.3-2

PRECIPITATION RATES FOR SOUTHEASTERN NEW MEXICO*#

(1972-1976)

Station and distance from WIPP, mi.	Elevation MSL, ft.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov .	Dec.	Ann.	1972	1973	1974	1975	1976
		Precipitation (inches)																	
Carlsbad	3,120	0.37	0.78	0.24	0.07	1.07	1.31	2.46	1.54	4.51	1.94	0.38	0.28	14.96	18.74	11.47+	23.11	10.22	11.26
25		(0.45)	(0.30)	(0.51)	(0.48)	(1.51)	(1.44)	(1.62)	(1.76)	(1.61)	(1.47)	(0.35)	(0.41)	(11.91)					
Duval Mine@	3,520	0.53	0.67	0.37	0.33	1.24	0.50	3.11	1.79	4.29	1.92	0.46	0.24	15.46	17.31	11.91	19.49	13.92	14.69
12																			
Jal	3,150	0.43	0.53	0.36	0.51	1.23	1.15	2.40	1.72	2.88	1.33	0.28	0.14	12.96	8.16	9.83	20.57	13.68	12.58
		(0.51)	(0.30)	(0.48)	(0.65)	(1.52)	(1.31)	(1.63)	(1.60)	(1.48)	(1.39)	(0.38)	(0.42)	(11.67)					
Pearl	3,806	0.35	0.69	0.32	0.32	2.01	2.19	3.74	2.08	3.81	1.50	0.39	0.20	17.64	17.92	11.62	22.10	24.68	11.87
25		(0.40)	(0.34)	(0.52)	(0.64)	(1.79)	(1.68)	(2.11)	(1.95)	(1.80)	(1.31)	(0.33)	(0.43)	(13.32)					
Ochoa	3,460	0.53	0.55	0.31	0.25	1.15	0.89	2.25	2.18	3.16	0.96	0.25	0.13	11.54	8.86	9.43	19.14	11.65	8.63
22		(0.49)	(0.30)	(0.51)	(0.63)	(1.38)	(1.35)	(1.48)	(1.54)	(1.53)	(1.24)	(0.40)	(0.32)	(11.17)					

* Local Climatological Data, Monthly Summaries 1972-1976, New Mexico (NOAA), Asheville, NC.

Monthly and annual average precipitation for the years 1972-1976, and normal precipitation (shown in parentheses, based on period 1941-1970) for stations in southeastern New Mexico.

@ Normal values not available. Now known as the Western Ag Minerals Mine.

\+ Underlined values are estimates.

Table 2.3-3

ANNUAL PRECIPITATION RATES FOR SOUTHEASTERN NEW MEXICO (inches)*

(1977-1985)

	Location				
Years	Carlsbad	Jal	Western-Ag	Pearl	Ochoa
1977	10.8	8.7	9.0	9.4	6.7
1978	19.8	17.2	16.9	17.5	22.9
1979	12.7	13.8	13.4	12.7	12.2
1980	13.6	15.2	16.5	14.9	13.7
1981	18.8	15.7	21.0	21.3	16.2
1982	17.2	12.8	12.6	12.4	8.4
1983	10.9	12.4	12.7	13.4	8.6
1984	20.1	18.9	19.1	20.0**	15.9**
1985	12.6	19.7	17.2	19.2**	16.3
1986	25.5	24.8	23.6	25.4	14.3**

*Local Climatological Data, Annual Summaries 1977-1985, New Mexico, NOAA, Asheville, NC.

**Data were not complete.

Table 2.3-4

NORMAL MEAN WIND SPEEDS FOR ROSWELL, NEW MEXICO*

(1951-1980)

Month	Mean wind speed, mph	Month	Mean wind speed, mph
January	7.9	July	8.5
February	8.6	August	7.8
March	10.5	September	8.1
April	10.4	October	8.0
May	9.8	November	7.8
June	9.6	December	7.6

*Local Climatological Data, Annual Summary (1985) with Comparative Data, Roswell, NM, NOAA, Asheville, NC.

Table 2.3-5

MAXIMUM RECORDED POINT RAINFALL AT ROSWELL, NEW MEXICO*

(Period of Record 1905-1961)

Duration	Depth, in	Intensity, in/h
24 hours	5.65	0.24
12 hours	5.19	0.43
6 hours	4.82	0.80
3 hours	3.38	1.13
2 hours	2.88	1.44
1 hour	2.22	2.22
30 min.	1.71	3.42
15 min.	1.34	5.36
10 min.	1.01	6.06
5 min.	0.55	6.60

*A. H. Jennings, Maximum Recorded U.S. Point Rainfall, Weather Bureau Technical Paper No. 2, (Rev.) U.S. Department of Commerce, (1963).

Table 2.3-6

MAXIMUM WIND SPEEDS FOR ROSWELL, NEW MEXICO*

Month	Max wind speed, mph	Month	Max wind speed, mph
January	67	July	66
February	70	August	72
March	66	September	54
April	75	October	66
May	72	November	65**
June	73	December	72

*Climates of the States, Vol. 2 - Western States, Roswell, NM, U.S. National Oceanic and Atmospheric Administration (NOAA), Water Information Center, Inc., Asheville, NC, 1974, p. 804. Local Climatological Data, Annual Summary 1985, Roswell, NM, NOAA-ED.

**Occurred more than once.

Table 2.3-7

RECURRENCE INTERVALS FOR HIGH WINDS IN SOUTHEASTERN NEW MEXICO*

	Speed, mph			
Recurrence, years	**30ft**	**50ft**	**100ft**	**150ft**
2	58	62	65	73
10	68	73	81	86
25	72	77	86	91
50	80	86	95	101
100	82	88	97	103

*O. G. Sutton, Micrometeorology (McGraw-Hill Book Co., Inc., New York, 1953), p. 238.

Table 2.3-8

SEASONAL FREQUENCIES OF INVERSIONS*

Season	Inversion frequency (% of total hours)	Maximum %**
Spring	32	65
Summer	25	68
Fall	35	72
Winter	46	78
Annual	35	70

*C. R. Hosler, "Low-Level Inversion Frequency in the Contiguous United States," Monthly Weather Review, 89 (9) (1961).

**Frequency of 24-hour periods with at least one hour of inversion based at or below 500 feet.

Table 2.3-9

SEASONAL VALUES OF MEAN MIXING HEIGHTS*

Season	Mean afternoon mixing height, m	Mean morning mixing height, in.
Spring	2800	480
Summer	3050	680
Fall	2000	440
Winter	1320	300
Annual	2400	470

*G. C. Holzworth, Mixing Heights, Wind Speeds and Potential for Urban Air Pollution Throughout the Contiguous United States, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC (1972).

Table 2.3-10

DISTRIBUTION OF WIND DIRECTIONS AT THE WIPP FACILITY, JUNE 1977-MAY 1979

MONTH	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	CALM
	Direction																
January	4.3	3.1	4.5	6.4	9.2	16.3	17.3	11.0	5.0	2.0	2.5	5.2	3.9	2.1	3.3	3.5	0.6
February	3.9	7.4	5.8	5.1	6.6	13.6	14.0	8.3	4.0	4.1	4.5	5.0	5.0	4.7	3.5	3.7	0.5
March	2.8	2.9	3.4	8.9	6.6	15.2	12.0	7.8	4.0	3.9	6.7	8.9	4.5	3.4	3.2	4.0	0.2
April	2.9	3.8	5.1	5.0	8.8	15.7	9.3	7.5	4.7	5.6	8.3	7.5	4.5	3.4	3.5	3.5	0.2
May	3.9	3.0	3.5	4.0	8.2	17.0	13.2	9.6	7.0	5.6	4.9	7.2	3.4	2.5	3.3	4.7	0.2
June	2.8	3.7	4.6	5.4	8.2	27.8	22.9	9.2	4.0	2.3	0.9	1.0	0.9	1.8	2.7	1.9	0.2
July	1.1	2.4	3.1	3.8	11.0	37.0	24.8	7.9	3.3	1.8	0.7	0.6	0.2	0.3	0.8	1.0	0.2
August	1.5	3.4	5.9	4.2	8.8	21.9	20.2	12.8	5.8	2.2	2.2	2.3	1.9	1.9	2.4	2.3	0.3
September	3.7	6.4	5.9	4.5	6.5	17.8	13.9	6.9	6.2	4.2	4.2	5.9	2.4	3.3	4.4	3.3	0.3
October	2.8	4.5	4.1	4.1	12.4	18.9	13.0	11.4	6.9	2.8	3.5	3.7	2.3	2.9	2.5	3.3	0.8
November	5.6	6.1	6.3	5.6	9.7	15.3	11.6	8.2	4.7	3.8	3.4	4.3	3.9	3.2	3.2	4.9	0.2
December	5.0	5.4	5.3	4.8	5.0	10.7	10.5	8.4	6.2	6.7	6.4	6.9	4.9	5.0	3.9	4.2	0.6

Table 2.3-11

TEMPERATURES (°F) AT ROSWELL AND THE WIPP FACILITY*

1976-1977

Month	Monthly Average Normal**	Monthly Average Roswell 5/76-4/77	Monthly Average WIPP Facility 5/76-4/77	Average Daily Maximum Normal**	Average Daily Maximum Roswell 5/76-4/77	Average Daily Maximum WIPP Facility 5/76-4/77	Average Daily Minimum Normal**	Average Daily Minimum Roswell 5/76-4/77	Average Daily Minimum WIPP Facility 5/76-4/77
January	41.4	38.6	38.7	55.4	52.5	51.6	27.4	24.7	27.1
February	45.9	48.2	48.6	60.4	63.0	61.9	31.4	33.4	36.9
March	52.8	52.1	54.3	67.7	68.2	67.6	37.9	35.9	40.6
April	61.9	62.3	63.5	76.9	76.7	77.2	46.8	47.9	48.6
May	70.3	68.7	67.5	85.0	82.4	79.9	55.6	54.9	53.8
June	79.0	79.3	78.4	93.1	93.4	91.2	64.8	65.2	65.1
July	81.3	78.6	75.4	93.7	90.1	87.8	69.0	67.1	65.1
August	79.2	80.3	78.6	91.3	93.1	91.2	67.0	67.4	66.7
September	72.3	71.2	70.3	84.9	82.9	82.0	59.6	59.4	60.8
October	61.7	56.2	56.1	75.8	70.3	69.6	47.5	42.1	44.2
November	49.0	42.7	46.4	63.1	56.5	58.1	35.0	28.9	34.5
December	42.5	39.3	42.1	56.7	56.1	57.0	28.2	22.5	28.9
Annual	**61.4**	**59.8**	**60.0**	**75.3**	**73.8**	**72.9**	**47.5**	**45.8**	**47.7**

*Local Climatological Data, Annual Summaries (1976 through 1985) with Comparative Data, Roswell, NM; National Oceanic and Atmospheric Administration (NOAA), Asheville, NC.

**Normal - Based on a period of 1951-1980.

Table 2.3-11

TEMPERATURES (°F) AT ROSWELL AND THE WIPP FACILITY*

1977-1978

Month	Monthly Average Normal**	Monthly Average Roswell 6/77-5/78	Monthly Average WIPP Facility 6/77-5/78	Average Daily Maximum Normal**	Average Daily Maximum Roswell 6/77-5/78	Average Daily Maximum WIPP Facility 6/77-5/78	Average Daily Minimum Normal**	Average Daily Minimum Roswell 6/77-5/78	Average Daily Minimum WIPP Facility 6/77-5/78
January	41.4	36.04	37.2	55.4	47.6	48.7	27.4	24.3	28.6
February	45.9	43.6	39.6	60.4	55.7	51.3	31.4	31.5	32.2
March	52.8	55.6	55.6	67.7	71.1	67.8	37.9	40.1	43.2
April	61.9	66.2	66.9	76.9	82.3	79.2	46.8	50.1	53.8
May	70.3	71.5	72.0	85.0	86.1	83.7	55.6	56.8	59.5
June	79.0	81.6	78.6	93.1	96.1	91.4	64.8	67.0	61.3
July	81.3	84.2	81.1	93.7	97.4	93.7	69.0	70.9	68.5
August	79.2	83.0	81.7	91.3	95.0	94.3	67.0	71.0	70.2
September	72.3	78.4	57.7	84.9	92.2	90.9	59.6	64.6	66.2
October	61.7	64.1	63.3	75.8	77.5	76.1	47.5	50.6	54.0
November	49.0	53.1	53.6	63.1	68.9	65.8	35.0	37.3	42.4
December	42.5	47.0	49.5	56.7	62.9	60.8	28.2	31.1	37.8
Annual	**61.4**	**63.7**	**61.4**	**75.3**	**77.7**	**75.3**	**47.5**	**49.6**	**51.5**

Local Climatological Data, Annual Summaries (1977 through 1985) with Comparative Data, Roswell, NM; National Oceanic and Atmospheric Administration (NOAA), Asheville, NC.

**Normal - Based on a period of 1951-1980.

Table 2.3-11

TEMPERATURES (°F) AT ROSWELL AND THE WIPP FACILITY*

1978-1979

Month	Monthly Average			Average Daily Maximum			Average Daily Minimum		
	Normal**	Roswell 6/78-5/79	WIPP Facility 6/78-5/79	Normal**	Roswell 6/78-5/79	WIPP Facility 6/78-5/79	Normal**	Roswell 6/78-5/79	WIPP Facility 6/78-5/79
January	41.4	34.9	37.0	55.4	45.5	46.8	27.4	24.2	28.6
February	45.9	43.6	45.7	60.4	59.2	57.9	31.4	28.0	35.1
March	52.8	50.5	52.9	67.7	65.6	63.5	37.9	35.3	43.2
April	61.9	60.6	62.8	76.9	75.8	73.8	46.8	45.3	44.6
May	70.3	67.5	68.0	85.0	81.2	79.5	55.6	53.7	57.2
June	79.0	79.37	78.4	93.1	92.7	90.9	64.8	65.8	66.6
July	81.3	83.4	82.6	93.7	96.2	93.0	69.0	70.5	72.1
August	79.2	78.0	79.0	91.3	89.9	89.6	67.0	66.0	68.7
September	72.3	69.2	70.2	84.9	79.8	78.6	59.6	58.6	62.6
October	61.7	60.3	61.7	75.8	74.1	72.9	47.5	46.5	52.2
November	49.0	49.0	52.0	63.1	58.7	60.3	35.0	39.3	44.4
December	42.5	37.2	42.3	56.7	50.7	52.7	28.2	23.7	32.2
Annual	**61.4**	**59.5**	**61.1**	**75.3**	**72.5**	**71.6**	**47.5**	**46.4**	**50.6**

*Local Climatological Data, Annual Summaries (1978 through 1985) with Comparative Data, Roswell, NM; National Oceanic and Atmospheric Administration (NOAA), Asheville, NC.

**Normal - Based on a period of 1951-1980.

TEMPERATURES (F) AT ROSWELL

1980

Month	Monthly Average Normal*	Monthly Average 1980	Average Daily Maximum Normal*	Average Daily Maximum 1980	Average Daily Minimum Normal*	Average Daily Minimum 1980
January	41.4	39.9	55.4	51.5	27.4	28.2
February	45.9	44.6	60.4	58.5	31.4	30.6
March	52.8	51.1	67.7	66.7	37.9	35.5
April	61.9	57.7	76.9	73.6	46.8	41.7
May	70.3	68.0	85.0	82.1	55.6	53.8
June	79.0	83.5	93.1	99.3	64.8	67.7
July	81.3	85.4	93.7	99.0	69.0	71.7
August	79.2	78.7	91.3	90.6	67.0	66.7
September	72.3	71.6	84.9	82.5	59.6	60.6
October	61.7	57.9	75.8	71.6	47.5	44.1
November	49.0	43.8	63.1	56.7	35.0	30.9
December	42.5	44.0	56.7	58.5	28.2	29.4
Annual	61.4	60.5	75.3	74.2	47.5	46.7

*Normal - Based on a period of 1951-1980.

TEMPERATURES (°F) AT ROSWELL AND THE WIPP FACILITY*

1981

Month	Monthly Average Normal*	Monthly Average 1980	Average Daily Maximum Normal*	Average Daily Maximum 1980	Average Daily Minimum Normal*	Average Daily Minimum 1980
January	41.4	41.6	55.4	54.0	27.4	29.2
February	45.9	46.2	60.4	63.0	31.4	29.3
March	52.8	51.7	67.7	65.0	37.9	38.4
April	61.9	63.5	76.9	78.5	46.8	48.4
May	70.3	68.5	85.0	81.9	55.6	55.0
June	79.0	79.0	93.1	94.3	64.8	63.7
July	81.3	79.9	93.7	92.5	69.0	67.2
August	79.2	75.7	91.3	87.3	67.0	64.0
September	72.3	69.9	84.9	82.1	59.6	57.7
October	61.7	59.8	75.8	72.1	47.5	47.5
November	49.0	53.7	63.1	69.7	35.0	37.6
December	42.5	45.3	56.7	61.5	28.2	29.0
Annual	**61.4**	**61.3**	**75.3**	**75.2**	**47.5**	**47.3**

*Normal - Based on a period of 1951-1980.

TEMPERATURES (°F) AT ROSWELL AND THE WIPP FACILITY*

1982

Month	Monthly Average Normal*	Monthly Average 1980	Average Daily Maximum Normal*	Average Daily Maximum 1980	Average Daily Minimum Normal*	Average Daily Minimum 1980
January	41.4	38.9	55.4	53.5	27.4	24.2
February	45.9	42.7	60.4	56.6	31.4	28.8
March	52.8	53.4	67.7	69.0	37.9	37.8
April	61.9	60.5	76.9	74.3	46.8	46.6
May	70.3	68.0	85.0	82.8	55.6	53.1
June	79.0	76.7	93.1	91.3	64.8	62.0
July	81.3	80.9	93.7	93.7	69.0	68.0
August	79.2	80.5	91.3	92.9	67.0	68.0
September	72.3	73.6	84.9	85.8	59.6	61.3
October	61.7	59.4	75.8	73.9	47.5	44.9
November	49.0	47.0	63.1	58.8	35.0	35.2
December	42.5	37.8	56.7	48.0	28.2	27.6
Annual	**61.4**	**60.0**	**75.3**	**73.4**	**47.5**	**46.5**

*Normal - Based on a period of 1951-1980.

TEMPERATURES (°F) AT ROSWELL AND THE WIPP FACILITY*

1983

Month	Monthly Average Normal*	Monthly Average 1980	Average Daily Maximum Normal*	Average Daily Maximum 1980	Average Daily Minimum Normal*	Average Daily Minimum 1980
January	41.4	38.9	55.4	51.6	27.4	26.2
February	45.9	45.5	60.4	59.0	31.4	32.0
March	52.8	52.8	67.7	66.9	37.9	38.6
April	61.9	54.7	76.9	69.5	46.8	39.9
May	70.3	66.3	85.0	82.1	55.6	50.4
June	79.0	76.5	93.1	91.3	64.8	61.7
July	81.4	81.6	93.7	94.4	69.0	68.7
August	79.2	81.4	91.3	94.0	67.0	68.7
September	72.3	76.1	84.9	88.8	59.6	63.4
October	61.7	62.9	75.8	74.2	47.5	51.6
November	49.0	51.8	63.1	64.3	35.0	39.3
December	42.5	35.2	56.7	47.4	28.2	22.9
Annual	61.4	60.3	75.3	73.6	47.5	47.0

*Normal - Based on a period of 1951-1980.

TEMPERATURES (°F) AT ROSWELL AND THE WIPP FACILITY*

1984

Month	Monthly Average		Average Daily Maximum		Average Daily Minimum	
	Normal*	1980	Normal*	1980	Normal*	1980
January	41.4	38.5	55.4	50.5	27.4	26.5
February	45.9	46.5	60.4	61.7	31.4	31.3
March	52.8	51.7	67.7	66.8	37.9	36.6
April	61.9	60.2	76.9	75.9	46.8	44.4
May	70.3	72.5	85.0	86.1	55.6	58.8
June	79.0	75.8	93.1	87.4	64.8	64.2
July	81.3	79.1	93.7	90.8	69.0	67.3
August	79.2	76.2	91.3	86.8	67.0	65.6
September	72.3	69.3	84.9	82.0	59.6	56.5
October	61.7	57.7	75.8	69.4	47.5	45.9
November	49.0	48.5	63.1	61.1	35.0	35.8
December	42.5	42.1	56.7	53.1	28.2	31.0
Annual	61.4	59.8	75.3	72.6	47.5	47.0

*Normal - Based on a period of 1951-1980.

Table 2.3-11

TEMPERATURES (°F) AT ROSWELL AND THE WIPP FACILITY*

1985

Month	Monthly Average		Average Daily Maximum		Average Daily Minimum	
	Normal*	1980	Normal*	1980	Normal*	1980
January	41.4	37.0	55.4	49.4	27.4	24.5
February	45.9	43.2	60.4	57.7	31.4	28.6
March	52.8	54.2	67.7	68.4	37.9	40.0
April	61.9	63.4	76.9	78.4	46.8	48.4
May	70.3	70.1	85.0	84.0	55.6	56.2
June	79.0	75.8	93.1	89.5	64.8	62.0
July	81.3	79.4	93.7	92.8	69.0	66.0
August	79.2	80.4	91.3	93.3	67.0	67.5
September	72.3	70.7	84.9	82.4	59.6	59.0
October	61.7	61.1	75.8	73.6	47.5	48.6
November	49.0	53.2	63.1	68.4	35.0	38.0
December	42.5	40.3	56.7	57.0	28.2	23.5
Annual	61.4	60.7	75.3	74.6	47.5	46.9

*Normal - Based on a period of 1951-1980.

Table 2.3-12

ROSWELL AND WIPP SITE STATION PRECIPITATION (inches)

(1976-1979)

		Roswell Station			WIPP Site Station		
Month	Normal*	76-77	77-78	78-79	76-77	77-78	78-79
June	0.91	1.55	0.25	4.31	0.67	1.09	3.74
July	1.38	2.44	0.46	0.52	0.65	0.69	0.63
August	2.17	1.98	4.45	3.49	0.57	0.57	2.01
September	1.72	2.29	0.29	3.58	3.29	2.09	5.19
October	0.99	0.69	0.62	1.47	0.67	2.02	1.33
November	0.33	0.41	0.48	1.25	0.11	0.19	3.51
December	0.27	0.00	0.02	0.43	0.08	T	0.65
January	0.24	0.07	0.50	0.41	0.24	0.07	0.13
February	0.28	0.36	0.48	0.44	0.07	0.43	0.59
March	0.27	0.27	0.39	0.13	0.38	0.07	0.04
April	0.37	1.25	0.02	0.32	0.55	0.20	0.15
May	0.77	2.43	1.81	1.25	1.31	1.63	2.22
Annual	9.70	13.74	9.77	17.60	8.59	9.05	20.19

T - Trace amount

*Normal - Based on a period of 1951-1980.

Table 2.3-13

ROSWELL PRECIPITATION (inches)

Month	Normal	1980	1981	1982	1983	1984	1985	1986
January	0.24	0.85	0.27	0.66	0.50	0.04	0.37	0.67
February	0.28	0.19	0.17	0.20	0.22	T	0.04	0.50
March	0.27	0.00	0.10	0.12	0.11	0.46	0.70	0.12
April	0.37	1.06	0.79	0.41	0.64	0.03	2.48	0.31
May	0.77	0.85	3.35	0.20	0.93	1.62	2.22	1.19
June	0.91	0.29	4.55	0.76	0.67	4.52	2.58	5.02
July	1.38	0.01	6.27	1.03	0.37	0.85	2.71	1.11
August	2.17	2.45	4.73	0.93	0.80	5.03	0.34	3.11
September	1.72	6.58	2.70	2.00	0.42	1.04	1.93	3.93
October	0.99	T	1.02	0.20	3.43	2.74	0.98	5.48
November	0.33	0.77	0.25	0.92	1.52	1.57	0.12	1.89
December	0.27	0.15	0.13	1.62	0.42	0.85	0.07	1.47
Annual	**10.61**	**13.20**	**24.33**	**9.05**	**10.03**	**18.75**	**14.54**	**24.80**

T - Trace amount

Table 2.3-14

AVERAGE TEMPERATURE AND DEW POINT TEMPERATURE AT ROSWELL*

(1973 - 1976)

	Temp., °F	Dew-Point Temp., °F
Average	59.4	36.1
Average maximum	73.0	42.4
Average minimum	46.9	30.0

*Local Climatological Data, Monthly Summary (1973-1976) for Roswell, NM, National Oceanic and Atmospheric Administration (NOAA), Asheville, NC.

Table 2.3-15

RELATIVE HUMIDITY (%) NORMALS AT ROSWELL*

	Hour (local time)			
	05	11	17	23
January	71	53	43	64
February	65	45	33	55
March	56	34	24	43
April	53	30	23	41
May	59	33	25	44
June	63	35	26	46
July	67	42	32	53
August	72	45	37	58
September	75	50	42	63
October	70	46	37	60
November	67	46	40	58
December	66	46	40	59
Annual	**65**	**42**	**34**	**54**

*Local Climatological Data, Annual Summary (1985) with Comparative Data, Roswell, NM, National Oceanic and Atmospheric Administration (NOAA), Asheville, NC. (Based on period of record 1951-1980.)

Table 2.3-16

OTHER METEOROLOGICAL DATA FROM WIPP SITE STATION

(JUNE-AUGUST 1976)

Month	Barometric Pressure, millibars	Relative Humidity, %	Radiation Parameters,* W/m2 SW SKY	SW REF	LW SKY
June	897.3	48	323	NA	NA
July	903.0	68	286	NA	NA
August	916.1	53	295	NA	NA
Average	**905.5**	**56**	**301**	**NA**	**NA**

*SW SKY = Short wave sky radiation averaged over period.
SW REF = Short wave reflected sky radiation averaged over period.
LW SKY = Long wave sky radiation averaged over period.
NA = Not available.

Table 2.3-17

MEAN NUMBER OF DAYS OF HEAVY FOG AT ROSWELL*

(Visibility of 0.25 mi or less)

Month	Normal
January	3
February	3
March	**
April	**
May	**
June	**
July	**
August	**
September	1
October	2
November	3
December	2
Annual	**16**

*Local Climatological Data, Annual Summary (1985) with Comparative Data, Roswell, NM, National Oceanic and Atmospheric Administration (NOAA), Asheville, NC. (Based on period of record 1951-1980.)

**Less than 0.5.

Table 2.3-18

MONTHLY FREQUENCY OF STABILITY CATEGORIES MEASURED AT THE WIPP SITE STATION, JUNE 1977 THROUGH MAY 1979

Category	J	F	M	A	M	J	J	A	S	O	N	D
A	28.7	31.1	34.2	41.5	44.7	46.3	48.1	44.3	36.9	32.7	26.5	27.7
B	2.4	1.7	1.5	0.7	0.2	1.0	0.7	1.2	0.7	1.3	1.5	0.8
C	1.2	0.9	0.8	0.3	0.5	0.7	0.2	0.3	0.3	0.6	0.6	0.7
D	10.7	6.7	2.7	3.2	2.6	4.5	3.6	4.8	2.0	4.0	3.4	4.1
E	13.1	14.0	6.8	5.8	8.9	10.5	9.6	9.6	8.3	10.0	9.9	4.9
F	8.6	7.7	10.0	11.0	14.1	23.9	15.6	18.0	13.3	10.3	11.2	7.8
G	35.8	38.1	44.1	37.5	29.1	13.4	22.8	20.4	38.5	41.1	46.9	54.0

Table 2.3-19

FREQUENCY OF STABILITY CONDITIONS AT ROSWELL AND AT THE WIPP SITE STATION

	Frequency (%)		
Stability Condition	Roswell,* 1973-1976	Roswell,* June 1977-May 1979	WIPP Site Station** June 1977-May 1979
A, extremely unstable	1.3	2.1	36.7
B, unstable	7.6	8.6	1.1
C, slightly unstable	16.2	14.1	0.6
D, neutral	37.0	38.1	4.2
E, slightly stable	15.9	14.7	9.2
F, stable	17.0	17.0	12.4
G, extremely stable	5.1	5.3	35.7

*Based on the Turner method.

**Based on the temperature-difference method.

Table 2.3-20

METEOROLOGICAL MEASUREMENTS SUMMARY WIPP SITE STATION

Item	Sampling Height, m	Recording Interval	Interval	Units
Pressure	3	1 h	1 h	mb
Precipitation	1	1 h	1 h	cm
Dew point	3	1 h	1 h	°C
Temperature	3,10,30**	15 s	15 s	°C
Wind speed	3,10,30**	0.1 s*	15 s	m/s
Wind direction	3,10,30**	0.1 s*	15 s	deg E of N
Temp. diff.	10-3	15 s	15 s	°C
Temp. diff.	30-3**	15 s	15 s	°C
Temp. diff.	30-10**	15 s	15 s	°C

*For each of the three levels of wind data, the 10s samples are processed to produce 15-s values of mean component values (east-west, north-south), standard deviation of each component, correlation coefficient between the two components, standard deviations of downwind and crosswind components, and downwind and crosswind components of turbulence intensity.

**The 30-meter height was changed to 40 meters after the installation of a new tower on September 1, 1978.

Table 2.3-21

METEOROLOGICAL SENSORS USED-WIPP SITE STATION

Wind Speed	
Threshold	0.33 m/s
Distance constant	1.5 m
Accuracy	0.1 m/s or ± 1% whichever is greater
Range	0 to 50 m/s
Linearity	±0.1% of full scale
Stability	±0.1% of full scale
Survivability	Gusts to 45 m/s, sustained to 33 m/s
Wind Direction	
Threshold	0.33 m/s
Distance constant	1.5 m
Accuracy	±2.5
Damping ratio	0.4 at 10 angle of attack
Range	0 to 540
Linearity	±0.1% of full scale
Stability	±0.1% of full scale
Survivability	Gusts to 45 m/s, sustained to 33 m/s
Temperature	
Range	-30 to +50C
Accuracy	±0.25C
Linearity	±0.2C
Dew Point	
Range	-40 to +42C
Accuracy	±0.5C
Response time	1C/min
Temperature Differential	
Accuracy	0.1C
Range	-2 to +10C
Station Pressure	
Range	850 to 975 mb
Linearity	±0.3%
Sensitivity	0.2%
Rain Gauge	
Type	Tipping bucket
Measurement	0.01-in. water per tip
Signal out	Momentary switch closure

Table 2.3-22

MONTHLY MAXIMUM, MINIMUM, AND AVERAGE TEMPERATURES AT THE WIPP FACILITY

	1985						1986					
	Maximum		Minimum		Average		Maximum		Minimum		Average	
Month	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
January	12	(54)	0	(32)	6	(43)	17	(63)	2	(36)	10	(50)
February	15	(59)	2	(35)	9	(48)	18	(64)	3	(37)	11	(52)
March	20	(68)	7	(44)	14	(57)	23	(73)	7	(45)	15	(59)
April	24*	(75)	10*	(50)	17	(63)	29	(84)	11	(52)	20	(68)
May	29	(84)	15	(60)	22	(72)	30	(86)	14	(57)	22	(72)
June	32	(90)	19	(65)	25	(77)	32	(90)	18	(64)	25	(77)
July	35	(95)	20	(68)	27	(81)	35	(95)	20	(68)	28	(82)
August	35	(95)	21	(70)	28	(82)	34	(93)	20	(68)	27	(81)
September	29	(84)	17	(63)	23	(73)	31	(88)	17	(63)	24	(75)
October	23	(73)	12	(54)	18	(64)	24	(75)	11	(52)	18	(64)
November	20	(68)	6	(43)	13	(55)	17	(63)	3	(37)	10	(50)
December	14	(57)	-1	(30)	7	(45)	12	(54)	0	(32)	6	(43)

*Not a full month of data.

January through June data referenced in Reference 25.

July through December data referenced in Reference 24.

Table 2.3-23

MONTHLY PRECIPITATION AT THE WIPP FACILITY

(inches)

	1985	1986
January		0.05
February		0.40
March		-0-
April		-0-
May		.91
June	1.85	7.64
July	2.02	1.9
August	1.14	2.25
September	7.40	3.8
October	1.63	1.02
November	0.06	2.18
December	-0-	2.87

Table 2.3-24

A BRIEF CHRONOLOGY OF THE CLIMATE OF THE SOUTHWESTERN UNITED STATES IN THE LAST 10,000 YEARS*

Dates	Climate
9000-6000 B.C.	Warm and arid in southern Arizona.
6800-5600 B.C.	Cool and dry, with possible extinction of mammals, particularly in Arizona and New Mexico.
5600-2500 B.C.	Warm and moist, becoming warm and dry by 3000 B.C. (Climate Optimum). Intermittent drought in the western United States after 5500 B.C.
2500-500 B.C.	Generally warm and dry with periods of heavy rain (after 660 B.C.) and intense droughts (near 510 B.C.) in the western United States.
330 A.D.	Drought.
800 A.D.	Start of moist period in Mexico.
1180-1215	Wet in the West.
1220-1290	Drought in the West.
1276-1299	"Great Drought" in the Southwest.
1300-1330	Wet in the West.
1500-1900	Generally cool and dry (Little Ice Age). Periodic glacial advances in North America (1700-1750). Drought in the southwestern United States from 1573 to 1593.
1880-1940	Increase of winter temperatures by 1.5C. Drop of 5.2m in the level of the Great Salt Lake. Alpine glaciation reduced by 25% and arctic ice by 40%.
1920-1958	25% decrease in mean annual precipitation in the Southwest.
1942-Present	Worldwide temperature decrease and halt of glacial recession.

*W. D. Sellers, Physical Climatology, University of Chicago Press, Chicago, IL, 1965).

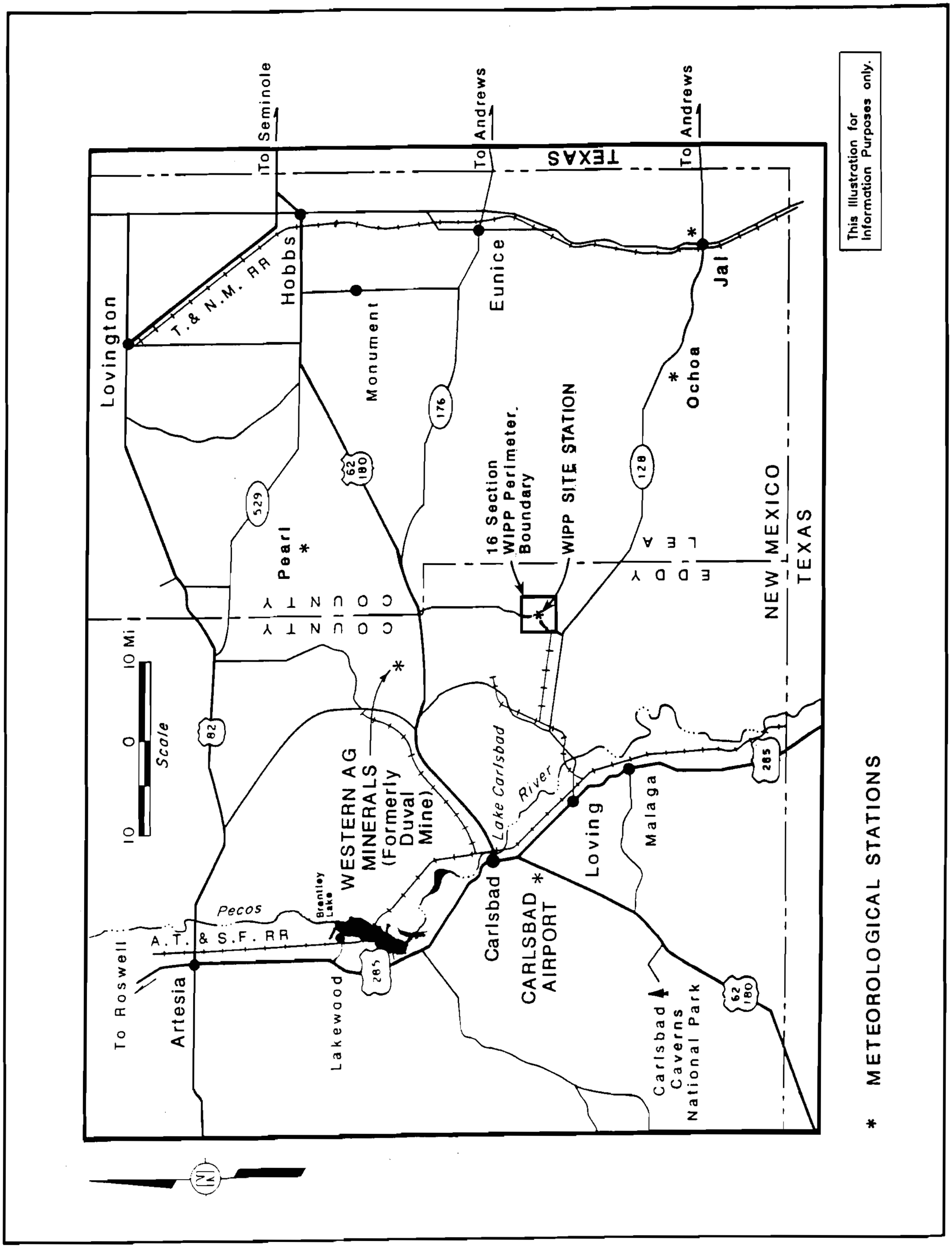
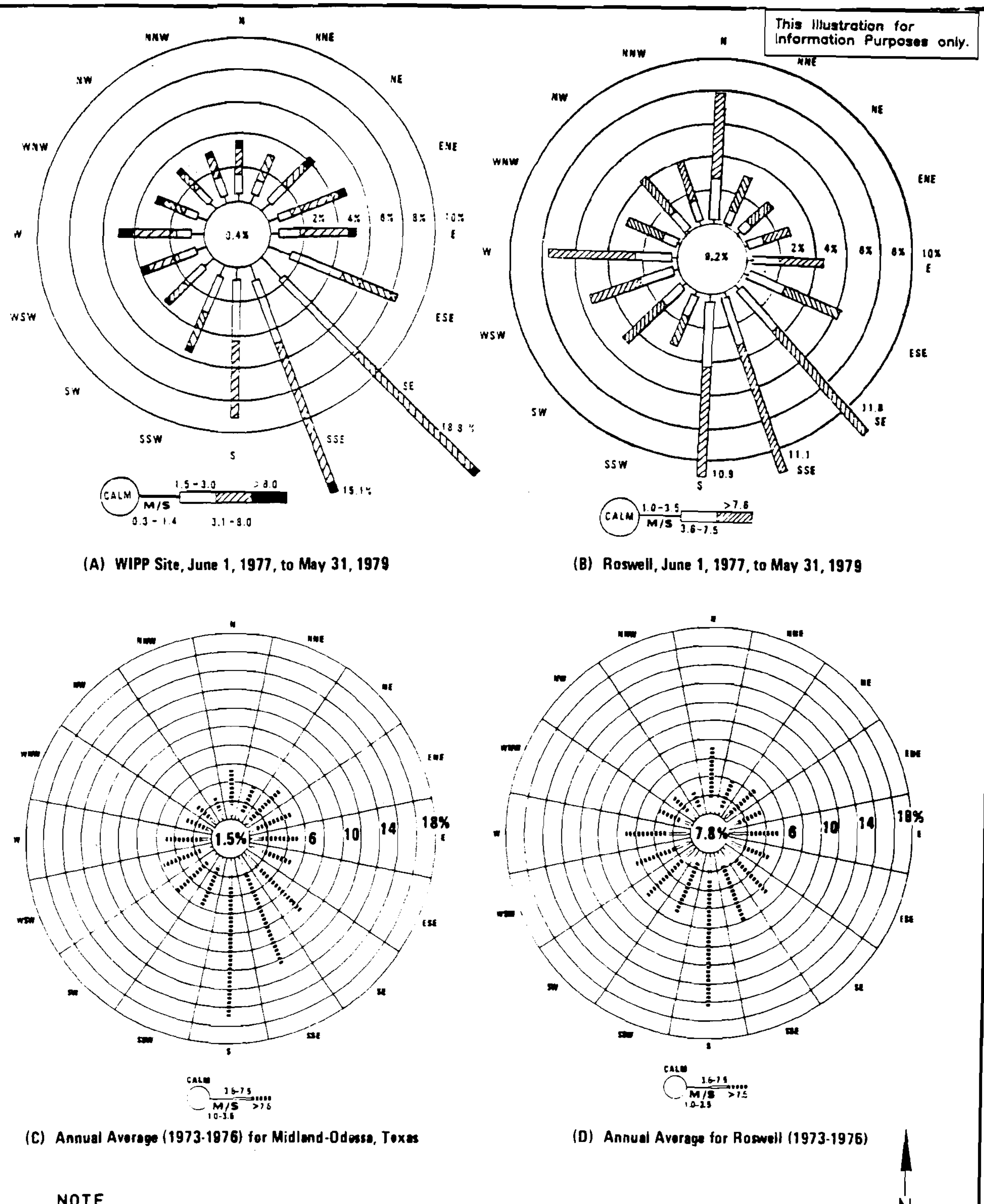


FIGURE 2.3-1
Stations Used for Gathering
Precipitation Data

This Illustration for Information Purposes only.



(A) WIPP Site, June 1, 1977, to May 31, 1979

(B) Roswell, June 1, 1977, to May 31, 1979

(C) Annual Average (1973-1976) for Midland-Odessa, Texas

(D) Annual Average for Roswell (1973-1976)

NOTE

Wind direction is the sector from which the wind is blowing

REFERENCE

Local Climatelogical Data, Monthly Summary 1973—1976 National Oceanic and Atmospheric Administration Asheville, N.C.

FIGURE 2.3-2
Annual Wind Roses

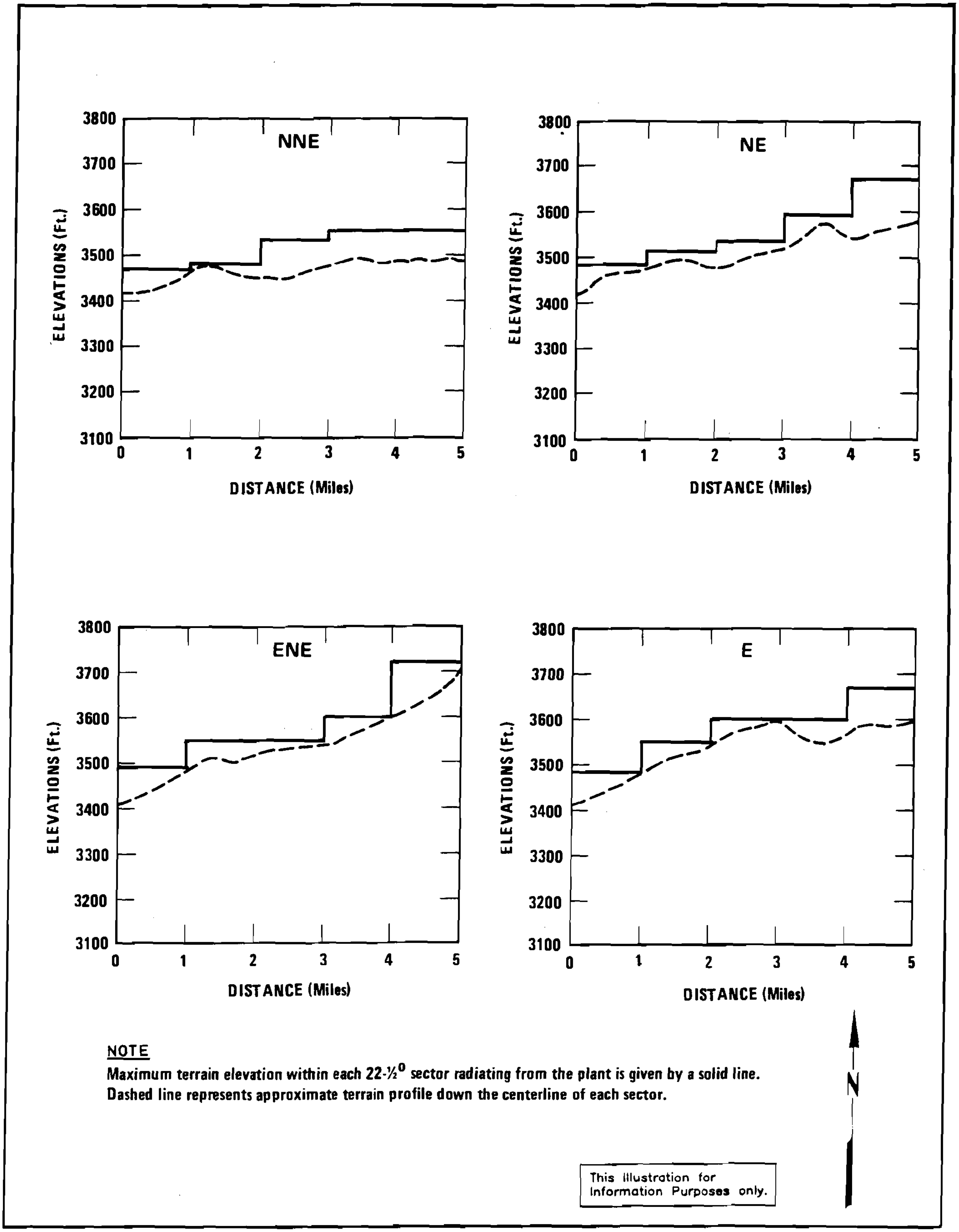
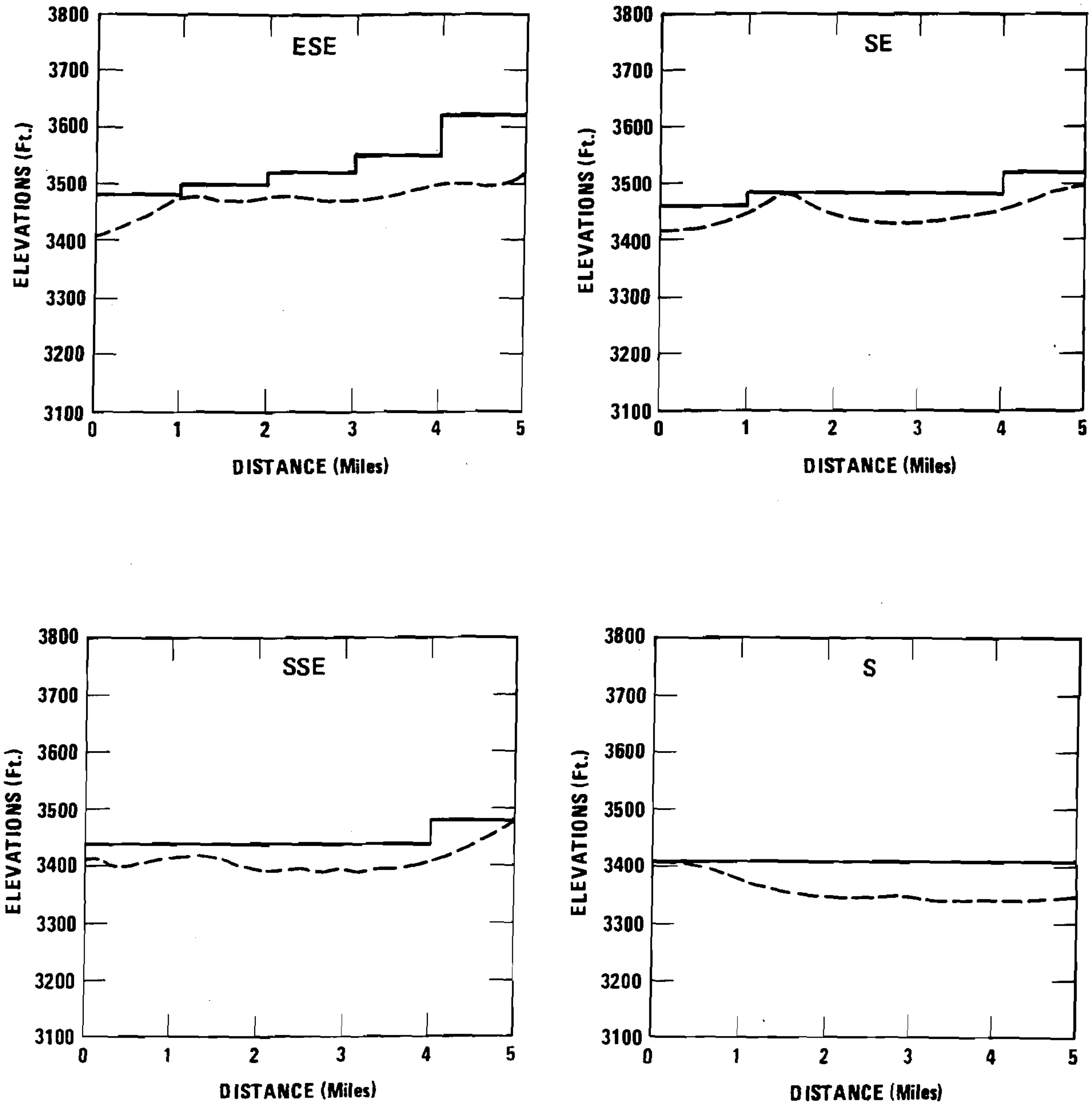


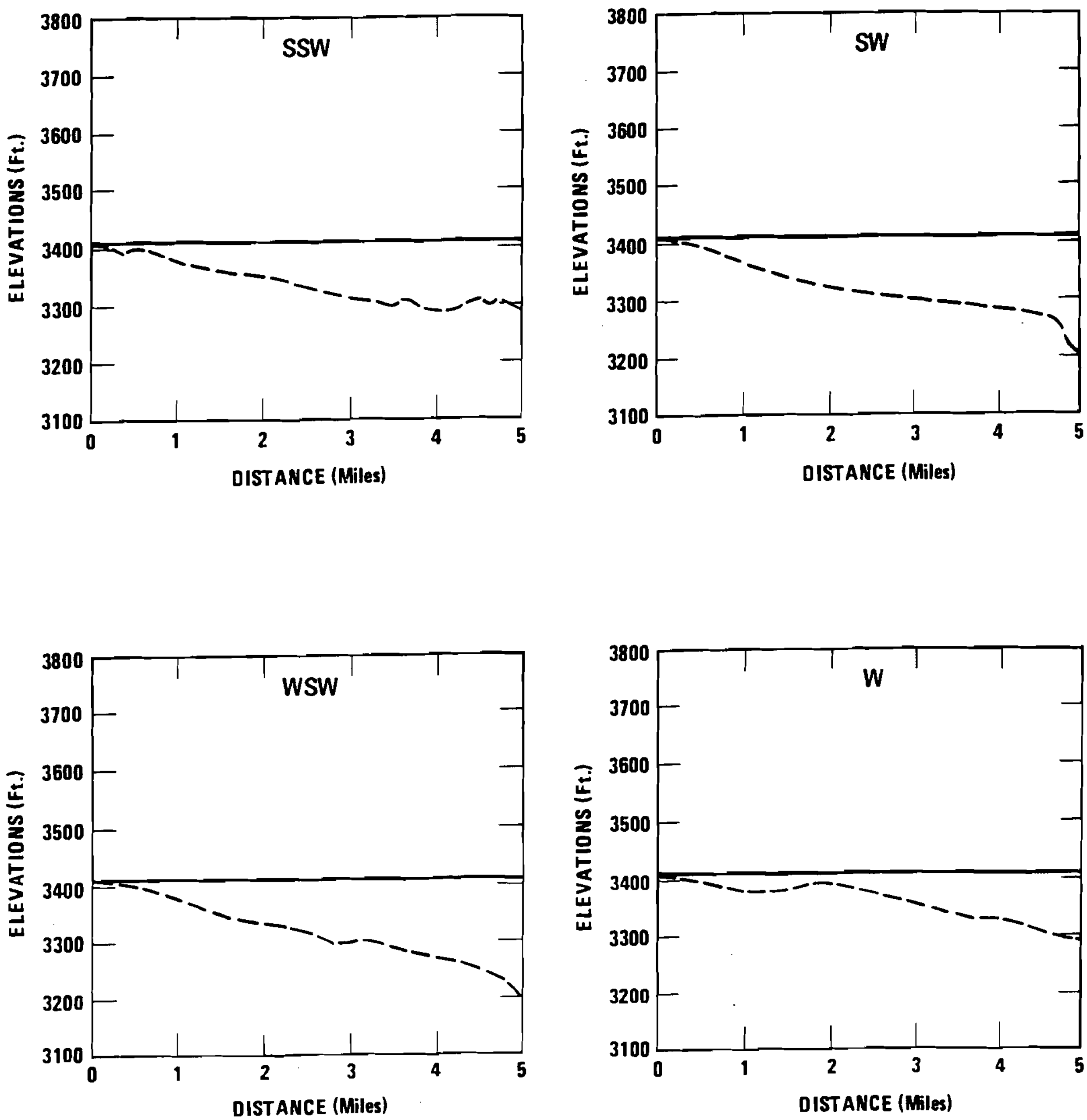
FIGURE 2.3-3A
Terrain Elevations Out to 5 Miles from Center of the WIPP Facility.
Sheet 1 of 4



NOTE
Maximum terrain elevation within each 22-½° sector radiating from the plant is given by a solid line.
Dashed line represents approximate terrain profile down the centerline of each sector.

This Illustration for Information Purposes only.

FIGURE 2.3-3B
Terrain Elevations Out to 5 Miles from Center of the WIPP Facility
Sheet 2 of 4

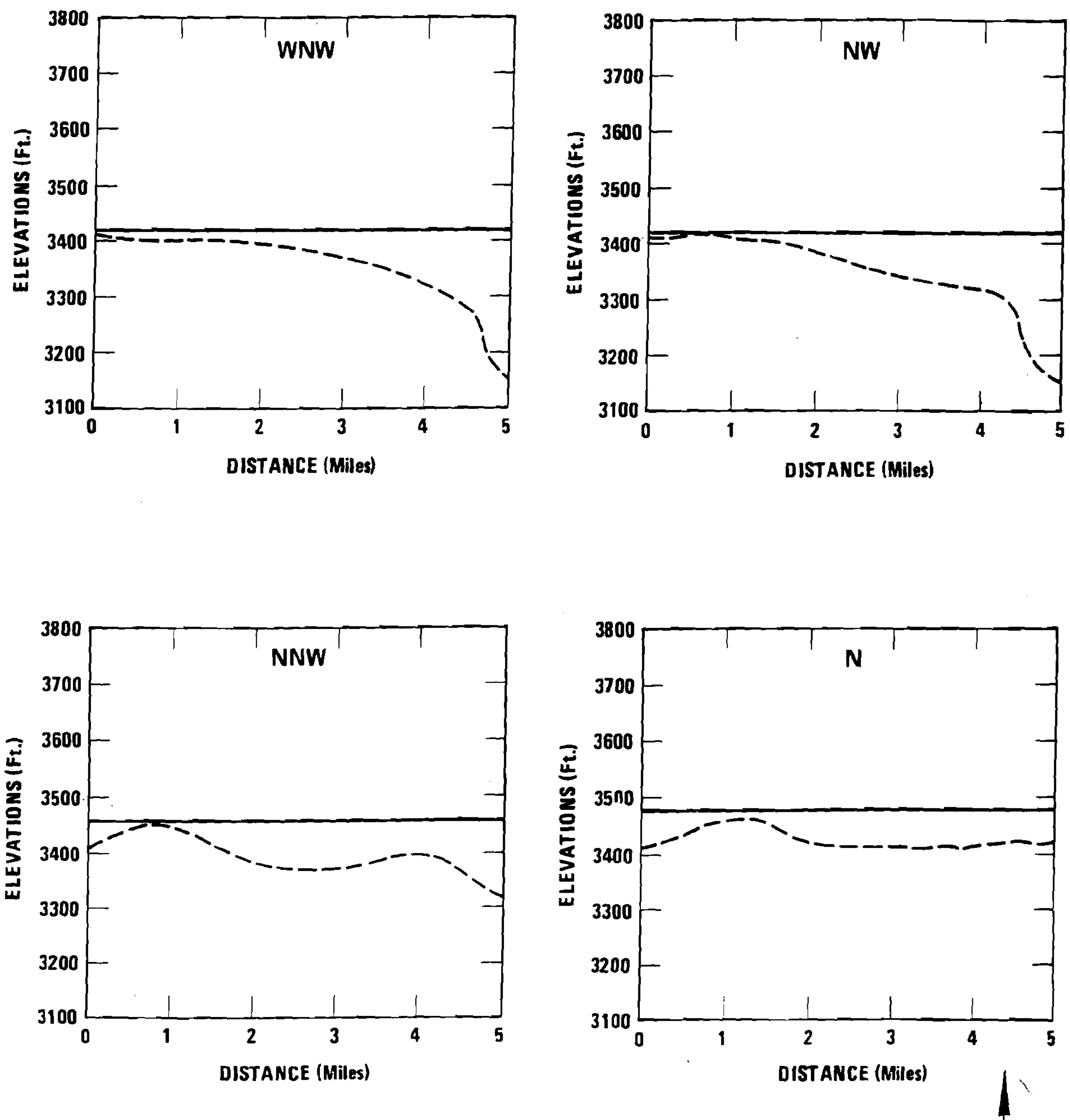


NOTE
Maximum terrain elevation within each 22-½° sector radiating from the plant is given by a solid line.
Dashed line represents approximate terrain profile down the centerline of each sector.

N

This Illustration for Information Purposes only.

FIGURE 2.3-3C
Terrain Elevations Out to 5 Miles from Center of the WIPP Facility
Sheet 3 of 4



NOTE
Maximum terrain elevation within each 22-½° sector radiating from the plant is given by a solid line.
Dashed line represents approximate terrain profile down the centerline of each sector.

This illustration for information Purposes only.

FIGURE 2.3-3D
Terrain Elevations Out to 5 Miles from Center of the WIPP Facility
Sheet 4 of 4

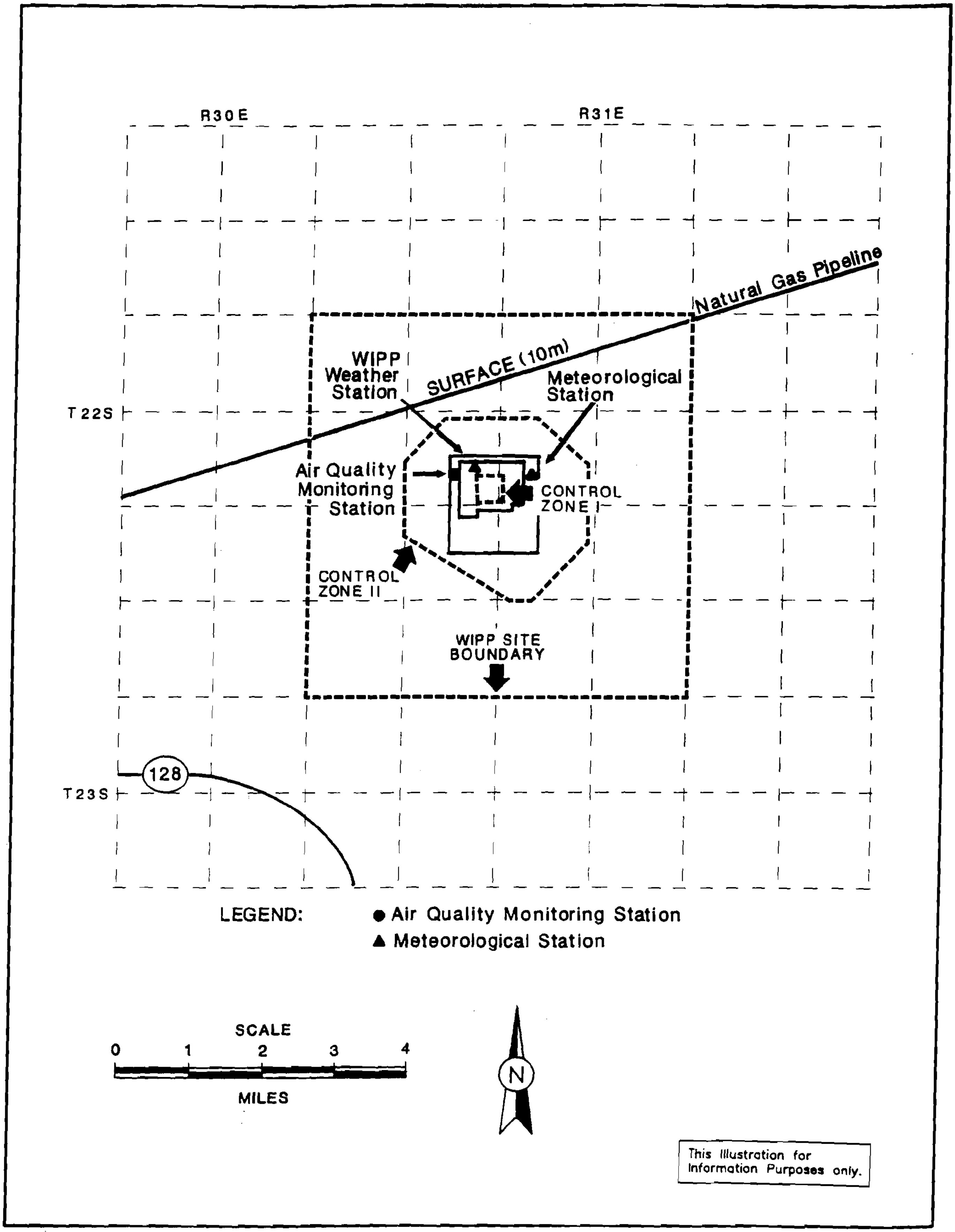


FIGURE 2.3-4
Location of the WIPP Facility Meteorological and Air Quality Monitoring Station

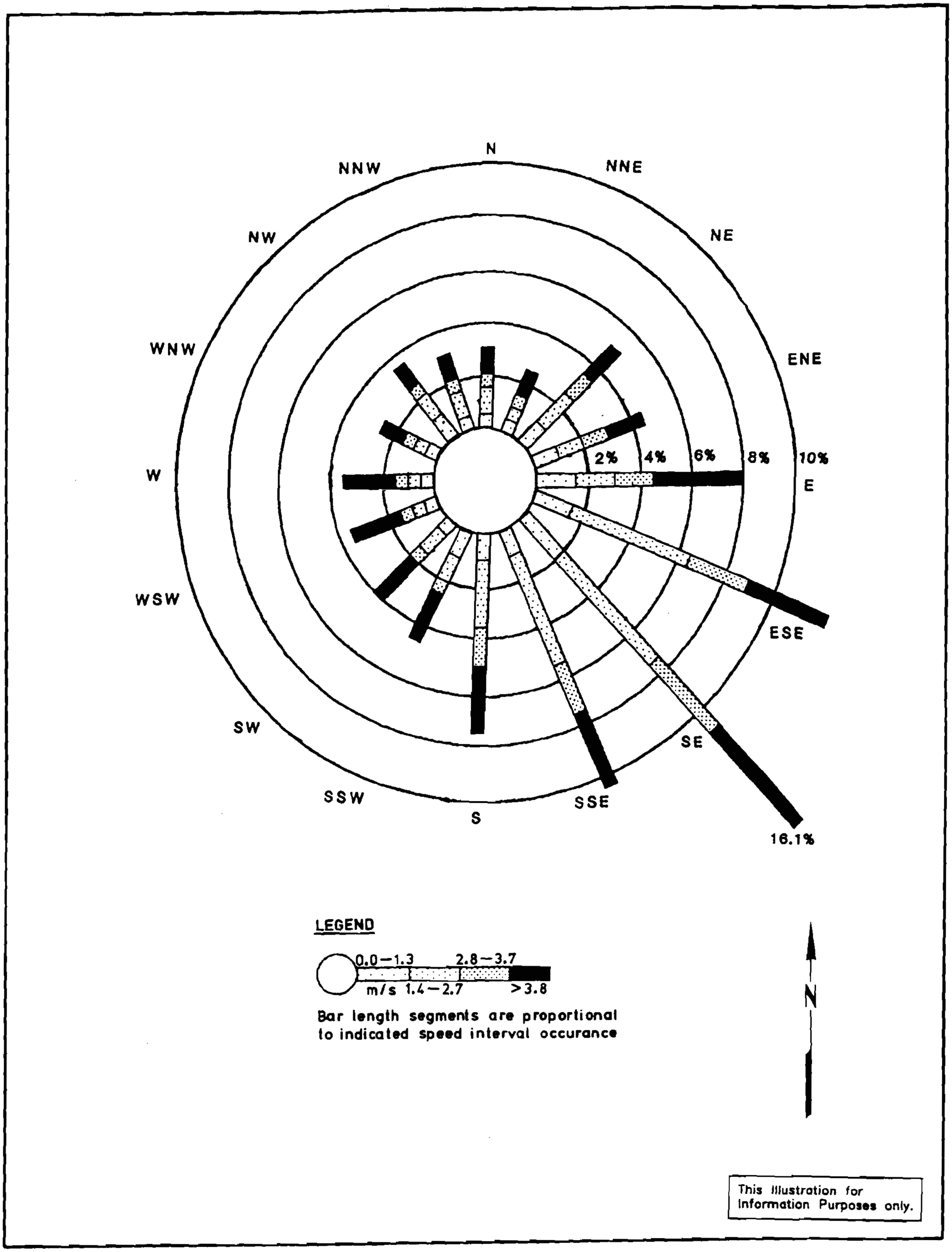


FIGURE 2.3-5
1985 Annual Windrose

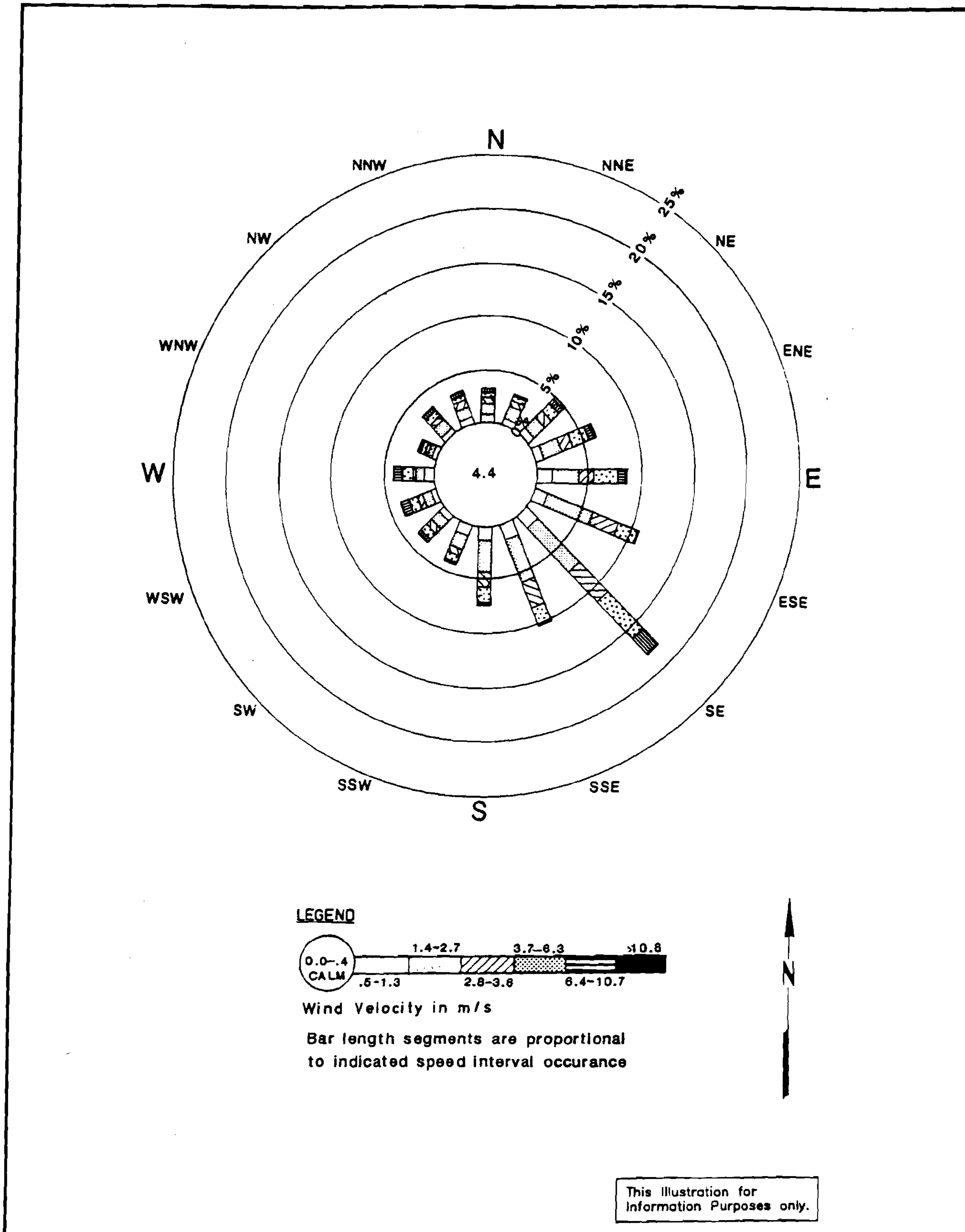


FIGURE 2.3-6
1986 Annual Windrose

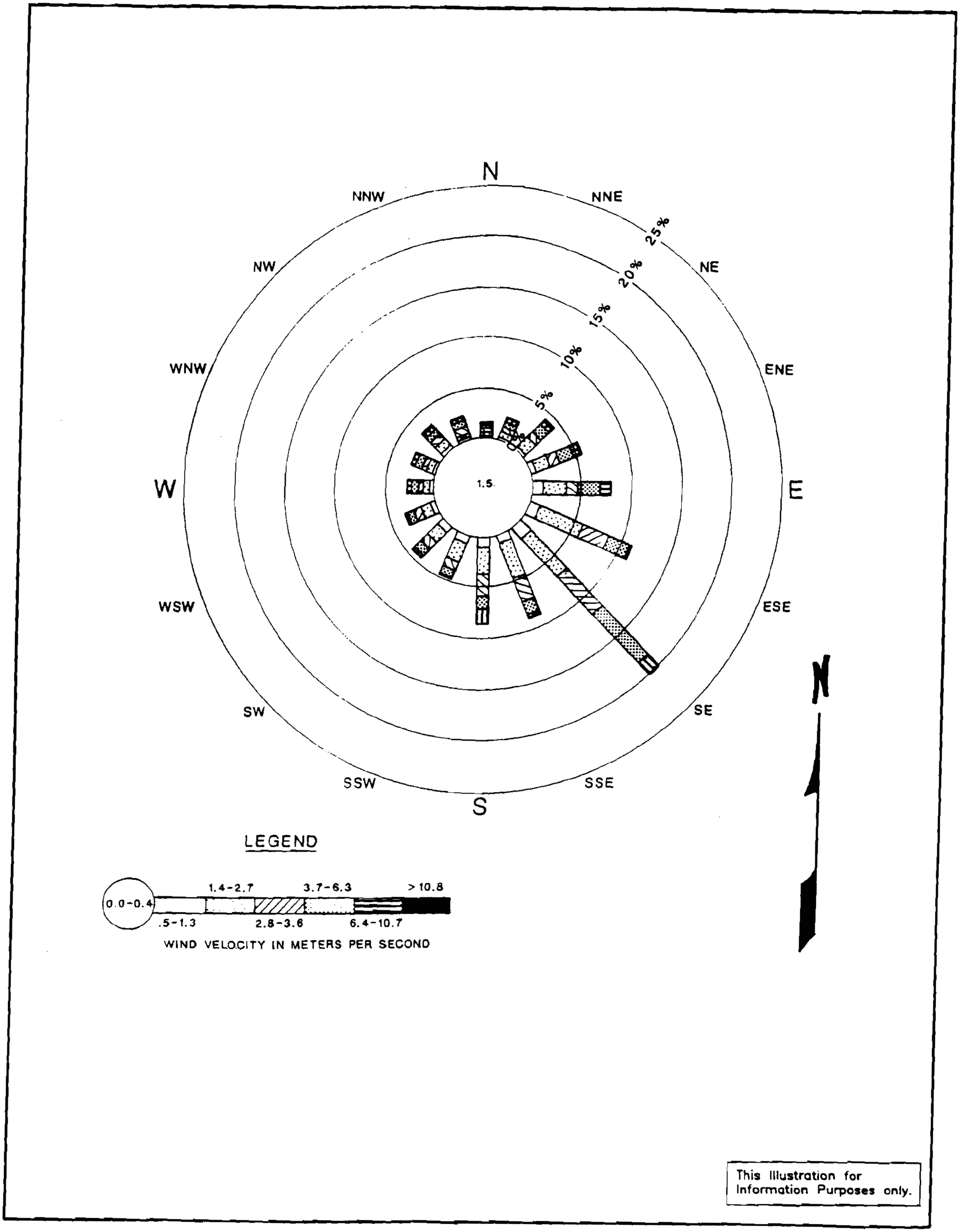
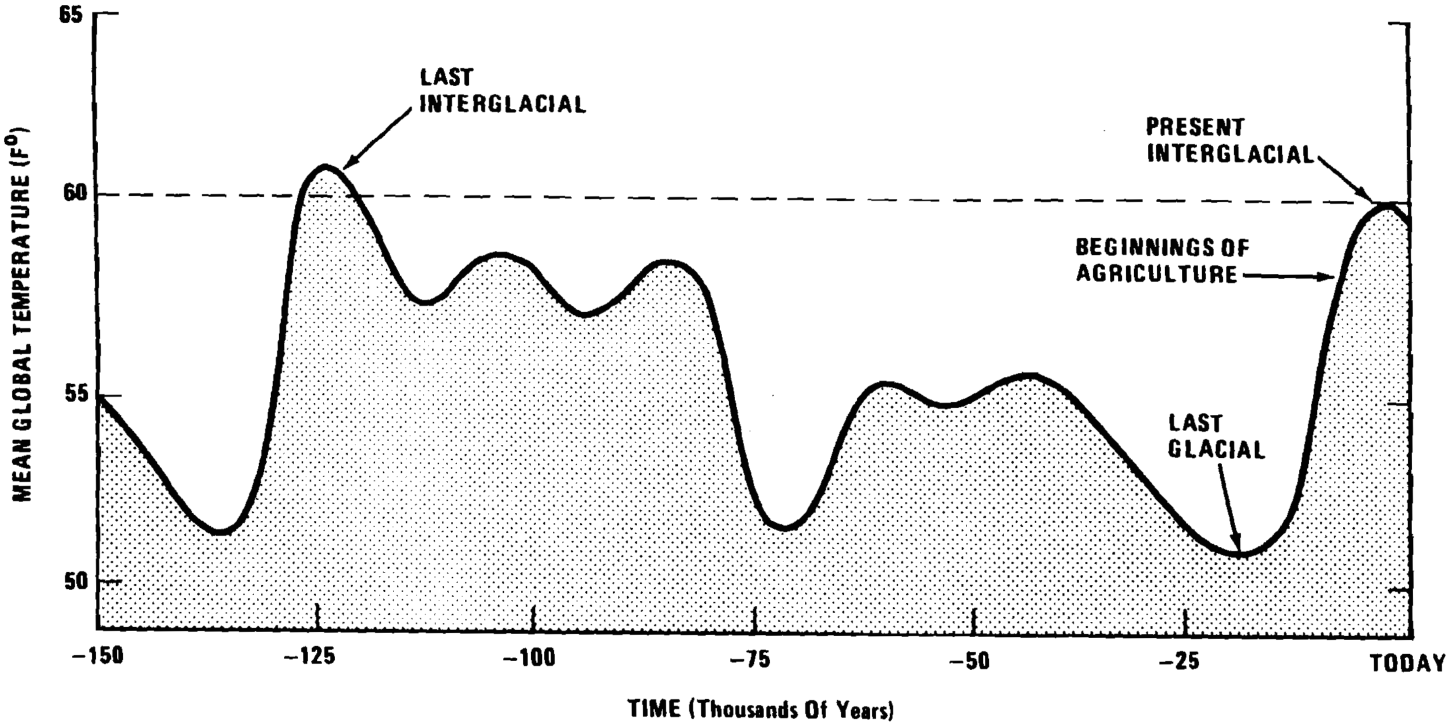


FIGURE 2.3-7
1987 Annual Windrose



REFERENCE

J. Norwine, "A Question of Climate," Environment, 19(8), (November 1977) pp 6−13f.

This Illustration for Information Purposes only.

FIGURE 2.3-8
Worldwide Temperature Variations

2.4 SURFACE HYDROLOGY

2.4.1 HYDROLOGIC DESCRIPTION

2.4.1.1 Site and Facilities

The WIPP facility lies within the Los Medanos area in the drainage basin of the Pecos River (Figure 2.4-1). The headwaters of the Pecos River are located northeast of Santa Fe, New Mexico; from there the river flows south through eastern New Mexico and western Texas until it discharges into the Rio Grande. The Pecos River has an overall length of approximately 500 miles, a maximum basin width of 130 miles and a total drainage area of roughly 44,500 square miles(mi^2). Of these, 20,500 $miles^2$ are classified as noncontributing.[1] Climatic characteristics of the basin vary from sub-humid in the mountains to semiarid at the lower elevations.

The Pecos River is about 14 miles west of the WIPP facility at its closest point (river mile 430 above the confluence with the Rio Grande), and has a drainage area of about 19,000 $miles^2$. The slope of the Pecos riverbed in this area is approximately 4.0 feet per mile.[2]

East of the river, near the WIPP facility, which includes the Los Medanos area, no outstanding natural drainage features exist. A few small unnamed drainage channels constitute all the tributaries joining the Pecos from the east within 50 miles north or south of the WIPP facility. From the west, the principal tributaries joining the Pecos north of Carlsbad are Rio Penasco with a drainage area (D.A.) of 1,060 $miles^2$ at river mile 496 (rounded to nearest mile), the Rocky Arroyo (D.A. = 64 mi^2) at river mile 475, and the Dark Canyon (D.A. = 451 mi^2) at river mile 459. Other smaller tributaries flowing from the west are the Little Walt Canyon, Willow Draw, Spencer Draw, and the North Seven, Middle Seven, and South Seven Rivers. Most of these tributaries originate in the Guadalupe Mountains.[2,3] Downstream from Carlsbad, the Black River (D.A. = 436 mi^2) joins the Pecos from the west at a point about 16 miles southwest of the WIPP facility at river mile 436. The Delaware River (D.A. = 689 mi^2) joins the Pecos from the west at river mile 406 and a number of other small creeks and draws join at various points between Carlsbad and Malaga.

In the reach between Carlsbad and Malaga (where the river is closest to the WIPP facility), the bed of the Pecos is made up of sand and gravel. The overbanks adjacent to the main channel consist of sandy soil dominated by mesquite and salt cedars. In general, the right (west) bank has a steeper slope than the left (east bank) and, at a few places, the banks are made up of bare rock. During major floods, river water spreads over a flood plain.

The Pecos River flow above Malaga (river mile 432) is regulated by storage in several dams, including Santa Rosa Lake (Los Esteros Dam-river mile 757), Lake Sumner (Alamogordo Dam - river mile 702), Lake Brantley (river mile 479), Lake Avalon (river mile 467) and several other smaller upstream dams that divert water for irrigation and power production. The locations of dams on the Pecos River and its tributaries are shown in Figure 2.4-1. Salient features of these structures are given in Table 2.4-1. Numerous stream gaging stations are located on the Pecos River and several of its tributaries. These gaging stations are shown in Figure 2.4-1. Information pertaining to several gaging stations, including average, maximum, and minimum recorded discharges, is contained in Table 2.4-2.

The stream gaging station at Malaga, New Mexico on the Pecos River is the nearest station to the WIPP facility. The maximum and minimum recorded flows at this station during the period 1938 to 1985 were 120,000 cubic feet per second (ft^3/s) (August 23, 1966) and 3.7 ft^3/s (October 20, 1976), respectively.[4]

There are no major surface water bodies located within 10 miles of the WIPP facility. Beyond 10 miles, several water bodies lie to the north including Laguna Gatuna, Laguna Tonto, Laguna Plata, and Laguna

Toston. All these lakes are situated at or above a mean sea level (MSL) elevation of 3,460 feet. As the floor elevation of the WIPP surface facilities is about 3,400 feet MSL, surface runoff from the WIPP facility would not flow north toward any of these lakes.

About four miles west of the WIPP facility, there is a topographical depression known as Nash Draw which contains an ephemeral drainage system. This drainage carries water only during very wet years and joins the Pecos River about a mile upstream from Malaga. At its nearest point to the WIPP facility, Nash Draw is about five miles wide. The general bed elevation of Nash Draw in the vicinity of the WIPP facility is 3,150 feet MSL, which is approximately 250 feet below the grade elevations of the WIPP surface facilities. Red Lake, located in Nash Draw about seven miles northwest of the WIPP facility, is at 3,160 feet MSL.[5]

Several brine lakes are located in southeastern Nash Draw. The largest of these, Laguna Grande de la Sal, is several square miles in area and is a downslope catchment basin for limited surface drainage and artesian saline water-bearing formations.[6] Emptying into its northern end are a large saline spring, Surprise Spring, and the much smaller, less saline Pupfish Spring. Only the northern third of the lake is perennial. The amount of water in the southern portion of the lake depends strongly on the amount of precipitation that falls.[7] The remaining brine lakes, including Laguna Tres, Laguna Quatro, Laguna Dos, Lindsey Lake, and Tamarisk Flat, lie northeast of Laguna Grande de la Sal. These lakes were formed between 1942 and 1979, apparently as a result of potash refining and oil brine disposal in Nash Draw.[7] These water bodies are located at elevations of approximately 3,000 feet MSL.[5]

Scattered throughout the area near the WIPP facility are livestock watering impoundments (tanks). Some of these include Hill Tank, Indian Tank, Red Tank, and Noye Tank.

There are no known domestic surface water users on the Pecos River downstream from Carlsbad. Most of the surface water is used for irrigation while less than one percent of the total water withdrawn is used for industrial purposes. The actual amount of water diverted by any user differs from year to year. Approximate quantities diverted in the years 1978 to 1985 from Carlsbad to the New Mexico-Texas border are listed in Table 2.4-3. Approximate allotments for 1986 in the reach from the New Mexico-Texas border to Girvin, Texas are shown in Table 2.4-4.

Water quality in the Pecos River Basin near the WIPP facility is strongly influenced by both man caused and natural factors. Man caused impacts on the Pecos River include irrigation water returned to the river and wastewater treatment plant discharges. Natural sources are from groundwater inflows and by water contact with the river banks and bottom causing dissolution of salts and other constituents.

In addition, wastewater from the potash and oil industries has been discharged into surface sediments, spoil piles and ponds contaminating the shallow brackish aquifers and recharging existing water bodies in Nash Draw. The land surface slope and shallow aquifer gradient around Nash Draw are toward the Pecos River.[1]

The water quality of the Pecos River between Carlsbad and Red Bluff has exhibited increasing concentrations of several analytes in a downstream direction. Selected water quality parameter concentrations per station are presented in Table 2.4-5. Especially noteworthy are the increases in sodium and chloride concentrations. Theories explaining these increases include contributions from groundwater inputs, irrigation return water, and dissolution of ions from river sediments.

Results of the chemical analyses of the Pecos River water at Malaga (river mile 432) for the 1985 water year are given in Table 2.4-6. The daily measured specific conductance and water temperatures at the same station for the 1985 water year are given in Tables 2.4-7 and 2.4-8, respectively.

2.4.2 PRECIPITATION IMPACTS

2.4.2.1 Local Precipitation Patterns

The WIPP facility is located in the Chihuahuan Desert with an arid to semiarid climate. Precipitation in this area varies between localities and years, but averages roughly 12 inches per year. Mean annual precipitation values at various locations in the region around the WIPP facility are given in Table 2.4-9. Precipitation amounts have also been recorded at the WIPP facility during the periods of May 1976 to February 1980, and June 1985 to February 1987. These data are noted in Table 2.4-10, which indicates that four complete years of precipitation data have been obtained at the WIPP facility. Using 12 inches of precipitation per year as an average, 1977 appeared to be a slightly dry year (9.3 inches), 1979 a normal year (11.8 inches), and 1978 and 1986 very wet years (19.4 and 23.0 inches, respectively).

The probable maximum precipitation (PMP) quantities during "all season" and "winter" for different durations within a 10 miles^2 drainage area in the vicinity of the WIPP facility are listed in Table 2.4-11. The corresponding intensities are shown in Figure 2.4-2. The PMP determinations have been used to design the drainage systems and roof loads for the surface structures at the WIPP facility (discussed in Sections 2.4.2.2 and 2.4.2.3, respectively).

2.4.2.2 Drainage Patterns

In the proximity of the WIPP facility, subsurface geologic formations are covered with smoothly rounded hills of dune sand. Surface drainage patterns in the area are not well defined, and rain that collects in pools between the sand dunes is lost through infiltration into the sand and evapotranspiration. Vegetation generally consists of mesquite, shinnery oak and other plants commonly found in the northern Chihuahuan Desert and southern Great Plains. Land is used primarily for cattle grazing; however, potash mining and petroleum extraction also occur in the area.

The general ground slope in the vicinity of the WIPP facility is about 50 ft/mi. downward from the east toward the west. The average ground slope from north to south is downward about 13 ft/mi. A topographic and surface water divide (Antelope ridge) exists about 10 miles east of the WIPP facility. The activities associated with operation of the WIPP facility are not expected to alter the existing drainage pattern of the area around the WIPP facility.

The local drainage pattern is such that normal surface runoff from contributing areas north, south, and west of the surface structures drains westward into Nash Draw without affecting the WIPP facility structures. Storm water runoff from areas around the surface structures, including that from the east, are diverted away from the structures by a system of peripheral interceptor diversions. As shown in Figure 2.4-3, this drainage system is designed so that storm runoff due to a PMP event on the contributing drainage areas does not flood the plant. In addition, the grade elevations of most roads, tracks, and surface facilities are designed so that storm water will drain away under the most severe conditions. For example, the floors of the Waste Handling Building (WHB) and other surface structures are 0.5 feet above the grade elevation.

2.4.2.3 Roof Load Design

In addition to designing the WIPP facility drainage system, precipitation impacts were considered for the roof load design of structures. To estimate the roof loads for the design of surface structures, the 100-year mean recurrence interval snow load of 10 pounds per square foot (lb/ft^2) is used, which is the value recommended by ANSI.[8] The adopted snow load is about 30 percent higher than the recorded monthly maximum snowfall in Carlsbad.[9]

To prevent the undesirable buildup of standing water on the roofs of confinement structures, they are designed without parapets. This limits the design roof load to the weight of the snowpack plus the weight of water required to bring the snowpack to threshold condition and the water depth necessary to begin flowing over the edges of the roof. The weight of water required to bring the snowpack (snow load of 10 lb/ft^2) to threshold condition is estimated to be seven lb/ft^2. The water depth required to initiate flow over the edges of the roof and discharge the PMP without any holdup on the roof is conservatively estimated at two inches. This provides an additional load of 10 lb/ft^2. Thus, the total roof load is estimated to be 27 lb/ft^2. Design loads of buildings are discussed further in Section 3.2.7.

2.4.2.4 Precipitation Losses

The maximum, average, and minimum mean monthly temperatures in Carlsbad (26 miles from the WIPP facility) over a period of 30 years (1951-1980) are given in Table 2.4-12. Generally, June, July, and August are the warmest months (average temperature for this period is 81.2F), and December and January are the coldest (average temperature for this period is 43.8F).[10] The record high temperature recorded in Carlsbad was 112F (June 1902), and the record low as -18F (January 1962). Wind speeds are usually moderate with the prevailing wind from the south. The maximum recorded wind in Roswell was a gust of 75 miles per hour. The average relative humidities at 5:30 a.m., 11:30 a.m., 5:30 p.m., and 11:30 p.m. in Roswell are 65, 36, 30, and 52 percent, respectively.

The potential evaporation in the vicinity of the WIPP facility is much greater than the average annual precipitation of about 12 inches. More than 90 percent of the mean annual precipitation at the WIPP facility is estimated to be lost by evapotranspiration.[7] National Oceanographic and Atmospheric Administration (NOAA) records show the average annual Class A pan evaporation rate at Lake Avalon to be 116 inches, with an average of 76 inches lost between May and October. The annual shallow lake evaporation for southeastern New Mexico is estimated at 80 inches. The maximum evaporation rate is typically in June while the minimum is typically in December or January.[11]

In the area around the WIPP facility, the natural soil material is comprised of loamy sand of depths of as much as 15 feet. A nearly continuous petrocalcic soil horizon (the Mescelaro caliche) that varies from zero up to 10 feet in thickness[12] underlies the surficial soil at the WIPP facility from a depth of a few inches to over 15 feet. The petrocalcic horizon forms by the precipitation of calcium carbonate at the limits of soil moisture penetration and forms an extremely impervious barrier. Thus, little, if any, soil moisture infiltrates beyond this horizon.[13] Preliminary investigations indicate that natural breaches of this horizon amount to only a very small percentage of the area underlain by it. Even under conditions of a rare, locally intense precipitation event which might cause deeper than average infiltration, the petrocalcic horizon is "an additional obstruction to infiltrating and recharging the underlying beds."[12] Where the petrocalcic horizon is close to the surface, a mat of plant roots forms on top of it. Almost all the infiltrating water that reaches the petrocalcic layer is retained above it and is typically lost by evapotranspiration.

The above discussion indicates that precipitation losses due to evaporation in the basin are high; therefore, the runoff coefficients are low. The mean annual runoff in the region is only 0.1 to 0.2 inch.[7]

2.4.3 PROBABLE MAXIMUM FLOOD (PMF) NEAR THE WIPP FACILITY

2.4.3.1 Flood History

Floods on the Pecos River can be generated by: (1) frontal storms that produce large runoff volumes and high flood peaks; (2) thunderstorms (convective storms) that produce small runoff volumes but very high peaks; and (3) snowmelt in the mountainous portion of the drainage area that produces large runoff volumes, but relatively low peaks.

Between the confluence of the Rio Hondo with the Pecos River (river mile 566) and river mile 484 (location of the former McMillan Reservior, now part of Lake Brantley), the channel capacity of the Pecos River, without any overbank flooding, is about 8,500 ft^3/s. In the reach between river mile 484 and the confluence of Dark Canyon near Carlsbad (river mile 459), the channel capacity is estimated to be 50,000 ft^3/s. From the confluence of Dark Canyon to Red Bluff reservoir (river mile 411), the channel capacity is approximately 20,000 ft^3/s.[2]

Large floods are reported to have occurred on the Pecos River in 1893, 1904, 1905, 1915, 1916, 1919, 1937, 1941, and 1966.[3,4,14] No data are available for the 1893 event. The earliest flood for which discharge information is available occurred on October 2, 1904 following the failure of Avalon Dam. This flood was caused by a storm that lasted five days and covered the upper catchments of the Pecos River, Rio Hondo, Rio Felix, and Rio Penasco. The runoff generated by that storm caused floods throughout the Pecos River basin, and during the flood, the peak flow at Avalon gaging station (river mile 466) probably exceeded 90,000 ft^3/s. The corresponding river stage is not available. The river stage at Red Bluff during this flood (river mile 411) is reported to have reached 28 feet (gage datum = 2,850.05 feet).

Based on the records of the gaging station at Carlsbad (river mile 459), there was another major flood on July 25, 1905, when the peak flow of the Pecos reached 54,900 ft^3/s. The fourth and fifth major floods of the Pecos were on April 17, 1915 and August 7, 1916, when the peak flows at the Carlsbad gaging station reached 80,000 and 85,700 ft^3/s, respectively, with regulation by the McMillan and rebuilt Avalon reservoirs. Another flood occurred in September 1919, when the river stage at the Malaga gaging station, approximately 27 miles downstream from Carlsbad (river mile 432), was recorded at 29.4 feet (gage datum = 2,895.64 feet). The corresponding discharge was 40,400 ft^3/s.

Another major flood on the Pecos River is reported to have occurred on May 30, 1937, when the peak flow at Artesia (river mile 504) and Lake Arthur (river mile 522) was 51,500 ft^3/s. The corresponding stage at Lake Arthur was 21.77 feet (gage datum = 3,327.07 feet). The area in the vicinity of Carlsbad was flooded again on May 22, 1941, when the peak flow at Dam site three (river mile 474) reached 60,000 ft^3/s with regulation by Alamogordo (Lake Sumner), McMillan, and Avalon reservoirs. This flood resulted from intense rainfall over the drainage area of the Pecos River upstream of Red Bluff reservoir. It produced a stage of 35.1 feet at Malaga.

The highest flood of record (through 1986) on the Pecos River occurred on August 23, 1966, when the discharge and stage at Malaga were 120,000 ft^3/s and 42.1 feet, respectively, with regulation by the Alamogordo, McMillan, and Avalon reservoirs. The water surface profile of the Pecos River in Carlsbad during this flood is shown in Figure 2.4-4.

The flood frequency curve of the Pecos River at Malaga is shown in Figure 2.4-5. An additional curve is included in this figure to show the attenuation at Malaga expected to be provided by the Brantley reservoir.

2.4.3.2 Flood Design Considerations

As noted earlier, the WIPP facility is approximately 14 miles from the Pecos River. The general ground elevation in the vicinity of the surface facilities (approximately 3,400 feet MSL) is about 500 feet above the riverbed and over 400 feet above the floodplain. As discussed in Sections 2.4.3.3 and 2.4.4, a probable maximum flood (PMF) or floods induced by potential dam failures on the Pecos River or its tributaries cannot raise the water level 500 feet to endanger the WIPP facility. Therefore, as far as the potential for flooding from the Pecos River is concerned, the WIPP facility is categorized as a "dry site."

In the past, the Pecos River has maintained a reasonably stable course in the vicinity of the WIPP facility and does not exhibit any marked tendencies to shift several miles east or west. This stability is demonstrated by the narrow width of alluvial deposits along the river's floodplain. Therefore, because the horizontal and vertical separations between the WIPP facility and the river are both large, any change in the river course accompanied by bank erosion during unprecedented future floods could not affect structures at the facility.

The nearest watercourse to the WIPP facility is Nash Draw, an irregular depression about four miles from the WIPP facility. Its bed is about 250 feet below the site grade. In view of the large horizontal and vertical separation, it is inconceivable that the PMF of Nash Draw could affect the WIPP surface structures.

As the WIPP facility is categorized as a dry site, it was not considered appropriate to develop a discharge hydrograph using complex basin and stream course response models. Developing detailed computations for providing a water surface profile were also not deemed necessary. However, brief discussions concerning PMF flow and water level determinations are contained in the following two sections.

2.4.3.3 Probable Maximum Flood (PMF) Flow

The peak flow of the Pecos River during a PMF near the WIPP facility was estimated using the conservative approach suggested in Appendix B of the NRC Regulatory Guide 1.59.[15] The WIPP facility lies just west of the 103rd meridian. The regional isolines of PMF peaks shown on the maps of Appendix B of the NRC Regulatory Guide extend slightly west of the 103rd meridian; however, they are recommended to be used for areas east of the 103rd meridian. In view of the proximity of the WIPP facility to the 103rd meridian, it is considered reasonable to use the extrapolated portions of these isolines. This gives a PMF peak flow for the Pecos River of 1,350,000 ft^3/s near the WIPP facility for a drainage area of 19,000 mi^2.

In Table B.1 of Appendix B to Regulatory Guide 1.59, the estimated PMF flow of the Pecos River at the Los Esteros Dam (D.A. = 2,430 mi^2) is shown as 352,000 ft^3/s. The same table indicates the PMF flow at Alamogordo Dam (D.A. = 4,390 mi^2) to be 277,000 ft^3/s. Both values are less than 60 percent of the values estimated from the extrapolated portions of the isoline maps from Appendix B of Reference 15. It is, therefore, concluded that the 1,350,000 ft^3/s value obtained from the extrapolated portion of the isoline maps for a drainage area of 19,000 mi^2 is conservatively large.

2.4.3.4 Water Level Determinations

The rating curve of the Pecos River at the United States Geologic Survey (USGS) gaging station 08406500 near Malaga, New Mexico is shown in Figure 2.4-6. Since this rating curve does not extend beyond a discharge of 25,000 ft^3/s, its extrapolation to the PMF peak flow of 1,350,000 ft^3/s is not appropriate. Therefore, the water surface elevation corresponding to the PMF peak flow was estimated by the slope area method using representative cross sections of the Pecos River applicable to the reach near Malaga. Three cross sections of the Pecos River near Malaga are shown in Figure 2.4-7. The water surface elevations of the historic flood of August 23, 1966 are marked on these cross sections, which were used by the USGS to estimate the peak flow of 120,000 ft^3/s that passed down the Pecos on August 23, 1966.

To compute the conveyances of the cross sections shown in Figure 2.4-7, the USGS divided each of these cross sections into four subsections. The values of Manning's n used for each subsection are shown in Table 2.4-13. Based on a comparison of the photographs of the Pecos riverbed with those available in the literature[16] for known values of n, the USGS values of Table 2.4-13 are considered reasonable.

The average water surface slope of the Pecos River in Carlsbad during the flood of August 23, 1966 was 0.00095 (see Figure 2.4-4). The average water surface slope, based on high-water marks near Malaga recorded by the USGS for the same flood, is 0.00123. The energy slopes used by the USGS for its estimates of the flood discharge of August 23, 1966, for two consecutive reaches of 752 feet and 645 feet with beginning and ending cross section shown in Figure 2.4-7, are 0.00113 and 0.00161, respectively. In view of these values, it is assumed that the average energy slope during the PMF on the Pecos River would be about 0.001, i.e., 5.28 ft/mi. For the three cross sections of the Pecos River near Malaga (Figure 2.4-7), weighted average values of Manning's n are computed using the equation:

$$n = \frac{AR^{2/3}}{\sum_{i=1}^{m} \frac{A_i R_i^{2/3}}{n_i}}$$

where

A = total cross sectional area
R = hydraulic radius of cross section, in feet
m = number of subsections in which a cross section is divided
A_i = Area of the i^{th} subsection
n_i = Manning's roughness coefficient applicable to the ith subsection
R_i = hydraulic radius of i^{th} subsection, in feet

Using the average of the weighted roughness coefficients computed previously (Table 2.4-13) and an average energy slope of 0.001, the water surface elevation corresponding to the PMF peak flow of 1,350,000 ft^3/s near the WIPP facility is estimated to be 2,980 feet MSL.

2.4.3.5 Flooding Protection Requirement

As calculated in the previous section, a very conservative estimate of the highest water surface elevation in the Pecos River during a PMF is 2,980 feet MSL. This is about 420 feet below the floors of the surface structures at the WIPP facility, which have an elevation of approximately 3,400 feet MSL. The horizontal and vertical separations between the Pecos River floodplain and the WIPP facility are great enough that floods in the Pecos River cannot affect the surface structures at the WIPP facility. Accordingly, there are no flood protection requirements for the WIPP facility. In addition, as stated in Section 2.4.2.2, the WIPP facility drainage structures will be designed so that ponding during a PMP event does not affect the surface structures.

2.4.4 OTHER POTENTIAL DAMAGE CONSIDERATIONS

2.4.4.1 Potential Dam Failures (Seismically Induced)

Major dams on the Pecos River and its tributaries upstream of the WIPP facility (Table 2.4-1) are the Los Esteros Dam (Santa Rosa Lake) at river mile 757, Alamogordo Dam (Lake Sumner) at river mile 702, Brantley Dam at river mile 479, Diamond A and Rocky Dams on the Rio Hondo and Rocky Arroyo, and Avalon Dam at river mile 466.

Los Esteros is an earthfill dam with a storage capacity of 447,100 acre feet. It is an irrigation and flood control reservoir belonging to the U.S. Army Corps of Engineers, located about 327 miles upstream from the WIPP facility. Sumner Lake (Alamogordo Dam) is an irrigation and recreation reservoir with a storage capacity of 101,600 acre feet located about 272 miles upstream of the WIPP facility. A flood wave generated by the seismic failure of these dams would be greatly attenuated during its long passage over the wide floodplains of the Pecos River and is not likely to produce a flood peak comparable to the PMF at the WIPP facility. Also, such a flood wave is unlikely to retain sufficient energy to cause a domino type failure of the Brantley and Avalon Dams which are, respectively, 218, 223, and 235 miles downstream from the Alamogordo Dam.

Diamond A and Rocky Dams on the Rio Hondo and the Rocky Arroyo Rivers, respectively, have a combined capacity of 166,200 acre-feet and are more than 145 miles upstream from the WIPP facility. Downstream from the confluence of the Rio Hondo and the Pecos River is Brantley Lake. Brantley Dam, which is about 49 miles upstream from the WIPP facility, has a storage capacity of 340,360 acre-feet. Lake Avalon, located about 37 miles upstream from the WIPP facility, has a storage capacity of 4,330 acre-feet. The heights of these dams vary from 40 to 212 feet (Table 2.4-1). A flood wave generated by the failure of one or more of these dams would be attenuated by the valley storage over a river length of 37 miles or more before reaching the closest point to the WIPP facility. It is inconceivable that this attenuated wave could create a water depth of 420 feet and spread a distance of 14 miles laterally to affect surface structures at the WIPP facility. Thus, a detailed analysis of the effect of potential dam failures on the flood conditions at the WIPP facility is not considered necessary.

2.4.4.2 Coincident Wind Wave and Tsunamis Considerations

Since the PMF estimated elevation (2,980 feet, MSL) is about 420 feet below the floors of the surface structures (Section 2.4.3.5) and the WIPP facility is about 14 miles from the river, wind wave runup is not a concern. In addition, since the WIPP facility is far from any major lake or ocean, the consideration of surges or tsunamis is not relevant. Therefore, detailed calculations concerning either event are not considered necessary.

2.4.4.3 Ice Flooding

None of the historic floods described in Section 2.4.3.1 were caused by ice jams on the Pecos River or its tributaries. There are no records of prolonged water surface freezing or of major ice jams in the basin. Therefore, ice jam flooding is not considered relevant.

Temperature records over a period of 30 years (1951-1980) in Carlsbad indicate that, on the average, 74 days in a year have temperatures that drop below 32F. Days with subzero temperatures are extremely rare. The 50-percent probability for a freeze free period is 223 days in a year.[10] Thus, the possibility of major ice formation in the river near the WIPP facility is very improbable.

2.4.4.4 Environmental Releases of Effluents

Any liquid effluents identified as liquid radwaste to be disposed at the WIPP facility as site-generated waste are expected to have very low concentrations or levels of radioactivity (Section 5.4). Liquid radwaste will be stored in tanks located within the WHB and solidified for emplacement underground. There are no normal or credible accident scenarios that will result in a release of liquid radwaste into the groundwater or surface water environments. However, in the unlikely event of an accidental spill from any of the tanks, the effluents would be contained within spill walls inside the building. Also, no liquid effluents are to be discharged from the WIPP facility into the Pecos River. Thus, it is concluded that the accidental release of effluents from the WIPP facility will be contained and will not have an adverse effect on the groundwater or surface water environments.

References for Section 2.4

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TABLE 2.4-1

SALIENT FEATURES OF DAMS UPSTREAM AND DOWNSTREAM OF THE WIPP FACILITY*

DAM NAME	RIVER/ APPROX. LOCATION	DRAINAGE AREA, mi2	TYPE OF DAM	YEAR OF COMPLETION	HEIGHT ft	MAX. STORAGE CAPACITY, acre-ft	PURPOSE
Santa Rosa Lake (Los Esteros)	Pecos (N.M.) River Mile 757	2,430	Earthfill	1980	212	447,100	Irrigation and flood control
Sumner Lake (Alamogordo)	Pecos (N.M.) River Mile 702	4,390	Earthfill	1937	164	101,600	Irrigation and recreation
McMillan**	Pecos (N.M.) River Mile 484	16,990	Earthfill	1893	40	33,620	Irrigation and recreation
Brantley	Pecos (N.M.) River Mile 479	10,800	Earthfill	1988	340,360***		Irrigation, flood control and recreation
Avalon	Pecos (N.M.) River Mile 467	18,070	Earthfill	1907	40	4,330	Irrigation
Red Bluff	Pecos (Texas) River Mile 411	20,720	Earthfill	1936	98	340,000	Irrigation and hydro power
Two Rivers Project Diamond A Dam	Rio Hondo (N.M.) River Mile 33	963	Earthfill	1963	93	166,200	Flood control
Rocky Dam	Rocky Arroyo (N.M.) 14 miles southwest of Roswell (N.M.)	64	Earthfill	1963	113		Flood control

*From Water Resources Data New Mexico, Water Year 1985, USGS Water-Data Report NM-85-1 (1986).

**The Lake M[c]Millan Dam was breached in 1989 as part of the completion of Brantley Dam

***Flood Control, Brantley Dam and Reservoir, Pecos River, New Mexico, U.S. Army Engineer District, Albuquerque, New Mexico (July 1964).

TABLE 2.4-2

DISCHARGES IN THE PECOS RIVER BASIN*

RIVER	LOCATION	APPROXIMATE RIVER MILE	DRAINAGE AREA (MILES^2)	PERIOD OF RECORD	DISCHARGE (cfs) AVERAGE	MINIMUM	MAXIMUM
Pecos	Pecos, NM	897	189	1919-1985	99.3	2.0	4,500
Pecos	Anton Chico, NM	808	1,050	1910-1985[(2)]	129	0	40,300
Gallinas	Colonias, NM	789[(1)]	610	1951-1985	15.6	0	13,700
Pecos	Santa Rosa, NM	748	2,650	1906-1979[(3)] 1980-1985[(4)]	135	0.28	55,200
Pecos	Below Sumner Dam, NM	702	4,390	1937-1985	200	0	42,800
Pecos	Acme, NM	585	11,380	1938-1985	179	0	45,000
Rio Hondo	Roswell, NM	566	1,070	1981-1985	--	0	373
Pecos	Artesia, NM	504	15,300	1937-1985	240	0	51,500
Rio Penasco	Dayton, NM	496	1,060	1951-1985	5.34	0	29,800
Pecos	Dam Site 3, Carlsbad, NM	474	17,980	1940,1945-1985	155	4.3	69,000
Pecos	Below Dark Canyon Draw, Near Carlsbad, NM	459	18,550	1970-1985	45.7	0	28,200
Black	Above Malaga, NM	436	343	1948-1985	12.9	0.51	74,600
Pecos	Malaga, NM	432	19,190	1938-1985	166	3.7	120,000
Pecos	Red Bluff, NM	411	19,540	1938-1985	161	0.19	111,000
Delaware	Red Bluff, NM	406	689	1938-1985	12.9	0	81,400
Pecos	Girvin, TX	200	29,560	1939-1975[(5)]	96	2.2	20,000

Data from Water Resources Data, New Mexico, Water Year 1985, U.S. Geological Survey Water Data Report NM-85-1 (1986),

(1) At confluence with Pecos River

(2) Varied from 1910 to 1925

(3) Varied, before completion of Santa Rosa Dam

(4) After completion of Santa Rosa Dam

(5) Data from Water Resourceds Data, New Mexico, Water Year 1975, U.S. Geological Survey Water-Data report NM-75-1 (1976).

--No data available

TABLE 2.4-3

SURFACE WATER USERS ON THE PECOS RIVER (1978-1985)

Between Carlsbad and New Mexico - Texas Border*

USER	1978 PUBLIC	1978 WELL	1979 PUBLIC	1979 WELL	1980 PUBLIC	1980 WELL	1981 PUBLIC	1981 WELL	1982 PUBLIC	1982 WELL	1983 PUBLIC	1983 WELL	1984 PUBLIC	1984 WELL	1985 PUBLIC	1985 WELL
	DIVERSION, ACRE-FEET PER YEAR															
Irrigation																
Carlsbad Irrigation District	57,190.0		73,550.0		76,780.0		47,270.0		72,140.0		84,200.0		72,140.0		79,870.0	
City of Carlsbad Golf Course, North and South Pumps	307.3		374.5		393.9		393.0		393.0		350.2		373.0		303.8	
Dowling, Mrs. F. V.	15.8		0.0		13.7		3.0		11.0		1.7		18.0		40.5	
Hines, E. J.	0.6		0.7		0.7		0.5		0.3		0.0		0.0		0.0	
Moutray, Hugh (in 1978 changed to McDonald, Clarence, et al.)	469.9		846.8		676.5		261.0		557.9		583.1		359.0		2,062.4	
O'Chesky Estate, Fred (in 1978 changed to Lopez, Angel; in 1982 changed to Sibley, William C.)		74.6		6.6		82.7		5.0		0.0		2.2		37.7		1.2
Valley Land Company City of Carlsbad-Harroun Canal	8,603.3		8,785.9		7,965.8		8,541.1		9,343.5		7,322.6		7,429.1		10,657.1	
Total Irrigation	**66,586.9**	**74.6**	**83,557.9**	**6.6**	**85,830.6**	**82.7**	**56,468.6**	**5.0**	**82,446.1**	**0.0**	**92,522.4**	**2.2**	**80,319.1**	**37.7**	**92,933.8**	**1.2**
Commercial																
Mississippi Chem.Corp.	105.3		630.2		0.0		0.0		0.0		0.0		0.0		0.0	
City of Carlsbad (Tansil Dam)***	6,904.7		14,249.9		11,679.0		11,925.0		7,871.2		7,267.2		11,451.2		13,025.1	
Bataan Recreational Lake**	373.6		373.6		373.6		373.6		373.6		373.6		373.6		373.6	
Total Commercial	**7,383.6**		**15,253.7**		**12,052.6**		**12,298.6**		**8,244.8**		**7,640.8**		**11,824.8**		**13,398.7**	

*Data is from annual "Watermaster Report, Pecos Valley Surface Water District", Table 6, compiled by New Mexico State Engineer, Roswell Office, Supplied by Eddie Trujillo of the New Mexico Interstate Stream Commission, Santa Fe, New Mexico, January 1987.
**This is not a diversion. Water just passes through the lake.
NOTE: Well water is supplemental to basic surface right.

TABLE 2.4-4

SURFACE WATER USERS ON THE PECOS RIVER BETWEEN NEW MEXICO-TEXAS BORDER AND CONFLUENCE AT GIRVIN, TEXAS*

USER	APPROXIMATE ALLOTMENT (ACRE-FT/Y) (BASED ON 1986 FIGURES)	PURPOSE
Loving County Water Improvement District No. 1	620	Irrigation
Reeves County Water Improvement District No. 2	1,760	Irrigation
Ward County Water Improvement District No. 3	1,660	Irrigation
Ward County Irrigation District No. 1	4,740	Irrigation
Ward County Improvement District No. 2	5,500	Irrigation
Pecos County Water Improvement District No. 2	3,060	Irrigation
Pecos County Water Improvement District No. 3	2,660	Irrigation

*Information provided by personal communication with John Hayes of the Red Bluff Water Power Control District, Pecos, Texas

TABLE 2.4-5

SELECTED WATER QUALITY PARAMETERS FOR SAMPLING STATIONS ON THE PECOS RIVER*

BASED ON DATA OBTAINED DURING WATER YEAR OCTOBER 1985 - SEPTEMBER 1986

STATION NO.	APPROXIMATE RIVER MILE	FLOW (cfs)[2]	DISSOLVED SOLIDS CONCENTRATION (mg/1)[1]				
			CALCIUM	MAGNESIUM	SODIUM	SULFATE	CHLORIDE
Carlsbad[3]	459	30.7	350	120	350	1100	590
Malaga	432	67.8	500	180	770	1600	1400
Pierce Canyon Crossing	426	66.9	500	2101	600	1800	2700
Red Bluff[4]	411	70.5	510	220	1800	2000	3500

*Data from Water Resources Data, New Mexico, water Year 1985, U.S. Geological Survey Water-Data Report NM-85-1 (1986).

(1)Mean value. Samples collected 12 times during year; roughly every 30 days.

(2)Mean value for water year.

(3)Flow measured at a location 0.1 miles downstream from mouth of Dark Canyon Draw; water quality samples obtained 0.2 miles upstream from Dark Canyon Draw. This tributary had no flow for water year 1985.

(4)Mean value for dissolved solids concentrations of five or six collections made during the water year.

Table 2.4-6

WATER QUALITY DATA OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO-BASED ON WATER SAMPLES COLLECTED DURING WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

(All Units in mg/l Unless Otherwise Indicated)

DATE	FLOW (cfs)	pH (FIELD)	DISSOLVED OXYGEN	HARDNESS AS $CaCO_3$	CALCIUM AS Ca*	MAGNESIUM AS Mg*	SODIUM AS Na*	POTASSIUM AS K*	SULFATE AS SO_4
10-04	75	8.0	8.6	1600	410	140	560	11	1300
10-30	69	8.2	10.3	1900	460	180	630	8.2	1500
12-11	59	8.3	14.2	2000	500	190	760	11	1600
12-31	69	8.4	13.9	1700	430	150	700	9.1	1600
2-05	130	8.2	11.6	1800	480	150	510	6.5	1400
3-13	49	8.3	13.2	2000	490	190	800	11	1600
4-02	64	8.6	12.8	2200	550	200	890	15	1900
4-30	53	8.5	8.9	2100	530	200	830	15	1400
5-30	45	8.2	8.6	200	490	190	720	11	1400
6-27	57	7.8	8.8	2200	550	210	840	15	1800
8-06	29	8.1	--	2000	530	160	740	14	1900
9-05	34	8.0	8.1	2500	630	220	1200	25	2200

DATE	FLOW (cfs)	pH (FIELD)	CHLORIDE AS CL*	FLUORIDE AS F*	SILICA AS SiO_2	NITRITE+ NITRITE AS N	TOTAL AMMONIA NITROGEN AS N	TOTAL ORGANIC NITROGEN AS N
10-04	75	8.0	1100	0.70	15	0.96	---	---
10-30	69	8.2	1200	0.80	13	1.4	0.180	0.52
12-11	59	8.3	1300	0.80	11	1.8	0.210	1.6
12-31	69	8.4	1200	0.70	13	2.1	0.230	1.3
2-05	130	8.2	950	0.70	12	1.5	0.210	0.79
3-13	49	8.3	1300	0.80	4.7	0.28	0.210	1.6
4-02	64	8.6	1600	0.80	5.7	0.94	0.290	0.11
4-30	53	8.5	1700	0.80	6.9	0.42	0.310	1.2
5-30	45	8.2	1200	0.80	12	0.25	0.210	1.4
6-27	57	7.8	1600	0.80	7.1	0.50	0.330	1.3
8-06	29	8.1	1400	0.80	16	0.58	0.200	1.9
9-05	34	8.0	2300	1.0	18	1.2	0.280	1.6

Data from Water Resources Data, New Mexico, Water Year 1985, U.S.G.S. Water-Data Report NM-85-1 (1986)

Specific Conductance and Temperature Data are presented in Tables 2.4-7 and 2.4-8, respectively.

*Dissolved component.

--Indicates no data available.

Table 2.4-6 Page 2 of 2

WATER QUALITY DATA OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO BASED ON WATER SAMPLES COLLECTED DURING WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

(All Units in mg/l Unless Otherwise Indicated)

DATE	FLOW (cfs)	pH (FIELD)	TOTAL PHOSPHOROUS AS P	ORTHO PHOSPHOROUS AS P*	BORON AS B*	IRON AS FE*
10-04	75	8.0	---		0.310	0.030
10-30	69	8.2			0.400	0.100
12-11	59	8.3	0.160		0.390	0.080
12-31	69	8.4	0.190	0.060	0.360	0.060
2-05	130	8.2	0.130	0.150	0.240	0.040
3-13	49	8.3	0.150		0.380	0.050
4-02	64	8.6	0.140		0.470	0.050
4-30	53	8.5	0.110		0.440	0.040
5-30	45	8.2	0.020	0.020	0.410	0.050
6-27	57	7.8	0.100	0.020	0.410	0.100
8-06	29	8.1	0.060	0.020	0.410	0.190
9-05	34	8.0	0.040	0.010	0.560	0.260

Data from Water Resources Data, New Mexico, Water Year 1985, U.S.G.S. Water-Data Report NM-85-1 (1986)

Specific Conductance and Temperature Data are presented in Tables 2.4-7 and 2.4-8, respectively.

*Dissolved component.

--Indicates no data available.

TABLE 2.4-7 Page 2 of 2

SPECIFIC CONDUCTANCE (MICROSIEMENS/CM AT 25 ° C) OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO BASED ON ONCE-DAILY OBSERVATIONS FOR WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
21	5410	5840	5520	5110	4930	6880	6910	5960	6920	7900	7290	2750
22	5490	5880	5540	4960	5030	6670	6980	6180	7330	8110	7740	2510
23	4820	5830	5580	4900	4960	6770	7160	6340	7270	8180	7870	3280
24	5400	5830	5580	4840	4930	6760	7320	6130	6740	8220	7500	3820
25	5430	5780	5580	4660	4900	6610	7440	6130	5800	8460	6770	4230
26	5440	5680	5590	4500	4810	6550	7520	6370	7260	8360	6410	4580
27	5670	5670	5690	4410	5110	6610	7210	6360	6740	6830	7290	4840
28	5760	5740	5780	4440	5200	6850	6840	6440	6920	---	---	5140
29	5810	5720	5790	4430	---	6980	7050	6550	7140	6930	6770	5370
30	5840	5750	5820	4490	---	7090	6980	6550	7350	7210	7200	5530
31	5960	---	5780	4600	---	7130	---	6550	---	7430	6440	---
MEAN	5490	5770	5800	5320	4940	6390	6950	6580	6949	7770	6990	5690

WATER YEAR 1985 MEAN 6220 MAX 8500 MIN 2510

Water Resources Data, New Mexico, Water Year 1985, U.S. G. S.

Water Data Report, NM-85-1 (1986)

--- Indicates no data available.

TABLE 2.4-8 Page 2 of 2

DAILY TEMPERATURE WATER (° C), OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO BASED ON ONCE-DAILY OBSERVATIONS FOR WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
21	16.5	11.0	11.5	6.0	13.5	12.0	20.0	21.0	27.0	25.0	27.0	22.0
22	16.0	10.0	10.0	4.5	14.5	14.5	20.0	22.5	26.0	28.0	30.0	---
23	14.0	10.0	9.5	6.5	14.0	14.0	20.0	22.0	25.5	26.0	29.0	23.0
24	13.0	10.5	10.0	6.0	13.0	15.0	21.0	23.0	27.0	26.0	26.5	22.0
25	13.0	9.0	9.0	7.5	12.0	18.0	20.0	24.0	26.5	27.0	26.0	22.0
26	13.5	11.5	9.0	8.5	12.5	17.0	20.0	24.0	25.5	26.0	25.0	22.0
27	13.5	10.0	9.0	9.0	12.0	16.0	19.0	24.0	25.0	26.5	26.0	22.0
28	15.0	9.0	10.0	8.5	12.0	16.5	21.0	26.0	26.5	---	---	21.5
29	15.0	10.0	12.0	8.5	---	16.5	19.0	24.0	24.0	26.0	28.0	20.5
30	18.0	9.0	10.0	9.5	---	14.0	20.0	25.0	23.5	29.0	28.0	17.5
31	18.0	---	10.0	7.5	---	14.5	---	22.0	---	31.5	26.0	---
MEAN	**17.5**	**13.0**	**9.5**	**8.0**	**9.5**	**15.0**	**19.0**	**23.5**	**26.0**	**27.0**	**27.5**	**24.0**

WATER YEAR 1985 MEAN 18.5 MAX 32.5 MIN 4.5

*Water Resources Data, New Mexico, Water Year 1985, U.S.G.S Water Data Report NM-85-1 (1986)

---Indicates no data available.

TABLE 2.4-9

AVERAGE PRECIPITAION AMOUNTS AT LOCATIONS NEAR THE WIPP FACILITY

1878 through 1982

STATION	MEAN ANNUAL PRECIPITATION (in)	YEARS OF RECORD THROUGH 1982
Chaves County		
Roswell	10.61	1878 through 1982
Eddy County		
Artesia	10.44 (N)	1905 through 1907, 1910 through 1982
Carlsbad	11.91 (N)	1889, 1891, 1894 through 1948, 1951, 1953 through 1982
Carlsbad FAA	11.25(M)	1949 through 1982 (1955 through 1980)
Duval Potash	14.21(M)	1955 through 1967, 1969 through 1982 (1955 through 1982)
Lake Avalon	11.01(N)	1914 through 1978
Lakewood	9.67	1912 through 1928
Loving	11.88(M)	1918 through 1939, 1945
Otis	11.84(M)	1901 through 1913
WIPP	13.53 (M)	1976 through 1980 (1977 through 1979)
Lea County		
Eunice	12.42(M)	1929 through 1935 (1931 through 1933)
Hobbs	14.36(N)	1913 through 1930, 1932 through 1935, 1938 through 1982
Jal	11.67(N)	1919 through 1921, 1923 through 1927, 1932 through 1933, 1941 through 1982
Maljamar	14.51(M)	1947 through 1982 (1955 through 1982)
Ochoa	11.17(N)	1943 through 1946, 1949 through 1950, 1953 through 1982
Pearl	13.32(N)	1906 through 1908, 1917, 1919 through 1922, 1927, 1930 through 1948, 1950, 1952 through 1982

N = Normal precipitation (i.e., mean of years 1941 through 1970, given by NOAA).

M = Mean precipitaion for the years indicted in parentheses or for total years of record.

Adapted from Hunter (1985). Compiled from Geohydrology Associates, 1978; National Resources Planning Board, 1942; and NOAA.

TABLE 2.4-10

MONTHLY AND ANNUAL PRECIPITAION SUMMARY FOR THE WIPP FACILITY (INCHES)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1976[(1)]	--	--	--	1.5	0.2	1.9	1.1	3.3	0.7	0.1	0.0	--	
1977[(1)]	0.2	0.1	0.4	0.5	1.4	1.1	0.7	0.6	2.1	.20	0.2	0.0	9.3
1978[(1)]	0.1	0.4	0.1	0.2	1.6	3.7	0.6	2.0	5.2	1.3	3.5	0.7	19.4
1979[(1)]	0.1	0.6	0.1	0.2	2.2	1.7	3.2	2.0	0.3	0.0	0.2	1.0	11.6
1980[(1)]	0.8	0.2	--	--	--	--	--	--	--	--	--	--	--
1981-1984	--	--	--	--	--	--	--	--	--	--	--	--	--
1985[(2)]	--	--	--	--	--	1.9	2.0	1.1	7.4	1.6	0.1	0.0	--
1986[(2)]	0.1	0.4	0.0	0.0	0.9	7.6	1.9	2.2	3.8	0.4	0.9	1.1	19.3
1987[(2)]	0.1	0.1	0.7	1.2	3.5	1.0	0.1	4.5	0.7	0.8	0.3	0.7	13.6
1988[(2)]	0.0	0.0	1.3	1.7	2.8	0.1	3.4	3.4	2.8	0.0	0.0	0.1	16.5
1989[(2)]	0.1	1.5	0.1	0.0	0.1	3.6	1.0	2.6	1.0	0.0	0.0	0.4	9.8

--Indicates precipitation data was not collected.

[(1)]Adapted from Hunter (1985). Based on data from Matejka, 1977; Pocalujka, Babj, and Church, 1979a, b, c; and Pocalujka, Babij, Catizone, and Church, 1980a, b; 1981a.

[(2)]Data from Annual Site Environmental Reports for the Waste Isolation Pilot Plant for the applicable year.

TABLE 2.4-11

ALL SEASON AND WINTER PMP FOR A DRAINAGE AREA OF 10 SQUARE MILES AROUND WIPP FACILITY

	PMP DEPTH (INCHES)			INTENSITY (INCHES/HOUR)		
DURATION	ALL SEASON (1)	ALL SEASON (2)	WINTER (2)	ALL SEASON (1)	ALL SEASON (2)	WINTER (2)
48 Hours	36.9	36.3	21.5	0.8	0.8	0.5
24 Hours	34.0	32.5	18.4	1.4	1.4	0.8
12 Hours	29.8	30.5	14.9	2.5	2.5	1.2
6 Hours	25.0	25.5	11.8	4.2	4.3	2.0
1 Hour	14.5	---	---	14.5	---	---
30 Minutes	11.0	6.9	3.2	22.0	13.8	6.4
15 Minutes	8.4	5.0	2.3	33.6	19.8	9.2
10 Minutes	6.9	3.9	1.8	41.4	23.6	10.9
5 Minutes	5.0	2.6	1.2	60.0	30.6	14.2

(1)Probable Maximum Precipitation Estimates--United States Between the Continental Divide and the 103rd Meridian, Hydrometeorological Report No. 55, U.S. Department of Commerce, (National Weather Service), U.S. Deparetment of Army (Corps of Engineers), and U.S. Department of Interior (Bureau of Reclamation), Silver Spring, MD. 1984 (revised 1987).

(2)Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for areas from 10 to 1,000 Square Miles and Durations of 6, 12, 24, and 48 hours, Hydrometeorological Report No. 33, U.S. Department of Commerce, Weather Bureau and U.S. Dept. of Army, Corps of Engineers, Washington, DC (April, 1956).

---Indicates no data available.

TABLE 2.4-12

MAXIMUM, AVERAGE, AND MINIMUM TEMPERATURES AT CARLSBAD, NEW MEXICO*

(Period of Record 1951-1980)

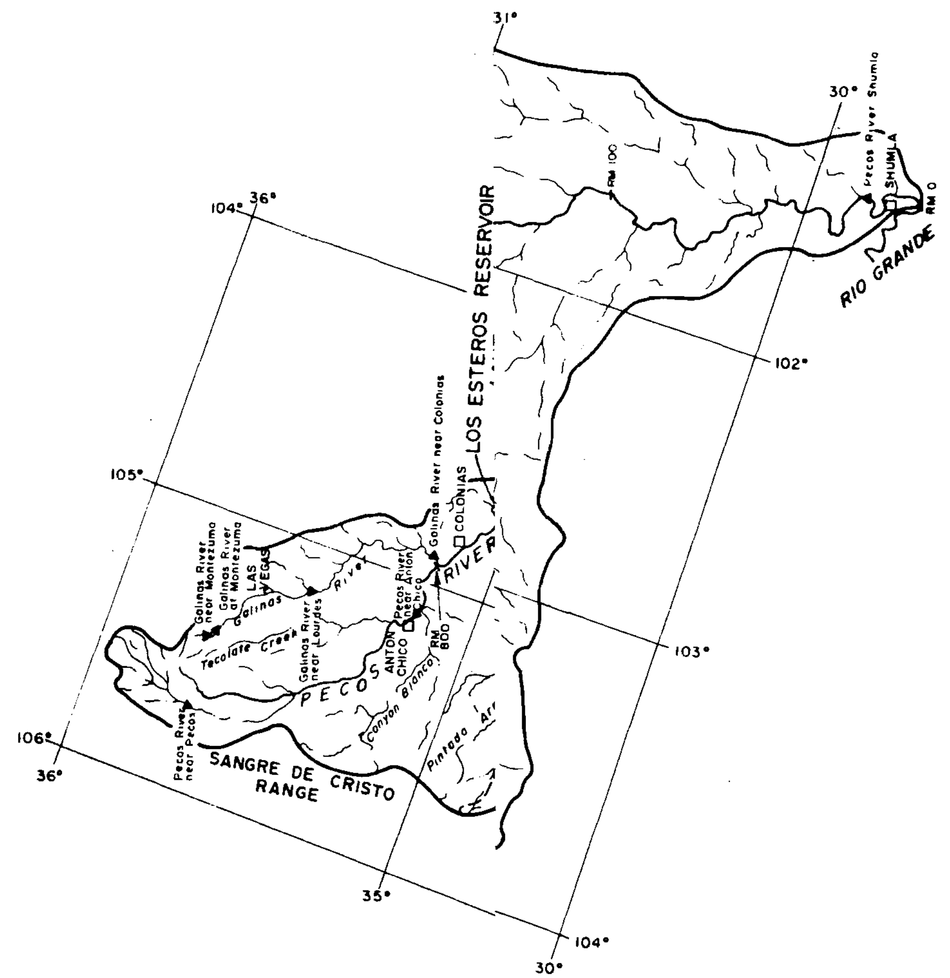
MONTH	TEMP., °F	TEMP., °F	TEMP., °F
January	57.1	43.2	29.2
February	61.9	47.4	32.8
March	69.4	54.3	39.1
April	79.1	63.7	48.2
May	87.4	72.2	57.0
June	95.5	80.6	65.6
July	95.6	82.5	69.3
August	93.6	80.6	67.6
September	86.9	73.9	60.9
October	77.5	63.2	48.8
November	64.8	50.8	36.7
December	58.3	44.3	30.3
Annual	**77.3**	**63.1**	**48.8**

*Climatological Summary, Means and Extremes for Period of Record 1951-1980, U.S. Department of Commerce, National Climatic Data Center (1986). Station: Carlsbad FAA Airport, New Mexico.

TABLE 2.4-13

VALUE OF MANNING'S n USED BY THE U.S.G.S.

SECTION NO. REFER FIG. 2.4-7	SUBSECTION	DISTANCE, FT	n
1	1	68 - 590	0.100
1	2	590 - 822	0.080
1	3	888 - 1185	0.040
1	4	1185 - 1318	0.045
2	1	360 - 725	0.090
2	2	725 - 859	0.060
2	3	859 - 1093	0.040
2	4	1093 - 1142	0.050
3	1	37 - 300	0.090
3	2	300 - 450	0.075
3	3	450 - 782	0.045
3	4	782 - 810	0.045



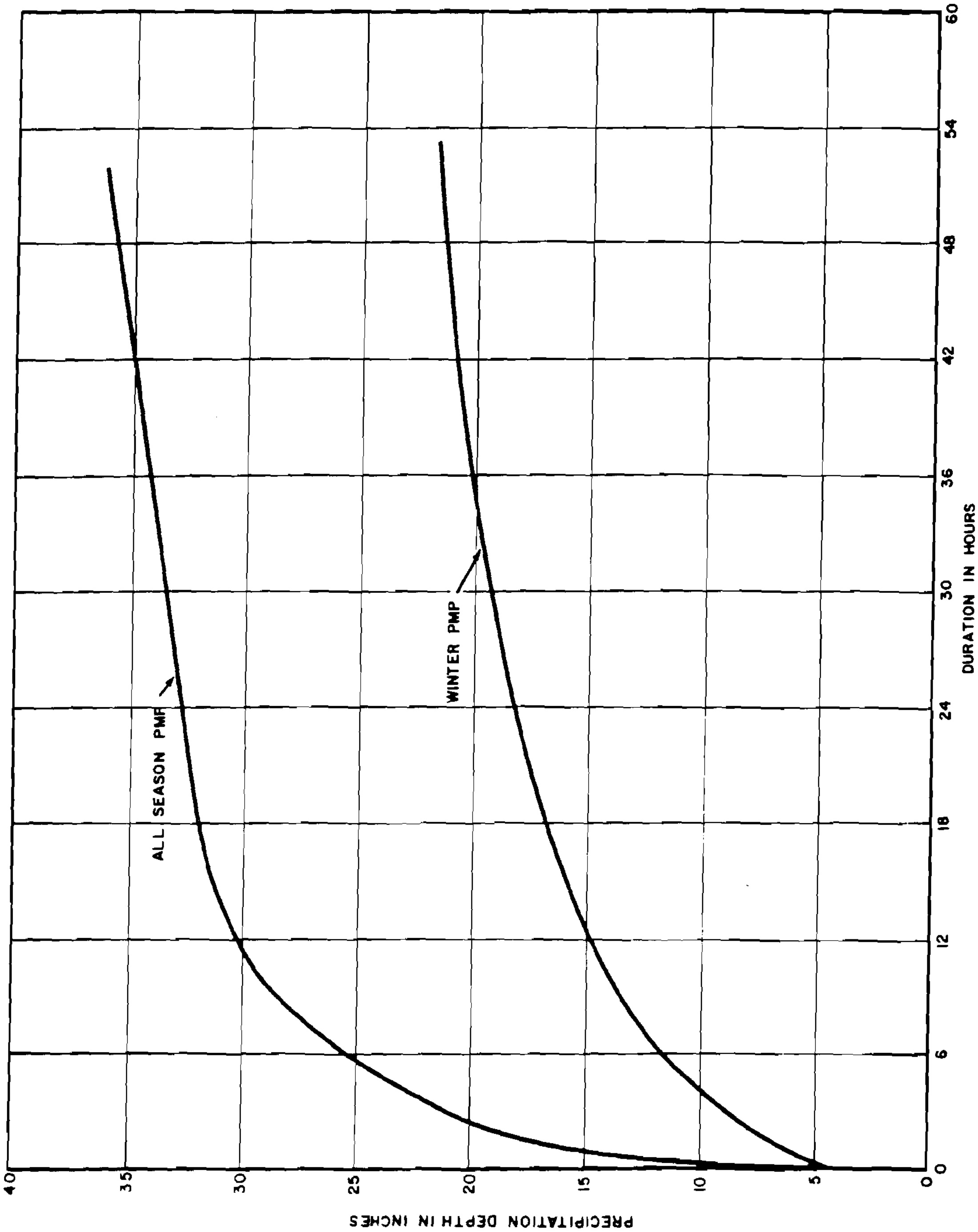
Reference:

Flood Control, Brantley Dam and Reservoir Pecos River, New Mexico, U.S. Army Engineer District, Albuquerque, New Mexico (July 1964)

GURE 2.4-1

ainage Pattern and Gaging Stations,
cos River Basin

This illustration for Information Purposes only.



REFERENCE:

Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas from 10 to 1,000 Square Miles and Durations of 6, 12, 24, and 48 Hours, Hydrometeorological Report No. 33, U.S. Dept. of Commerce, Weather Bureau and U.S. Dept. of Army, Corps of Engineers, Washington, D.C., (April 1956).

FIGURE 2.4-2
Winter and All-Season PMP for a Drainage Area of 10 Sq. Mi. Around the WIPP Facility

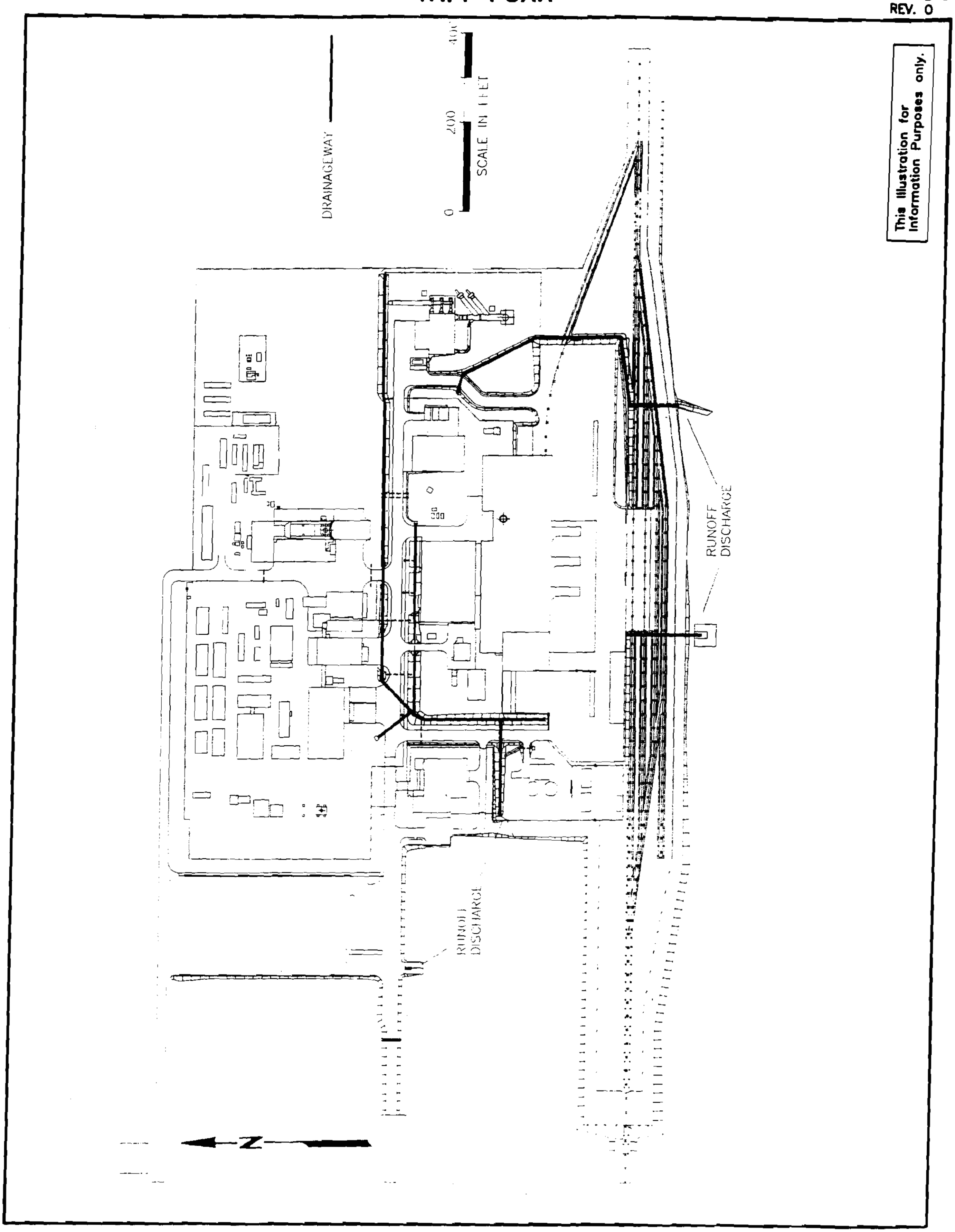
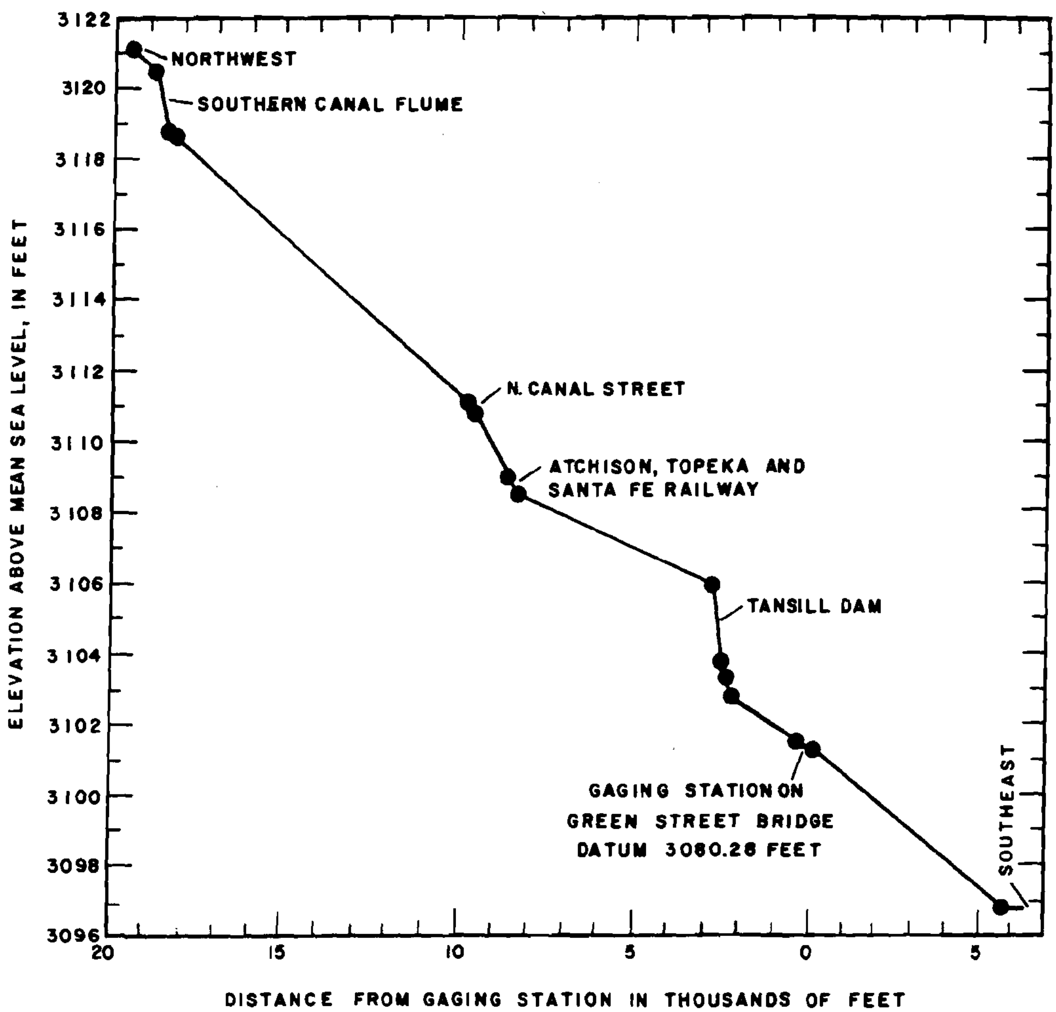


FIGURE 2.4-3
WIPP Facility Drainage



REFERENCE:

Flood of August 1966 at Carlsbad, New Mexico, Hydrologic Investigations Atlas HA-318, U.S. Geological Survey, Washington, D.C., (1968).

LEGEND

● FLOODMARK ELEVATION

This Illustration for Information Purposes only.

FIGURE 2.4-4
Water-Surface Profile of August 23, 1966 Flood on Pecos River in Carlsbad

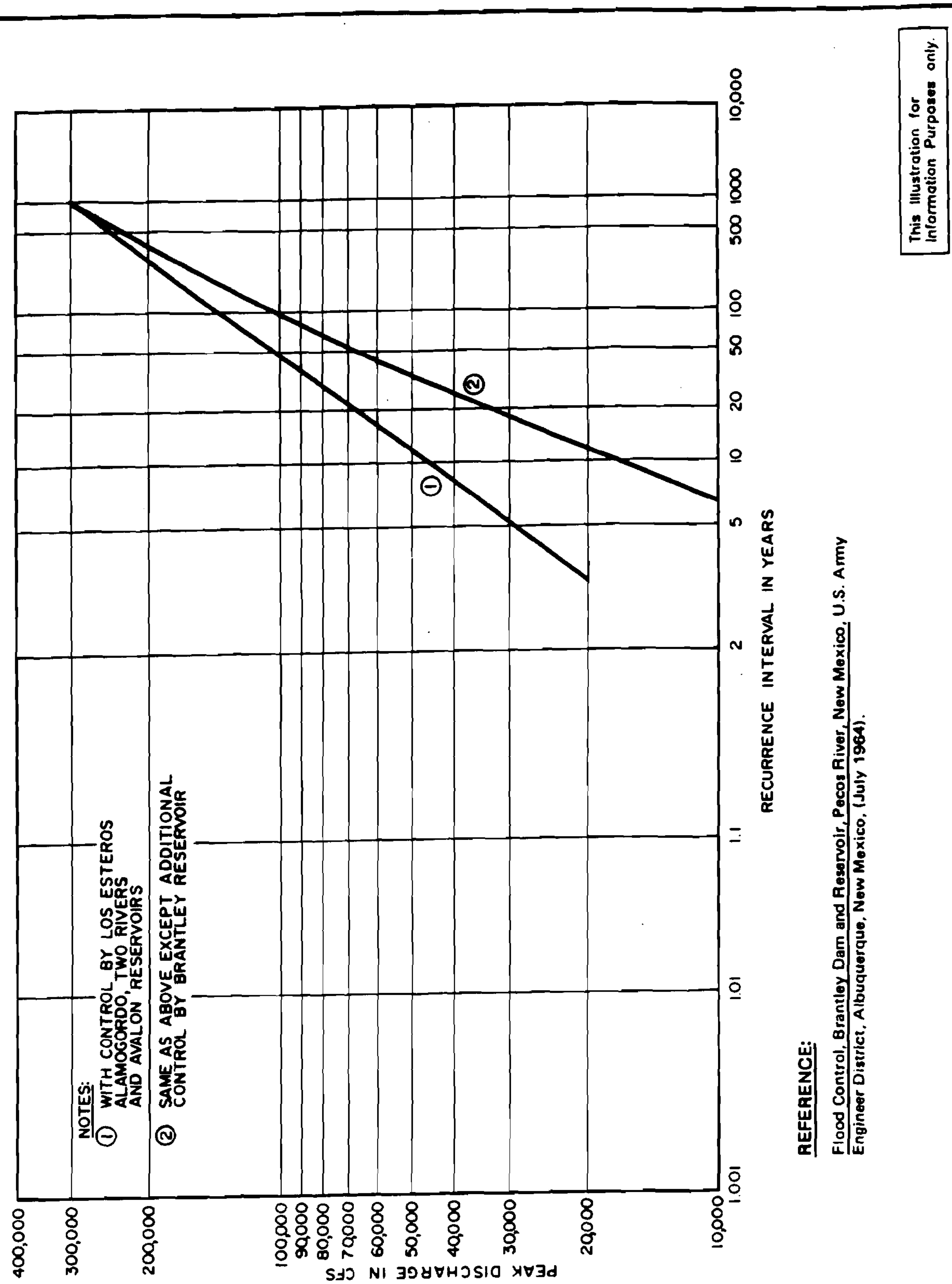


FIGURE 2.4-5

Flood Frequency Curve of the Pecos River in Malaga, N.M.

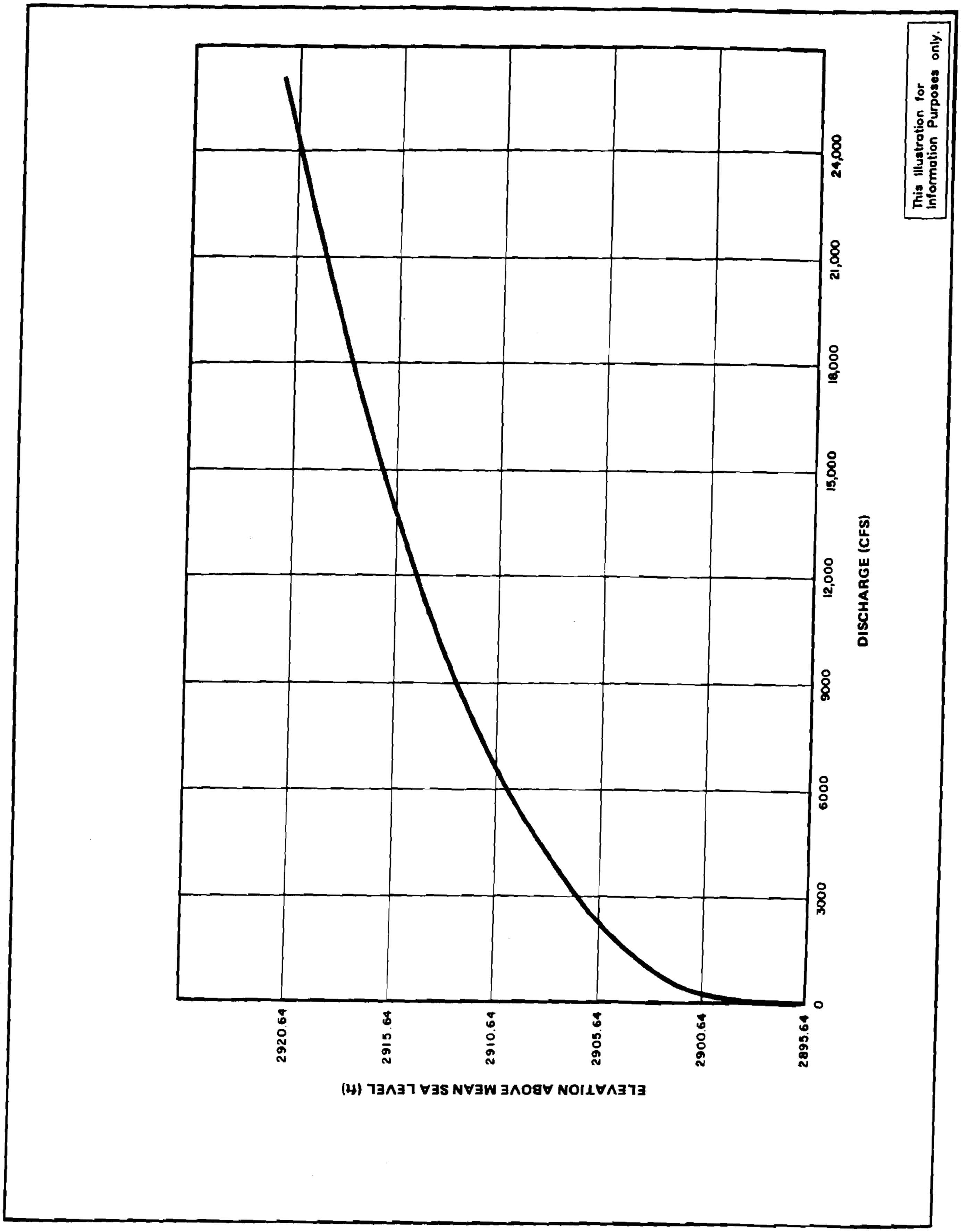


FIGURE 2.4-6
Rating Curve of Pecos River near Malaga, N.M.
USGS Sta. 08406500

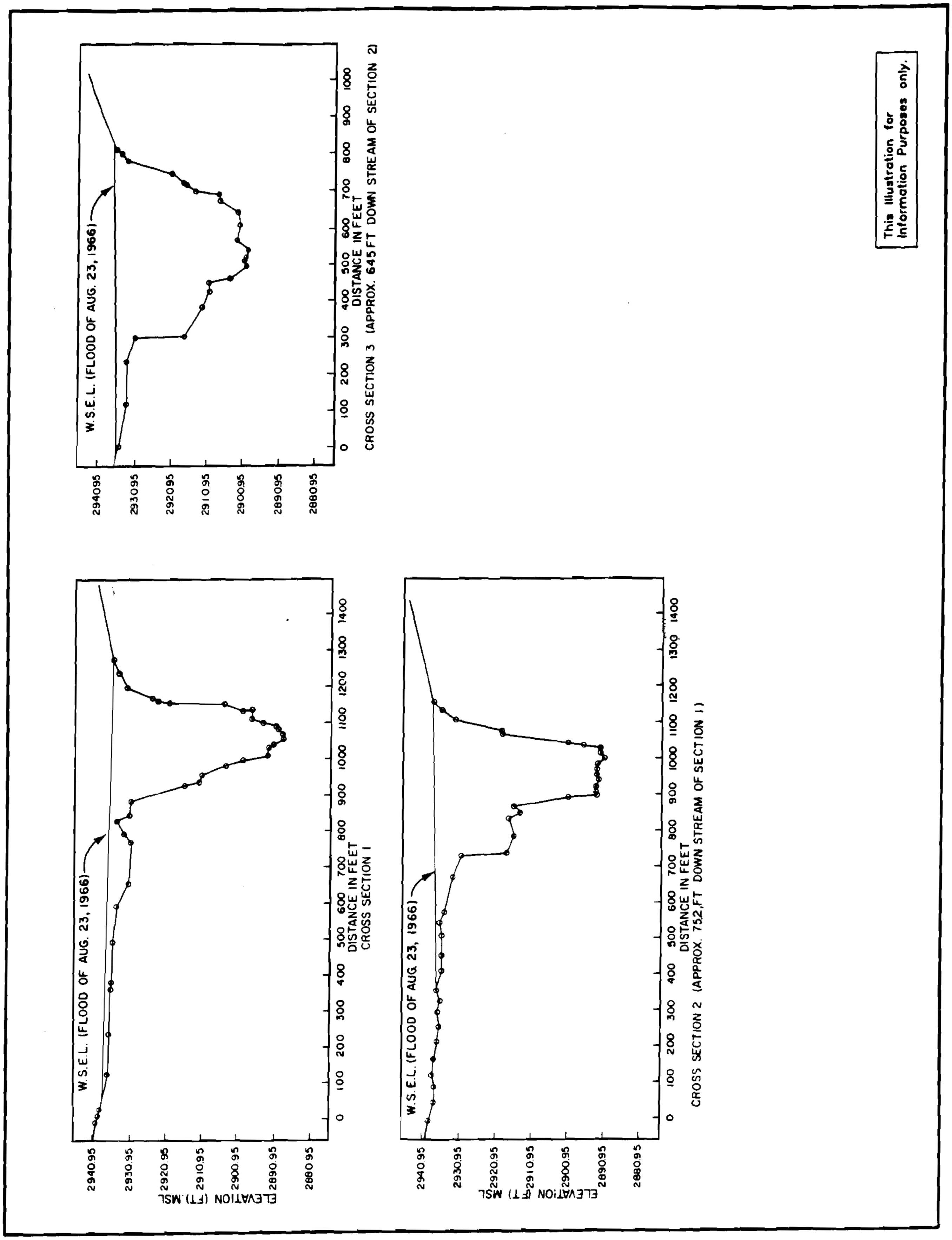


FIGURE 2.4 -7
Cross Section of Pecos River near Malaga, N.M.

2.5 SUBSURFACE HYDROLOGY

The WIPP facility is located in the Pecos Valley section of the Great Plains physiographic province in the north central part of the Delaware Basin (Section 2.6.1), 26 miles east from Carlsbad, New Mexico (Figure 2.5-1). The WIPP facility underground storage area is at a depth of about 2150 feet, which is near the middle of the 1750 to 2000 feet thick Permian Salado Formation (Figure 2.5-2). The stratigraphy and structural geology of the region around the WIPP facility are described in Sections 2.7.2 and 2.7.3, respectively.

The characterization/evaluation of the subsurface hydrology in the region consisted of the following principal tasks/items:

- Compilation and evaluation of available data and literature, mainly from potash, oil and gas, and Pecos River investigations
- Drilling and logging of about 80 exploration holes as part of the "Site Characterization," "Stipulated Agreement," and "Site Validation" programs; about 52 of these holes were the subject of hydrologic testing
- Extensive field testing programs consisting of drill stem tests, flow tests, pump tests, packer tests, etc.
- Laboratory testing of physical and chemical properties of selected rock units
- Laboratory testing of fluid samples
- Monitoring of water levels and water pressures in wells and piezometers and monitoring surface discharge at gaging stations
- Performing hydrologic and geotechnical observations and measurements during excavation of the WIPP facility (three shafts, approximately 25,000 feet of drifts, and four design validation test rooms) and during construction of the WIPP facility
- Numerical modeling of the hydrologic systems, including assessment of various hypothetical accident/breach scenarios (see Chapter 8)

Groundwater within the Delaware Basin varies from fresh to saline. Water-bearing zones that consistently produce potable water exist west of the Pecos River north of Malaga in the alluvium, and east of the WIPP facility in the Triassic Dockum Group and Tertiary Ogallala Formation (Figure 2.5-3). In the vicinity of the WIPP facility, there are limited occurrences of potable water and several water-bearing zones able to produce poor quality water.[1] Discussions of regional groundwater conditions are included in Hendrickson and Jones,[2] and Nicholson and Clebsch.[3] Detailed discussions of groundwater conditions in the vicinity of the WIPP facility are given by Mercer.[4]

The characterization/evaluation program identified (in descending stratigraphic order) the following regional and WIPP facility specific hydrologic systems/units (Figures 2.5-2 and 2.5-4):

- Fresh water aquifers in alluvial deposits along streams, primarily the Pecos River; regional
- Perched bodies of fresh water in near surface Quaternary and Tertiary deposits, such as the Gatuna Formation, Dockum Group, and the Permian Dewey Lake Redbeds; regional and WIPP facility specific
- Two fresh to saline water-bearing units, the Magenta and Culebra dolomites of the Permian Rustler Formation; regional and WIPP facility specific
- A saline water-bearing unit along the contact between the Rustler and Salado formations; regional and WIPP facility specific
- Pressurized brine reservoirs in fractured anhydrite units of the Castile Formation; regional and WIPP facility specific

- Brine and gas is known to occur in potash mines north and west of the WIPP facility, primarily in the McNutt potash zone which is 800 feet above the facility horizon; regional
- Brine and gas occurrences in the Salado evaporites at the facility horizon; WIPP facility specific
- A major aquifer in the Guadalupian reef complex (Capitan Reef, in particular) forming a long arcuate belt around most of the margin of the Delaware Basin; regional
- Shelf aquifers of the "back-reef" zone of the basin; regional
- Saline water-bearing zone(s) in the fine-grained sandstones of the Bell Canyon Formation of the Delaware Mountain Group; regional and WIPP facility specific
- Oil and gas-bearing strata below the Delaware Mountain Group, particularly the Pennsylvanian Morrow Formation; regional and WIPP facility specific

2.5.1 REGIONAL HYDROGEOLOGY

The principal factors governing the movement of groundwater in the northwestern part of the Delaware Basin (Figure 2.5-4) are as follows:

- The Delaware and Guadalupe Mountains are the principal recharge areas for most of the shallow aquifers west of the Pecos River, and for the reef and Bell Canyon aquifers.
- The Pecos River cuts many of the rock units that contain shallow aquifers, and fluid in these units discharges into the river directly or into the adjacent alluvium from both the west and east.
- Capitan Reef (the oldest permeable formation cut by the Pecos River) has the highest permeability and contains the most productive aquifer of those in the basin vicinity and produces fluids for oil field flooding. The general direction of flow in the Capitan is clockwise from the Guadalupe Mountains.

To the west of the Pecos River, many of the rock units of the basin crop out (Figure 2.5-5). In these areas, the soluble salts have been leached from the Ochoan evaporites. The remaining, fairly permeable strata provide a conduit for percolation of precipitation into the subsurface and for movement of relatively fresh water to the east. The only large quantities of potable groundwater in these units are found west of and along the Pecos River. The near surface aquifers east of the Pecos River are limited in extent, and the water present usually contains more than 3000 mg/l of TDS (milligrams per liter of total dissolved solids). These shallow aquifers are recharged from precipitation on out crop areas or from overlying formations. The direction of migration of the groundwater is not uniform but is generally to the south or southwest, eventually reaching the Pecos River.

Yield from Rustler Formation water-bearing zones, present above the Salado, typically ranges from less than one gal/min to over 80 gal/min[5] to wells. The water in these zones ranges from less than 100 mg/l TDS to greater than 180,000 mg/l TDS[6] and occurs under both unconfined and confined conditions.

The Salado Formation, due to its extremely low permeability and limited small amounts of isolated fluids (discussed in Section 2.5.4), functions as a regional aquifuge.

The underlying Castile Formation also acts as an aquifuge despite the occasional presence of brine reservoirs encountered within fractured anhydrite beds of the formation. Since the reservoirs are not connected to other fluid containing units in the basin, their presence does not diminish the aquifuge properties of the Castile.[7]

Water-bearing zones stratigraphically below the evaporite sequence (Bell Canyon, in particular) are widespread and contain large quantities of saline to brine fluids under confined conditions. These fluids move very slowly towards the northeast and eventually discharge into the partially depleted Capitan aquifer.[8]

Little development of groundwater has occurred in the WIPP facility area. The waste storage horizon within the Salado Formation is hydrologically isolated by thick, confining beds of the Salado, Rustler, and Dewey Lake Formations overlying it and by the beds of the Salado and Castile Formations underlying it. Any significant circulation of fluids, particularly in a vertical direction, within the Salado is precluded by the self-healing, practically impermeable character of the evaporite beds. Dissolution of the Salado beds, based on the geologic evidence and similar conditions, will progress at such slow rates that the formation is expected to maintain its practically impermeable character for at least one million years.

The Natural Resources Study[9] indicates that the WIPP facility area may contain several potential productive horizons (pay zones) of hydrocarbons within the rocks that underlie the evaporite deposits. However, the crude oil resources in the WIPP facility area are not considered reasonably extractable at the present time.

2.5.1.1 Hydrologic Systems Evaluated at the WIPP Facility

At the WIPP facility and its vicinity, fluid-bearing horizons from the surface through the Bell Canyon were investigated. Additionally, the geologic observations and documentation of the conditions encountered in the three shafts and other underground openings provided additional data on penetrated fluid-bearing zones; i.e., on the two Rustler dolomites, the Rustler/Salado contact, and the Salado Formation, in particular.

In the immediate vicinity of the WIPP facility, groundwater above the Salado Formation is commonly of such poor quality that it is not usable for most purposes. Groundwater of marginal quality, if available in the near surface perched bodies of water, is used for watering livestock and is considered a valuable resource.

Exploratory holes were drilled with air through the Gatuna Formation, Dockum Group, Dewey Lake Formation, and Rustler Formation. Saturated zones are readily detected with this drilling method. The Gatuna Formation and Dockum Group (Figure 2.5-2) occur within 50 feet of the surface, but little or no water is present. The Dockum Group is found only in discontinuous thin lenses beneath the eastern half of the WIPP facility and is not present to the west. Small zones of moisture were reported in three holes in the Dewey Lake and one hole in the Dockum. Otherwise, no moisture was encountered until the Magenta Dolomite was reached. Observation wells constructed in the Dewey Lake and Dockum are dry, confirming the absence of large saturated zones and aquifers above the Magenta Dolomite. Occasional bodies of perched water have limited extent and yield.

Hydrologic exploration at the location of the WIPP facility has identified and tested five fluid-bearing zones. These include the Magenta and Culebra Dolomites of the Rustler Formation and the Rustler/Salado contact zone (discussed in a greater detail in Section 2.5.3), each of which may be a potential avenue for radionuclide transport.

The fourth zone tested was the Castile Formation, the hydraulic conductivity of which is generally very low in the WIPP facility vicinity, as determined by drill stem tests in exploratory drillholes AEC-7, AEC-8 and ERDA-10.[10] In some cases, deformation of the Castile beds has occurred, resulting in anticlinal structures with local fracturing of anhydrite beds (e.g., the areas around ERDA-6 and WIPP-12). In some of these areas, brine reservoirs have been encountered that have substantially higher hydraulic conductivities than those determined for intact anhydrite. However, interbedded halite units are not fractured and exhibit low permeabilities typical of halite.[7]

The fifth zone tested consists of sands underlying the Bell Canyon Formation, which contains a confined fluid-bearing zone of undersaturated brine under sufficient head to reach the Salado salt.

Additional hydrologic observations and investigations in the WIPP underground openings addressed localized weeps of small quantities of brine and gas. Section 2.5.4 contains a more detailed discussion of these phenomena.

The permeability of the fluid-bearing zones above the Salado Formation and within the WIPP Site Boundary is highly variable. The range of transmissivities and storage coefficients is given in Table 2.5-1. Modeling studies have shown large areas of the Culebra Dolomite to have transmissivity values as great as 2×10^{-4} m^2/s.[11]. Static heads in the fluid bearing zones are generally more than 200 feet below land surface, except for the initial heads of the isolated brine reservoirs encountered in the Castile Formation.

2.5.2 HYDROLOGIC TESTING AND EVALUATION METHODOLOGY

The geologic and geophysical exploration conducted at and near the WIPP facility as well as geologic mapping and related investigations of the underground openings provide a detailed understanding of the stratigraphy, structure, rock properties, etc. of the subsurface geology. These investigations and their results are described in Section 2.7. In coordination with the geologic characterization, a program of hydrologic testing and monitoring was established. The primary objective of this program was to identify individual hydrogeologic units/systems and their potential effect on the WIPP facility. To fulfill this objective, investigations were conducted to determine the characteristics of the fluid-bearing zones, such as equivalent potentiometric surfaces, formation transmissivity, and the chemical and physical properties of the formation and wellbore fluids. These data were used to develop mathematical models of the hydrologic systems and provided input into breach consequence calculations.

An inventory was made of existing water wells in the vicinity of the WIPP facility prior to the development of site-specific test wells (Table 2.5-2). During the early testing history of the WIPP Project from about 1977 to 1981, the U.S. Geological Survey (USGS) and Sandia National Laboratories (SNL) conducted hydrologic tests in 39 exploratory drill holes within the WIPP Site Boundary and in the WIPP facility vicinity. Additionally, unsaturated zones were tested in shallow, site-specific holes to determine the potential permeability of the shallow units. From 1981 through 1986, SNL and the Westinghouse Electric Corporation recompleted existing wells and established new testing sites comprising either single or multi-well pads. Pressure transient hydraulic tests, chemical analyses, and nonsorbing tracer tests were conducted in wells installed prior to 1981 and in the newly completed or installed wells. Figure 2.5-6 shows the location of selected wells used for hydrologic testing in the vicinity of the WIPP facility. Table 2.5-3 lists the locations, types, and status of tests conducted since 1981. Future testing and monitoring activities are discussed in Section 2.5.10.

Hydrologic testing was also conducted during shaft and repository construction of the WIPP facility. During the site validation phase, the effects of shaft construction on the local water-bearing units were assessed,[12,13,14] detailed geologic and hydrogeologic mapping was conducted in the shaft after construction, hydrologic observations were performed during underground mapping and reconnaissance/ inspection trips, and facility horizon brine and gas occurrences were evaluated.[15]

Hydraulic testing of fluid-bearing zones was performed by using hydraulically inflated packers to isolate specific horizons and pressure transducers to measure changes in pressure head. Withdrawal (pumping and flow tests), slug injection, and pressure pulse tests were conducted in zones of lower permeability, and standard pressure transient tests were performed in zones of greater permeability. Test methods used are discussed in Mercer and Orr,[16] Popielak et al.,[7] Basler,[17] Ward and Walter,[18] and Beauheim.[19]

Multiple well interference tests were conducted at a number of three well hydropads completed in the Culebra Dolomite. This testing program consisted of pressure transient and nonsorbing tracer tests to determine the principal transmissivities, porosity, storage capacity, and dispersivity ability of the Culebra. Test methods employed during these interference tests are discussed in Gonzalez,[20] Ward and Walter,[18] Walter,[21] Hydro Geo Chem, Inc.,[22] Kelly and Pickens,[23] and Beauheim.[24]

A summary of the results of hydraulic testing activities is listed in Tables 2.5-4 through 2.5-10.

Fluid samples have been collected from fluid-bearing zones in the hydrologic test wells by bailing, swabbing, or pumping. These fluid samples were obtained both during initial drilling and installation of the test wells and during dedicated sampling programs. To maximize the probability that the fluid samples obtained were representative of the zone being tested, analyses of key chemical indicator parameters have been performed in the field on a periodic basis during fluid removal until stabilization of these parameters occurred. Results, plans, and discussions from this testing are given in Mercer and Orr,[16] Mercer,[4] Lambert and Robinson,[25] Mercer and Orr,[26] Colton and Morse,[27] and Uhland and Randall.[6] A summary of the results of the sampling activities is listed in Tables 2.5-11, 2.5-12, and 2.5-13.

Boreholes in which hydrologic testing was performed were completed as observation wells and are used to monitor the hydrostatic heads in fluid-bearing zones (Table 2.5-14).[16,4,5,28,29,30,31] Several of the deep test holes were completed as multiple observation wells and are used to monitor fluid levels of two separate zones by means of packers and an inner tubing string (Figure 2.5-7). In some wells, a third zone was perforated and tested, and a bridge plug was later set above it; consequently, the zone is not available for periodic monitoring. Other wells were completed to monitor one zone in an open hole rather than through perforations in casing. In addition to zones found to yield fluid to wells, selected shallow test holes were completed as observation wells to allow detection of perched or transitory saturated conditions that may develop. Shallow zones monitored include near surface alluvium, the Gatuna Formation, the Dockum Group, and the Rustler Formation. Some observation or test wells have been temporarily or permanently plugged.[32]

Periodic monitoring of fluid levels in the wells began after the initial series of hydrologic tests in each well was completed. Because of the low yields of the tested fluid-bearing zones, considerable time is required after water removal for the fluid level in the well to stabilize. The rate of recovery would be slowed if the interconnection between the well and the water-bearing zones were impaired by the well's construction, such as by having insufficient perforations. Most fluid levels have stabilized, however, and provide an estimate of the potentiometric levels of the monitored zones, as well as data to establish potentiometric gradients (Tables 2.5-15 and 2.5-16). An example of fluid level monitoring is presented in Figure 2.5-8.

During the site validation phase, the effects of shaft construction on local aquifer hydrology were assessed[12,13] by:

- Groundwater inflow tests in the ventilation shaft (diameter of six feet)
- Drawdown analysis of the Culebra aquifer in the unlined ventilation shaft using piezometer data from the exploratory shaft and nearby monitor wells at pads H-01, H-02, and H-03
- Chemical analyses of inflow samples collected in the ventilation shaft

The zones of interest were the two principal water-bearing zones in the Rustler Formation, the Magenta and Culebra Dolomites, and the Rustler/Salado contact.

Two methods were used for the inflow tests:

- Measuring the change in water level in the shaft sump during three separate test intervals

- Installing a water collection ring to determine the inflow from the Rustler Formation dolomite members

After enlarging the SPDV ventilation shaft to the approximately 20-foot diameter waste shaft, hydrologic observations were included as part of the detailed geologic mapping.[14,33] Hydrologic observations were also performed during underground mapping and reconnaissance/inspection trips.

During the excavation of the SPDV underground drifts, several occurrences of minor gas emissions were noticed in vertical core holes drilled into the roof and floor of the drifts. A subsequent test program consisted of:

- Inventory of core holes and determination of their suitability for gas testing
- Gas testing in existing accessible holes penetrating Anhydrites "a" and "b" and Marker Bed 138:
  - Determination of gas-producing zones using straddle packers
  - Measurements of gas flow rates
  - Collection of gas samples
- Testing of an available drill rig underground for its suitability for gas testing, which included drilling a new hole to the bottom of Marker Bed 139, measurement of gas flow, and collection of gas and brine samples.

Later tests included drilling four one-inch diameter holes into the roof of the drifts with rapid shutin (after gas was encountered), enabling initial flow rate and pressure buildup measurements to be made. These boreholes penetrated Anhydrites "a" and "b."[34]

During the SPDV phase, samples of the facility horizon halite were also subjected to laboratory testing to determine:

- The fluid content or releasable water/brine in the form of fluid inclusions or as hydrated minerals
- Permeability

Hydrologic data presented and/or referenced in Section 2.5 have been collected or calculated by a number of individuals in different organizations over a period of many years using various values/units for similar phenomena, such as hydraulic conductivity versus permeability versus transmissivity or mg/liter versus ppm, etc. These values are presented as they have been used in the individual references because their unification could lead to inaccuracies and/or interpretative errors.

2.5.3 HYDROGEOLOGIC SYSTEMS ABOVE THE SALADO FORMATION

Several water-bearing zones have been identified overlying the Salado Formation on both a regional and WIPP facility-specific scale. The Quaternary alluvial deposits of the Pecos River valley, the Tertiary Ogallala Formation, and portions of the Triassic Dockum Group east of the WIPP facility are the only units in the area that consistently yield more than 10 gal/min to wells. The remaining water-bearing zones in the WIPP facility vicinity exhibit a wide range of transmissivity and water quality values.

The hydrology of the following horizons/strata will be discussed (Figure 2.5-2):

- Quaternary deposits, including the extensive alluvial deposits along the Pecos River, and alluvium, lake or playa deposits in closed depressions, and the lowermost Gatuna Formation
- Tertiary Ogallala Formation

- Strata of the Triassic Dockum Group and the Permian Dewey Lake Redbeds
- Permian Rustler Formation, including the Magenta and Culebra Dolomites
- Permian Rustler/Salado contact

2.5.3.1 Quaternary Deposits

The most extensive Quaternary alluvial deposits in the northern Delaware Basin are along the west side of the Pecos River north of Malaga. There are only isolated patches of alluvium along the Pecos to the south of Malaga. In some areas the alluvium is nearly 200 feet thick and yields are reported to be as much as 3000 gal/min.[2] The water is from several sources, primarily underflow from the Pecos River, augmented by leakage from canals and irrigation return flow.

Alluvium east of the Pecos River north of Malaga Bend (Figure 2.5-9) is restricted to relatively small, closed depressions. Nash Draw and Clayton Basin contain Quaternary alluvium and lake or playa deposits in locations such as Laguna Grande del Sal. The thickest alluvial deposits occur within San Simon Swale where they are in excess of 500 feet. Groundwater in the San Simon alluvium may be discharged from the Dockum Group. Water wells in or near these depressions yield some water, but it is generally highly mineralized.[2]

The Gatuna Formation is the oldest known Quaternary formation in the area. It fills channels and steep-walled valleys cut primarily into the Dewey Lake Redbeds and Rustler Formation. In the vicinity of the southern part of Clayton Basin and the northern part of Nash Draw, where the Gatuna type section is readily recognizable, the top of the formation is engulfed by an extensive caliche zone that marks the Mescalero surface.

East of Nash Draw there are few outcrops of the Gatuna Formation. The formation yields limited amounts of water to wells where water occurs in isolated gravel and sand lenses. Yields are small, but usually sufficient for livestock and domestic use in the area near the Project Gnome site.[35] However, no water has been detected in the area immediately surrounding the WIPP facility. Groundwater in the Gatuna may percolate downward into underlying permeable materials such as the Dockum Group or may be discharged by evapotranspiration.

Seven permeameter tests (Bureau of Reclamation designation E-19) were performed in the surficial sands present at the WIPP facility.[36] Results of these tests, listed in Table 2.5-5, indicate a range of hydraulic conductivity from 3.2 to 17.7 ft/day, which is about one order of magnitude more permeable than the underlying consolidated sands.

2.5.3.2 Ogallala Formation

The Ogallala Formation (Figure 2.5-3) underlies the High Plains of eastern New Mexico and the panhandle of Texas and forms many of the prominent ridges in southern Lea County.[3,37,38,39] Figure 2.5-5 shows the extent of the Ogallala near the northern portion of the Delaware Basin. The Ogallala is heterogeneous in nature and composed of calcareous, unconsolidated sand with layers of clay, silt, and gravel and generally capped by a dense caliche layer.[38,39] The Ogallala ranges in thickness from a few inches to over 300 feet and provides an excellent source of potable water. The Ogallala is topographically high and isolated, and recharge is due entirely to precipitation.[3] The Ogallala is absent west of San Simon Swale, except for thin exposures at the Divide, about 7 miles east of the WIPP facility.

2.5.3.3 Dockum Group

Away from the WIPP facility, the Dockum Group has been subdivided into three formations. In descending order, they are the Chinle Formation equivalent, the Santa Rosa Sandstone and the Tecovas Formation. McGowan et al.[40] indicate that it is preferable to refer to the Triassic deposits in the vicinity of the WIPP facility as Dockum undivided, not as the Santa Rose Sandstone. The few wells completed in the Dockum Group in southeastern New Mexico yield only small quantities of poor quality water.

Sandstones in the Dockum Group are aquifers in several areas including Winkler and Ward Counties in Texas and the western third of southern Lea County.[3] They produce fresh or saline water, depending on the location. The westernmost extent of the Dockum Group lies just beyond a north-south line drawn through the center of the WIPP facility, as shown in Figure 2.5-10. The formation is not believed to contain a continuous zone of saturation at the WIPP facility. Wells completed in the Dockum east of the WIPP facility have specific capacity values ranging from 0.14 to 0.2 gal/min per foot of drawdown. At one well completed east of the WIPP facility, the Dockum has a reported porosity of about 13 percent.[3] The city of Oil Center obtains its public water supply from one well completed in the Dockum, and until 1954, the city of Jal received its public water supply from wells completed in the Dockum.[3]

Pump-in tests to measure hydraulic conductivity of the near surface deposits (Gatuna, Dockum, and Dewey Lake) were performed in 23 of the WIPP facility foundation exploration holes shown in Figure 2.5-11. These tests were done in accordance with the Bureau of Reclamation procedure designation E-18. Results of the testing are listed in Table 2.5-4.[41] These data indicate that the Gatuna and Dockum are relatively permeable, with hydraulic conductivities ranging between 0.2 and 5 ft/day. Some zero values were obtained due to lack of sensitivity of the testing method to low permeability.

The Dockum has been encountered in the test holes generally east of the ERDA-9 borehole. The holes nearest the western limit of the Dockum generally contain no indication of water. The only test hole that encountered measurable water was at the H-05 borehole complex where drilling and subsequent logging indicated the lower two feet to be saturated. During 12 hours of testing by air-jetting, the yield from the zone was estimated to be less than 0.1 gal/min. Water-level measurements following air-jetting confirmed the presence of about 2 feet of water.

The Dockum Group is probably recharged by precipitation in areas where it is overlain by permeable deposits. The water moves downward until it is impeded by the low permeability Dewey Lake Redbeds and then may move down the structural dip to the east. Small quantities of water likely discharge locally into the Dewey Lake through fractures and along bedding planes. Nicholson and Clebsch[3] believe that farther to the east, water movement in the Dockum is controlled by the collapse features of San Simon Swale; they show pressure gradients to be toward this feature. Water movement in the Dockum in the western part of Lea County, north of the San Simon Swale (Figure 2.5-9), is toward the south and southwest. In the area of Mescalero Ridge, groundwater in the Dockum moves southwest towards Laguna Plata and possibly discharges downward into Permian rocks.[3]

2.5.3.4 Dewey Lake Redbeds

The Dewey Lake Redbeds mark an abrupt change in depositional environment from the predominantly evaporitic deposits of the underlying Rustler Formation. The Dewey Lake Redbeds are composed of a deltaic sequence of alternating thin, even beds of orange red siltstone and mudstone with lenticular interbeds of fine-grained sandstone.[4] This formation has been removed from the western and southern parts of the Delaware Basin by post-Permian erosion, but is present in the subsurface throughout the remainder of the basin.

Hydrologic investigations at and near the WIPP facility have not identified a continuous zone of saturation within the Dewey Lake Redbeds.

Localized zones of permeability were detected by losses of circulation during drilling, and minor zones of saturation were detected in several of the thin sands in the upper part of the Dewey Lake. Geologic data for the area around the WIPP facility indicate the sands to be lenticular, pinching out laterally. Where water is present, it is likely perched or semi-perched, and its occurrence is very localized, probably depending to a great extent on locally favorable conditions for recharge. Several wells used for domestic and stock purposes believed to be completed in the Dewey Lake Redbeds are located approximately 5 miles south of the WIPP facility near the Mills Ranch[4] (Figure 2.5-6).

The saturated zone identified in the Dewey Lake Redbeds has been found only by the increase in moisture in the cuttings during drilling. Attempts to test the zone in boreholes H-01, H-02c, and H-03 proved unsuccessful. In each case, drilling was stopped and the hole was monitored for at least five hours, but the zones did not yield enough water to test. Further evaluation from both geologic and hydrologic data has shown most of the sand lenses to be discontinuous and normally quite thin.

Four intervals of Dewey Lake Redbeds were tested in WIPP facility foundation holes (Holes B-8, B-38, B-52, and B-53) (Figure 2.5-11). The two intervals at B-52 and B-53, selected because fractures were observed in the core, indicated hydraulic conductivities of 0.7 and 0.5 ft/day, respectively (Table 2.5-4).[41] All other foundation borings that encountered the formation indicated the Dewey Lake was unfractured. Testing in B-38 indicated a conductivity of less than 0.003 ft/day.

Although no saturated condition was encountered in the foundation exploration holes, ten observation wells were installed in these shallow holes. They provided a monitoring system to determine whether transient saturated zones might develop. Construction design of these is shown in Figure 2.5-7, and zones monitored are listed in Table 2.5-16. Observation well B-54, the deepest of this group, is open to a zone of permeable but unsaturated material that was encountered in the Dewey Lake Redbeds.

The water levels in the observation wells were measured on a regular monthly basis during an approximate 18-month period; the data from some of the measurements are listed in Table 2.5-16. In all wells, the water levels were below the lowermost perforations in the monitor tubing, indicating that the water encountered was from well flushing after installation, as was confirmed by bailing observation wells B-4 and B-13. The apparent fluctuation of water levels is within the limits of precision of the measurement method.

2.5.3.5 Rustler Formation

The Rustler Formation overlies the Salado Formation (Figure 2.5-2) and consists of interbedded sulfates, carbonates, halite, and clastic rocks.[14,33] Two 20 to 30 feet thick dolomite beds, the Magenta and Culebra, yield water to wells and are areally extensive. A local, relatively permeable zone is at the Rustler/Salado contact. For the following discussion, the Rustler/Salado will be considered part of the Rustler Formation.

2.5.3.5.1 Magenta Dolomite

The Magenta Dolomite is a persistent and distinctive clastic carbonate bed 20 to 30 feet thick, with laminae of anhydrite. Water, when present, usually occurs in thin silt or silty dolomite beds but is also found along bedding planes and in fractures. The structural character of the Magenta Dolomite is affected by the amount of dissolution that has occurred in the underlying beds (see more detailed discussion in Section 2.5.9 of this document). The Magenta along the eastern edge of Nash Draw and in the northern and central parts of (Figure 2.5-9) is a relatively continuous unit. Farther south to Malaga Bend, most of the Magenta has been stripped by erosion, with isolated erosional remnants remaining. Fairly continuous outcrops of the Magenta are present along part of the western edge of Nash Draw, but they are highly fractured and unsaturated. It is likely that the deformation that created the fractures in the Magenta also fractured the rocks between the Magenta and Culebra, allowing some water to drain from the Magenta Dolomite into the underlying Culebra Dolomite, particularly along the east flank of Nash Draw.

At the WIPP facility area, the Magenta Dolomite was tested in 16 cased and open holes (Table 2.5-1).[4,19] Transmissivity values calculated from results of these tests range from 1×10^{-3} to 3×10^{-1} ft^2/day for wells within the WIPP Site Boundary (Figure 2.5-6). The Magenta was unsaturated in some of the test wells outside this area, and transmissivity at these locations was undeterminable. For wells farther outside the WIPP Site Boundary for which data were obtainable, transmissivities for the Magenta range from 4×10^{-3} to 375 ft^2/day. All transmissivity values greater than 1 ft^2/ day were calculated from results of testing in wells located in Nash Draw. The two wells tested in Nash Draw, WIPP-25 and WIPP-27, have transmissivity values of 375 ft^2/day and 53 ft^2/day, respectively. The static fluid levels measured in the test holes are given in Table 2.5-15. These data were used to determine the "potentiometric" surface shown in Figure 2.5-12. Additional water level data can be found in Winstanley and Carrasco,[31] Hydro Geo Chem,[28] INTERA Technologies and Hydro Geo Chem,[29] INTERA Technologies,[5] Saulnier et al.,[30] and Mercer.[4]

The contours on the equivalent potentiometric surface map for the Magenta Dolomite indicate that the general direction of fluid movement[(1)] is westward across the WIPP facility toward Nash Draw, where fluid then discharges. In the northwestern part of Nash Draw, flow is generally to the southwest, perhaps moving down through fractures into lower units in the central part of the draw. Recharge for the Magenta is from outside the WIPP facility area, as it is for other hydrologic units in the Rustler. The most likely area for recharge is to the north or northeast. The potentiometric surface map (Figure 2.5-12) seems to indicate recharge to the east of the WIPP facility.

The dissolved solids in water associated with the Magenta (Table 2.5-11) range in concentration from 5,460 mg/l to 270,000 mg/l and consist primarily of sulfate, chloride, calcium, potassium, magnesium, and sodium.[4] The major constituents are sodium and chloride.

2.5.3.5.2 Culebra Dolomite

The Culebra Dolomite is a vuggy, finely crystalline dolomite commonly associated with anhydrite. Although the Culebra Dolomite is areally persistent, the availability of water from it varies considerably from place to place depending on the size and number of fractures and openings in the rock. The structural character of the Culebra is affected by the amount of dissolution that has occurred in the lower Rustler and upper Salado evaporite beds.[4] In areas such as Nash Draw, where significant dissolution of evaporites at the Rustler/Salado contact has occurred, the Culebra is locally highly fractured. The effects of dissolution are discussed in more detail in Section 2.5.9 of this document.

The hydraulic properties of the Culebra Dolomite, as determined by testing in cased and open holes, vary considerably depending on its structural character (Table 2.5-10).

The Culebra has been studied extensively in the WIPP facility area through the site characterization program. Mercer,[4] and Mercer and Orr,[16] provide detailed test results and analyses for a number of wells completed in the Culebra and other water-bearing zones prior to 1983. Beauheim presents hydraulic test analyses for both

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(1)Exact direction of the fluid movement cannot be determined from the equivalent potentiometric surface maps without a detailed analysis, because, in general, the contour lines presented do not represent true fluid potential, and flow lines do not have to be perpendicular to equipotential lines in an anisotropic medium.

single-well and multi-well tests[19,25] at the DOE-2 and H-03 hydro-pads, and for single-well tests at DOE-1, H-04, H-08, H-14, H-15, WIPP-18, WIPP-19, WIPP-21, WIPP-22, ERDA-9, P-17, Cabin Baby, and Engle. Additional hydraulic testing has been completed at H-02, H-05, H-06, H-07, H-09, H-11, H-12, and WIPP-13.[5,28,29,30,42] Testing has shown that the Culebra is a fractured, heterogeneous system with varying local anisotropy.

Transmissivities calculated for the Culebra in Nash Draw range from 18 ft^2/day to 1250 ft^2/day.[4] Laboratory tests of two samples of the Culebra taken from the Project Gnome Shaft (Figure 2.5-6) indicate total porosities of 13.7 percent and 14.4 percent and effective porosities of 7.8 percent and 11.1 percent. Transmissivities calculated for the Culebra Dolomite for wells within the WIPP Site Boundary range from 7×10^{-2} to approximately 69 ft^2/day.[4,18] Tests in three-well arrays indicate the heterogeneous nature of the Culebra. It was found that the ratio of major to minor transmissivity components ranges from 2.1 to 2.7.[20]

Tracer tests have been conducted at hydropads H-02, H-03, H-04, and H-06.[20,28] The types of tracer tests conducted include: convergent flow, with pumping of one well and addition of tracer(s) to one or more wells at the same hydropad, and injection withdrawal, where one well is pumped and the water injected with the tracer(s) into a second well. The tracers used for these tests were organics.[43]

The tracer test conducted at the H-02 hydropad has been analyzed using a porous medium conceptualization where the model predictions generally are in poor agreement with field measurements.[23] A tracer test analyzed at the H-03 hydropad[24] utilized a double porosity conceptualization and assumed longitudinal dispersivities from 5 to 10 percent of the flow path, a fracture porosity of $1.9 \times 10,^{-3}$ and effective matrix block sizes of 0.25 to 2.1 m. Analysis of the H-04 tracer tests did not provide reliable quantitative estimates of physical solute transport parameters for the Culebra.[24]

From the observations and measurements in the Ventilation Shaft, later reamed out and called the Waste Shaft, it was determined that most of the observed inflow of about 0.5 to 0.6 gallons per minute (gpm) was from the Culebra. The analyzed drawdown of the fluid levels in the Rustler water-bearing zones resulting from shaft construction corresponded well to the measurements in observation wells H-01, H-02, and H-03. A long-term effect of less than 10 feet of drawdown at a distance of about 4200 feet from the shaft was observed.[12]

During construction of the three shafts, Waste Handling, Salt Handling, and Exhaust, a record of leakage or drainage and corresponding pressure changes has been compiled.[11] Leakage and drainage into the shafts is reported only for the Culebra Dolomite.[44] Attempts have been made to incorporate this information into a transient flow model for the WIPP facility area, and preliminary interpretations of this effort are provided in Haug et al.[11]

The best estimate of undisturbed freshwater head has been calculated using most of the tested wells, and those data are given in Table 2.5-17. This information was used to prepare the equivalent potentiometric surface map in Figure 2.5-13. Additional water level data for the Culebra can be found in Winstanley and Carrasco,[32] Hydro Geo Chem,[28] INTERA Technologies and Hydro Geo Chem,[29] INTERA Technologies,[5] Saulnier et al.,[30] and Mercer.[4]

Flow directions may be estimated from the contours on the map. However, the flow path of water moving in rock such as the Culebra Dolomite is affected by fractures, variable density, and heterogeneity. Consequently, the regional direction of flow may have little or no relationship to the localized flow paths that may be visualized using Figure 2.5-13. In Nash Draw, the Culebra hydrologic unit is so extensively fractured that a local flow system may exist that has little relationship to the regional flow in the Culebra. Based on this premise and on inspection of the equivalent potentiometric surface map, the flow trend in Nash Draw generally is southward toward Malaga Bend.[4] Local flow paths in the area of the WIPP facility indicate flow to the west, southwest, and southeast. If steady-state flow conditions exist, the recharge area for the Culebra Dolomite appears to be to the north and northeast of Nash Draw.

The dissolved mineral constituents in the water from the Culebra (Tables 2.5-11 and 2.5-13) consist primarily of sulfate, chloride, calcium, magnesium, sodium, and potassium. The filterable residue dried at 105°C in waters associated with the Culebra Dolomite range in concentration from 3100 mg/l to 420,000 mg/L. The water is classified as being slightly saline to brine. It should be noted in comparing Table 2.5-11 with Table 2.5-13, that the latter gives values believed to be more representative of actual formation fluids, due to a much more rigorous sampling and analysis protocol.[27] A listing of undisturbed formation water densities has been compiled and is shown in Table 2.5-18 and the observed formation water densities are contoured in Figure 2.5-14.[11]

2.5.3.5.3 Rustler/Salado Contact

The Rustler/Salado contact is commonly referred to as the Rustler/ Salado contact residuum and is composed of clay with interlayered seams of broken gypsum and fine-grained sandstone.[45] The clay is considered to be the result of dissolution of clay halite and other evaporites in the upper part of the Salado.[4]

In the vicinity of Nash Draw, the Rustler/Salado contact residuum has been referred to as the "brine aquifer."[4,16] The "brine aquifer" extends to the Pecos River in the vicinity of Malaga Bend (Figure 2.5-15). The "brine aquifer" is apparently replenished from precipitation that penetrates the overlying units through fractures and solution zones, then moves southward along the top of the salt, increasing in salt concentration until it discharges into the Pecos River at Malaga Bend.[46] The dissolved solids content of the brine discharging into the river is in excess of 400,000 ppm. Theis and Sayre[47] calculated the discharge from the "brine aquifer" into the Pecos River at Malaga Bend to be about 200 gal/min. Hale et al.[48] calculates a transmissivity of 8000 ft^2/day from aquifer tests in the area between Malaga Bend and Laguna Grande del Sal.

At the WIPP facility area, the contact zone between the Rustler and Salado Formations was tested in 20 cased and open holes (Table 2.5-1).[4] All tests within the WIPP Site Boundary produced results indicative of very low transmissivities. Mercer[4] calculates transmissivity values for the contact zone in this area to range from 3 x 10^{-5} to 3 x 10^{-3} ft^2/day. Substantially greater transmissivities are exhibited by the contact zone in some wells in Nash Draw to the west. Within the draw, transmissivities of 2 x 10^{-4} to 8 ft^2/day were determined for the Rustler/Salado contact zone. Transmissivity values for the remaining wells as listed in the two tables range from less than 6 x 10^{-5} to 7 x 10^{-1} ft^2/day.

After testing, fluid recovery to static levels in some of the wells required many months, due to the low transmissivity of the fluid-bearing zone. Construction of the well, however, may impair the response of the well to water level fluctuations. The static fluid levels measured in selected test holes are given in Table 2.5-19. These data were used to construct the equivalent potentiometric surface map shown in Figure 2.5-16. Additional water-level measurements have been taken from wells completed in the Rustler/Salado.[4,5,28,29,30]

Samples of fluid were collected from all 20 of the test wells. Analysis of these samples shows that the fluid in the Rustler/Salado contact zone is a brine containing 79,800 to 480,000 mg/l total residue at 105°C (Table 2.5-11).

The zone surrounding the Rustler/Salado contact was frequently considered to have been affected regionally and at the WIPP facility by post depositional dissolution and removal of halite from the upper Salado.[14] However, in the Waste Shaft[14] and Exhaust Shaft,[33] features commonly associated with dissolution such as brecciation, collapse of overlying rock, and the disruption of primary features were not observed during detailed mapping. The overlying rock was intact, and bedding was not disrupted. Also, halitic claystone at the contact contained abundant small, sediment displaced halite crystals which probably formed in a soft mud shortly after deposition.

2.5.4 SALADO FORMATION HYDROGEOLOGY

The Salado Formation represents a regional aquifuge due to the hydraulic properties of the bedded halite which forms most of the unit. During geologic mapping activities in the Exhaust Shaft, the Salado did not yield any observable fluid inflow.[33] The porosity of the Salado halite is very low, and interconnected pores are virtually nonexistent. The salt does not readily maintain open fractures or solution channels due to the high plasticity of the material at the depths of interest. As a result, the hydraulic conductivity of the halite beds is nil.

Because halite is quite soluble, it would readily dissolve if the beds were to come in contact with circulating solutions unsaturated with respect to sodium chloride. West of the WIPP facility where the Salado rises to the surface, progressively less halite is present. This condition is a result of leaching by percolating groundwater.

Dissolution of the salt has left behind a residuum of halitic clay, gypsum, and sand. Along the Pecos River in the Carlsbad area and to the west, this residuum forms dense redbeds. This low permeability residue retards groundwater infiltration and subsequent salt removal.[2] The average gas permeability of rock salt samples from the WIPP facility at lithostatic confining pressures is less than 0.05 microdarcy (about 1.2×10^{-7} ft/day).[49] Interbedded seams or Marker Beds of anhydrite, clay, polyhalite, etc. which are laterally continuous throughout the Salado should not provide substantial conduits for fluids as their permeabilities are also quite low. Typical permeabilities for these type clay assemblages generally range from 10^{-6} to 10^{-3} darcy at atmospheric pressure.[50] Under lithostatic compression at depth, permeability would generally be less. Other seams occur as thin (a few hundredths of an inch to about a tenth of an inch) discontinuous stringers dispersed within the argillaceous halite zones. Field permeability tests have been conducted on a 100-foot thick salt layer centered at the 2264-foot depth in AEC-7.[51] This interval contained numerous clay seams and yielded permeabilities between 12 and 21 microdarcies, demonstrating the minimal effect of the clay seams on permeability.

Very small angular cavities, containing both brine and gas, exist within and between the grains of halite. The cavities, in the core samples inspected, constituted an average of 0.61 percent of the rock sample by volume.[49] Analyses of 26 rock samples, taken from the facility interval during the SPDV Program, indicate a brine and other volatile content averaging about 0.59 percent by weight.[12]

Brine occurrences in the McNutt potash zone (a zone in the Salado stratigraphically located about 800 feet above the WIPP facility horizon) have been encountered in three potash mines during mining operations. Estimated brine volumes in the three mines are 190,000 gallons in the Eddy Potash Mine (17 miles from the WIPP facility), 2500 gallons in the Western Ag Mineral Co. Mine (5 miles from the WIPP facility), and 15,000 gallons in the New Mexico Potash Corp. (10 miles from the WIPP facility).[52] The brine occurrences do not appear to be interconnected and seem to be in isolated porous zones. Geochemical evidence tends to preclude interconnection of these brine occurrences or connection with water-bearing zones in the area.[7]

Detailed hydrologic investigations[53] performed in the underground openings were directed toward attaining a better understanding of minor fluid/moisture and gas occurrences and their movement within the Salado Formation in and around the facility horizon. These efforts addressed local weeping of small quantities of brine and/or gas (mostly nitrogen with traces of methane, carbon dioxide, and ethane) directly from freshly excavated halite and from layers of impurities. These types of liquid/gas movement are typically associated with the redistribution of stress induced by the excavation activities. Therefore, the fluid migration observed in the underground excavations should decrease with time and with increased distance from the openings as the pressure gradient approaches the low undisturbed value. Pressurized gas, consisting of mostly nitrogen with some amounts of methane, has been encountered during drilling and mining activities resulting in small gas releases. The gas appears to be associated primarily with clay seams, although it may occur in fractures and pores in evaporites.

Preliminary observations from the WIPP facility brine sampling and evaluation program show that brine inflow usually occurs as "weeps" on the exposed surfaces and occasionally as small inflows into drill holes.

These brine inflows are small, usually less than a few hundredths of a liter per day or less. Considerable variations in brine inflow were found between locations even when the locations are only a few feet apart.[15,53]

Experiments are being conducted as part of the near field effects/waste package performance tests to study brine migration due to thermal gradients. For this mechanism, thermal gradients were established using heaters placed within the salt. Because of the temperature dependence of solubility of halite, movement occurs towards the higher temperature. Results from the Brine Migration Study[54] showed that combined inflow rates under both a thermal and pressure gradient were higher for higher borehole wall temperatures.[54] Rates at the WIPP facility were in the range of 65 to 75 grams/day from Room B at 115° to 125°C wall temperatures.

The gas testing in selected drifts of the WIPP facility has produced the following observations:[34]

> The emission of gas appears to be associated with clay layers at the base of the anhydrite strata, such as Marker Bed 138, anhydrites "a" and "b," and Marker Bed 139.
>
> The flow from the vertical core holes (penetrating the above-mentioned beds) is very low, erratic, often pulsating, and rapidly decreasing. Maximum flow rates of over 12 liters per minute, decreasing to a few milliliters per minute within four days, and shut in pressures of up to 120 psi were recorded. The flow rates decreased to one half of the initial rate in less than an hour. There is a definite relationship between gas flow rates and stress relief from underground excavations, and possibly the atmospheric pressure.
>
> The samples of emitting gases were composed mainly of nitrogen (78 to 94 percent). Some oxygen (5 to 21 percent) was observed; however, this was probably due to air contamination of the samples as a consequence of the low flow rates of gas. Minor amounts of methane (0.02 to 6.6 percent), carbon dioxide (less than 0.6 percent), and ethane (less than 0.1 percent, with one exception of 0.9 percent) were also detected.
>
> The highest flow rates appear to be from the base of Anhydrite "b," which is the anhydrite layer closest to the roof of the underground workings.

Gas releases from halite exposed during the excavation of the WIPP repository have occasionally been noted.[53,55,56] These releases occurred during mining and the drilling of probe holes. In some instances, the gas occurred within porous zones and fractures in the salt, not obviously related to clay seams. The releases were the result of excavation-induced stress redistributions, involved small and unmeasured volumes of gas, and were audible for only short periods of time. They appear to fall within the range of the better documented releases reported above as part of the gas testing program.

Hydrologic testing at DOE-2 was completed within the Salado Formation (Table 2.5-6) to determine if high pressure zones were present and to obtain information on the hydrologic properties of the Salado.[19] A pulse withdrawal test was completed on an interval that includes the Marker Beds 138 and 139 and the facility horizon at a depth of 2195 to 2309 feet below the ground surface (BGS). The maximum permeability obtained was less than 0.3 microdarcy with a corresponding transmissivity of less than 6×10^{-5} ft^2/day and a hydraulic conductivity of less than 6×10^{-7} ft/day. The entire Salado interval, between 1040 and 3095 feet BGS, was also tested with a pulse withdrawal test and an additional pulse injection test, but had an apparent permeability too low to measure.

Hydrologic testing of the Salado Formation at DOE-2 produced the following conclusions:

- There are no high-pressure zones within the Salado Formation at DOE-2

- The Salado interval from Marker Bed 138 to Marker Bed 139, which includes the WIPP facility horizon, has an average permeability of less than 0.3 microdarcy

2.5.5 HYDROGEOLOGIC SYSTEMS BELOW THE SALADO FORMATION

The Salado Formation is immediately underlain by thick anhydrite and halite beds of the Castile Formation (Figure 2.5-2). These beds act as an aquifuge, separating the Salado from the underlying sandstones of the Bell Canyon Formation, the youngest formation of the Guadalupian Delaware Mountain Group, containing one of the most significant aquifers of the Delaware Basin and surrounding area. The Bell Canyon Formation belongs to the basin aquifer group of the Guadalupian hydrologic system, which comprises two other groups: the shelf aquifers (including the San Andres Limestone and the Artesia Group), and the reef aquifers (primarily the Capitan and the Goat Seep reef limestones). All these aquifers may be interconnected through the Capitan aquifer but are distinguished in most areas by contrasting permeabilities, water quality, and potentiometric levels. Along the northwest interface between the Capitan and shelf aquifers, the shelf aquifer permeability is considerably lower than the permeability of the Capitan aquifer. The basin water-bearing zones are much lower in permeability than the Capitan and shelf aquifers, and the Capitan acts as a sink or discharge point for them. Recharge to these water-bearing zones probably occurs along the west flank of the basin in their outcrop areas. Groundwater moves generally eastward with a downdip in the tilted beds. Data on aquifer characteristics are presented in Table 2.5-8.

The Delaware Mountain Group has several zones that contain water and oil or gas, or both, and are under enough pressure to maintain a potentiometric surface at an elevation above the Salado Formation.

Underlying the Guadalupian hydrologic system is the less permeable Bone Springs Formation of the Leonardian Series. Formations below the Bone Springs Formation are of similar or lower permeability than that of the Guadalupian formations, and the measured potentiometric levels are of similar magnitude to that of the Delaware Mountain Group.[57] These conditions, along with the fact that the older formations are more distant from the WIPP facility horizon than the Guadalupian system, indicate that pre-Guadalupian zones are hydrologically insignificant to the WIPP facility. Therefore, further discussion of the hydrology of rocks underlying the Salado will be directed to the Castile Formation and to the Guadalupian system.

2.5.5.1 Castile Formation

The Castile Formation is 1300 to 2000 feet thick over most of the Delaware Basin. West of the Pecos River, where the Castile crops out or is near the surface, the salt beds have been removed and the residuum is relatively permeable. Water is extracted by a few wells in these weathered zones along the western side of the Delaware Basin.[2]

In the northern Delaware Basin, isolated reservoirs of brine and associated methane, carbon dioxide, and hydrogen sulfide gas have been encountered by various hydrocarbon drilling companies and the U.S. Department of Energy exploratory boreholes ERDA-6 and WIPP-12. Of approximately 100 boreholes drilled into or through the Castile in this area, thirteen intersected pressurized brine reservoirs (Figure 2.5-17).[7] Eleven of these thirteen occurrences are located north and east of the WIPP facility center (WIPP-12 is approximately one mile north) and are associated with known anticlinal structures in the Castile. The Belco occurrence, located southwest of the WIPP facility, is also thought to be related to an anticline, though the structure is not as pronounced as those to the north and east. The H&W Danford occurrence is located west of the WIPP facility, where structural contours are not well defined. All known brine encounters in the Castile flowed to the surface with initial rates estimated between about 700 and 20,000 barrels per day (Table 2.5-20).[7] Initial downhole pressures were estimated to range from 1460 to 2519 psi.[7]

Extensive geologic, hydrologic, and geochemical studies were performed on the reservoirs intersected by boreholes ERDA-6 and WIPP-12. These studies showed that the brine is located in fractures in the Castile anhydrites (Anhydrite III at WIPP-12 and probably in Anhydrite II at ERDA-6) likely formed during creation of the anticlinal structures. Also, hydrologic and geochemical data indicate that the reservoirs at ERDA-6 and WIPP-12 are not interconnected and are not connected to water-bearing units in the area. Geochemical data support the hypothesis that the brines represent trapped, concentrated Permian seawater that is currently saturated with sodium chloride in equilibrium with the reservoir host rock.[7] Other hypotheses have been proposed for the origin of the brine. These include water from the Capitan or other basin aquifers trapped in the past[49] and fluid from dehydration of gypsum in the Castile.

Thus, the reservoirs are thought to represent stagnant, isolated pockets of fluid that cannot naturally become connected to the WIPP facility storage rooms. The consequences of connecting a brine reservoir to the facility by a surface drilled borehole in the future are being evaluated as part of ongoing performance assessment studies which are discussed in Chapter 8.

2.5.5.2 Shelf Aquifers

The shelf aquifers do not have a direct impact on hydrologic conditions at the WIPP facility. The intervening Capitan aquifer is a hydrologic boundary due primarily to its extremely high permeability relative to juxtaposed strata. The contact between the Capitan and the shelf aquifers is gradational and difficult to identify in some areas. The hydraulic properties are substantially different, however, due to a large difference in solubility between the Capitan Limestone and the sandy, dolomitic shelf facies.[39] On the northeastern side of the basin, the shelf aquifers are in close hydraulic connection with the Capitan aquifer and would accept discharge from the Capitan should extensive pumping from the Capitan be discontinued. The lowermost aquifer of the Guadalupian age shelf or "back-reef" facies is the San Andres Limestone. It extends over much of southeast New Mexico and into northwest Texas and is about 1500 feet thick. Overlying the San Andres Limestone are permeable formations of the Artesia Group.

In the Pecos River valley between Carlsbad and Roswell and to the west of that area, the shelf aquifers are quite permeable and yield large quantities of potable water. East of the Pecos River and in the Central Basin Platform, the permeability of the aquifers is significantly lower than it is to the west of the river. Measurements of the hydraulic conductivity and porosity of core samples of the shelf aquifers are summarized in Table 2.5-8. The permeability of the shelf aquifer east of the Pecos River is about one to two orders of magnitude lower than the permeability of the Capitan aquifer.

Potentiometric levels of the shelf aquifer are similar to those of the Capitan aquifer along the east side of the Delaware Basin. In the vicinity of Carlsbad, however, the levels are as much as 200 feet higher than those of the Capitan. This suggests poor interconnection between aquifers in that area.

Water quality in the shelf aquifers varies considerably from one area to another but is generally poor east of the Pecos River. Chloride ion concentrations are in excess of 150,000 parts per million (ppm) north of the Capitan aquifer and along the east flank of the Delaware Basin. However, there is a narrow band of less saline water (salinity of less than 5000 ppm) in the San Andres Limestone east of the Capitan aquifer and beneath the area between the communities of Hobbs and Eunice.[39]

2.5.5.3 Capitan Aquifer

The Capitan Limestone and possibly the underlying Goat Seep Dolomite constitute the main body of the Capitan aquifer, which is the reef facies of the Guadalupian basin rocks. The aquifer is a long continuous unit that extends in an arcuate strip along the north and east margins of the basin, with exposures in the Guadalupe and Glass Mountains, as well as the Delaware and Apache Mountains (Figure 2.5-4). The thickness of the aquifer ranges from a few hundred to nearly 2400 feet, and the width is about 10 to 14 miles. It is one of the most productive aquifers of the region and is a major control in the hydrologic system.

Relatively few aquifer tests have been made to measure the hydraulic conductivity of the Capitan aquifer (Table 2.5-8). Along the western margin of the Central Basin Platform in Texas and New Mexico and northeast of Carlsbad, the hydraulic conductivity is estimated to range from 1 to 25 ft/day.[39] The presence of high production wells, caverns, and high porosity suggest that the hydraulic conductivity of the Capitan west of the Pecos River is higher than that east of the river.

Sources of recharge to the Capitan aquifer include infiltration on outcrops in the Guadalupe and Glass Mountains (Figure 2.5-4) for the western and eastern portions of the Capitan, respectively. The Capitan also receives much smaller quantities of recharge from the basin and shelf aquifers along the north and east margins of the basin and the Pecos River. Water table conditions exist in the aquifer west of the Pecos River and in the Glass Mountains, but confined conditions exist north of the Glass Mountains and east of Carlsbad. Water entering the Capitan aquifer in the Guadalupe Mountains moves northeastward toward Carlsbad where most of it discharges into the Pecos River and Carlsbad Springs. The Pecos River controls the movement of groundwater in the Capitan aquifer in the vicinity of Carlsbad and east to the groundwater divide just west of the Eddy-Lea County line.[39]

East of the county line, the potentiometric surface declines with an eastward gradient. The eastward gradient is caused primarily by the large withdrawal of water from the Capitan aquifer for the water flooding of oil fields in eastern New Mexico and western Texas.

The similarity of the potentiometric heads and directions of groundwater movement within the Capitan and shelf aquifers along the northeast and east sides of the basin[39] suggests that some discharge from the Capitan to the shelf aquifer also occurs. An analysis of potentiometric data obtained prior to 1950, before large amounts of water were extracted from the Capitan, indicates that discharge was originally into the shelf aquifers to the east. The much lower permeabilities of the shelf aquifers (one to two orders of magnitude lower than the Capitan), however, severely restrict hydraulic communication.

Water that is hard but otherwise of good quality for most uses is available in the Capitan aquifer in the area west of Carlsbad, as well as in the Glass Mountains. However, the water quality in the major portion of the aquifer, east of the Pecos River, is poor. Chloride ion concentration increases from 200 ppm just west of Carlsbad to as much as 23,000 ppm east of the community. Along the east flank of the basin, the salinity of the Capitan water is significantly lower than that in the adjacent shelf and basin aquifers, ranging from about 1100 to 5000 ppm in most wells.[39]

2.5.5.4 Delaware Mountain Group

The Delaware Mountain Group includes, in descending order, the Bell Canyon, Cherry Canyon, and Brushy Canyon formations (Figure 2.5-3). The thickness of these formations ranges from less than 2000 feet in the southern part of the Delaware Basin to more than 4000 feet in southwestern Lea and eastern Eddy counties, New Mexico.

The Cherry Canyon and Brushy Canyon formations produce only minor quantities of oil and gas; most of the oil and gas is produced from sandstone in the upper part of the Bell Canyon Formation. The oil fields developed in the upper Bell Canyon do not seem to occur in structural features or structural "traps." Thus, it is likely that the oil, gas, and water in the Bell Canyon occur in the relatively clean, elongated "channel" sandstones of the formation that are porous and permeable but grade laterally and vertically into relatively impermeable siltstones and laminated shales. The Cherry Canyon and Brushy Canyon formations have considerably lower permeability than the Bell Canyon due largely to the increased cementation of the lower units. This fact, coupled with the proximity of the Bell Canyon to the base of the evaporite section, causes the Bell Canyon Formation to be the Guadalupian fluid-bearing zone of interest.

An average hydraulic conductivity of 0.016 ft/day and an average porosity of 16 percent have been determined from analysis of about 4,500 samples of rock core cut from the Delaware Mountain Group.[39] Testing and analysis of the upper sandstones of the Bell Canyon indicate intergranular porosities ranging from 20 percent to 28 percent and permeabilities of 14 to 90 millidarcies.

An equivalent potentiometric surface map of the upper part of the Bell Canyon Formation in the northern Delaware basin is shown in Figure 2.5-18. This map was developed using the base map shown by Hiss[39] and incorporating new information obtained by WIPP facility characterization efforts. In general, very little modification of the Hiss map was necessary. Due to the facies changes of the Bell Canyon Formation, the lateral continuity of the sandstones is irregular and limited; therefore, the calculated equivalent potentiometric surface map can be misleading if used to determine local fluid flow directions.

The quality of the water in the upper Bell Canyon Formation is generally poor for most uses. Chloride ion concentrations range from 50,000 to 150,000 mg/l in the eastern part of the Delaware Basin.[39] Concentrations diminish to about 1000 mg/l southward in the vicinity of the Glass Mountains and northwestward in the vicinity of the Guadalupe Mountains. Similarly, the dissolved solids concentrations of the Bell Canyon fluids range from very low in areas of Bell Canyon outcrop to more than 300,000 mg/l in the northern and eastern part of the basin.[4] Although much of the dissolved solids concentration of the fluid is comprised of sodium and chloride, the abundance of calcium, magnesium and potassium cations and the measured low hydraulic conductivity support the concept of extensive brine rock interaction as the water moves slowly northeastward across the basin.[4] This concept is supported further by the $^{18}O/^{16}O$ and D/H ratios in the water samples which exhibit deviations from ratios characteristic of meteoric waters. These deviations are likely the result of interaction of the water with the rock of the Bell Canyon.[8,58]

Recharge to the Bell Canyon Formation probably originates in the western part of the basin, in the Delaware and Guadalupe Mountains. If the assumption is made that the sands of the Bell Canyon are laterally continuous, the pseudo-potentiometric surface (Figure 2.5-18) would indicate that water moves north and northeastward across the basin and possibly discharges a small quantity of water to the Capitan and shelf aquifers.

Standard and modified[17] (for very low permeability formations) drill stem tests were performed on sand and shale units in the Bell Canyon Formation in exploratory holes AEC-7, AEC-8, ERDA-10, Cabin Baby, and DOE-2.[4,19,59] Analysis of water samples collected from the sand units indicates that they contain brine; the concentrations of the major constituents in AEC-7, AEC-8, ERDA-10, Cabin Baby, and DOE-2 are given in Tables 2.5-11, 2.5-12, and 2.5-13. The density of the brine ranges from 1.06 to 1.16 g/cm^3. The shale horizons overlying the sands in these three holes were tested to evaluate their effectiveness as a confining bed which would restrict upward movement of fluids. Hydraulic conductivity values calculated for the sands and shales from the results of testing ranged from 2×10^{-6} to 5×10^{-2} ft/day and are given in Table 2.5-9.

2.5.6 INTERRELATIONSHIP BETWEEN SURFACE AND GROUNDWATER AT THE WIPP FACILITY AREA

An analysis of hydrologic data indicates that there is little interconnection between the underlying groundwater and the surface water at the WIPP facility.

Near-surface materials are found to be unsaturated, with moisture contents of less than 10 percent in samples taken from eight borings ranging from 20 to 75 feet deep.[60] The shallowest known occurrence of groundwater in the vicinity is in the Dockum Group at a livestock well two miles northeast of ERDA-9, where the perched water is more than 100 feet deep.

Localized saturated zones have been detected within the WIPP Site Boundary in the underlying Dewey Lake Redbeds during test drilling in test holes H-01, H-02, and H-03.[4] Some low yielding livestock wells are known to be completed in the Dewey Lake Redbeds south of the WIPP facility.[4,31]

Directly beneath the WIPP facility the Magenta Dolomite water-bearing zone is areally continuous and more than 600 feet below ground surface. Groundwater in the Magenta is confined, and fluid levels in observation wells open to it rise to within about 200 feet of ground surface. The nearest probable area of interconnection of surface waters with the Magenta Dolomite is in Nash Draw where the Magenta crops out.[61] The Culebra Dolomite and the Rustler/Salado contact zone are also probably interconnected to surface waters in this area. In Nash Draw, the dissolution of salt and the resulting collapse and fracturing of the interbeds provides interconnection with the brine aquifer (Figure 2.5-15) and pathways for percolating waters to reach the Culebra and Rustler/Salado contact. Low gradients in the vicinity of Nash Draw shown in Figure 2.5-16 reflect this interconnection. However, the regional potentiometric levels (Figure 2.5-16) indicate that the Rustler/Salado contact in Nash Draw is hydrologically quite different from the Rustler/Salado contact in other locations.

A regional water balance study covering approximately 2000 mi^2 in Eddy County east of the Pecos River has been conducted (Figure 2.5-9).[62] The study incorporated stratigraphic units above the Sálado Formation and below the Ogallala Formation. Recharge to the Rustler Formation is thought to occur at a groundwater ridge between former Lake McMillan and Lake Avalon and the northern portion of Eddy County, and also east of Clayton Basin. Local groundwater from the Rustler Formation, Triassic rocks, and alluvium appears to discharge in Clayton Basin.[62] The basin is presently hydraulically separate from Nash Draw and the area around the WIPP facility, but may discharge into Nash Draw in the future if the groundwater ridge that lies between Clayton Basin and Nash Draw is altered by man's activities.

San Simon Swale does not appear to be connected hydrologically to the area around the WIPP facility. Water in the Dockum is separated by a groundwater divide, and any water recharging the Capitan from the Dockum near San Simon Swale flows to the southeast. If the water in the Dockum is not recharging to the Capitan Limestone, then the water is flowing southeast or discharging to the surface in spite of the great depth of water in this area.[62]

In the water balance study area, the only area that is certainly connected hydrologically to the area around the WIPP facility is approximately 400 mi^2 south of Highway 180, west of the Divide, and east of the Pecos River including all of Nash Draw. Recharge in this area appears to take place at the Divide and Mimosa Ridge, while discharge occurs from Laguna Grande de la Sal by evaporation and to the Pecos River.[62]

The amount of surface water available for percolation to the fluid-bearing zones beneath the site is not readily measured directly. A common method of measurement is to take the difference between precipitation and evapotranspiration. Several investigators have studied these parameters for the Delaware Basin. Their studies have been reviewed by Geohydrology Associates, Inc. for the U.S. Bureau of Land Management.[63] They report that evapotranspiration is at least 96 percent of the precipitation. The average annual precipitation at the WIPP facility is about 12 inches (Table 2.3-2), so the average amount of annual recharge would be less than a half inch. The presence of a well-developed petrocalcic soil horizon (Section 2.7.2.4.2.) indicates that little or no moisture infiltrates beyond the zone of deposition in the calcic horizon, several feet beneath the land surface. Inaccuracies in the parameters used to estimate recharge over the area make it difficult to arrive at a precise figure. However, because no near surface groundwater body or evidence of a near surface regional water table has been encountered in the exploratory holes at the WIPP facility, the quantity of precipitation that migrates downward is apparently negligible.

The Bell Canyon Formation, the water-bearing unit below the Castile Formation, contains water with $^{18}O/^{16}O$ and D/H ratios unlike that of meteoric water, indicating chemical interaction between the water and the formation. The long residence time required for significant interaction suggests that recharge and discharge points for the Bell Canyon are far from the WIPP facility and that the Bell Canyon beneath the WIPP facility may be isolated from meteoric water.[58]

2.5.7 ESTIMATES OF RADIONUCLIDE TRANSPORT CHARACTERISTICS

As an aqueous fluid migrates through the geosphere, certain reactions occur between the fluid and its dissolved constituents, other fluids, and solid phases that come in contact with the fluid. These geochemical reactions may affect the rate at which dissolved species in the migrating fluid travel with respect to the average velocity of groundwater. Commonly, the generic term "sorption" has been applied to describe certain interactions that affect the transport rate of dissolved species such as ion exchange, adsorption, coprecipitation, and colloid filtration. It should be remembered that sorption processes do not permanently immobilize radionuclides, but rather, retard their rate of transport. If sorption can be adequately characterized, it may be significant in the assessment of long-term waste isolation and the rate at which radionuclides contained in migrating aqueous solutions move within the geosphere to the biosphere at the WIPP facility.

For the purpose of hydrogeologic and radionuclide transport modeling, a parameter called the distribution coefficient, K_d, has been used to quantify sorption reactions. The K_d for a specific nuclide and solid material, or "sorber," may be defined as the ratio of the activity of the nuclide sorbed onto a specific solid phase to the activity remaining in a specific solution; yielding units of ml/g.

$$K_d = \frac{\text{Activity on solid phase, Ci/g}}{\text{Activity in solution, Ci/ml}}$$

The distribution coefficient can also be defined in terms of the surface area of the sorbing material, yielding units of ml/m^2. This may be significant because many of the interactions that cause the sorption phenomenon are surface area dependent. The decision is based upon whether one is assuming chemical interactions throughout a porous media, or flow through cracks or fissures with chemical interactions occurring only on the exposed surfaces.

The retardation factor, R, is defined as the ratio of the fluid velocity to the radionuclide velocity, and is related to the K_d by the following equations:

Porous Flow Case

$$R = 1 + \frac{d}{p} K_d$$

where

R = retardation factor
d = bulk density of porous media (g/cm^3)
p = fractional porosity of porous media
K_d = distribution coefficient (ml/g)

Fracture Flow Case

$$R = 1 + \frac{SA}{L_v} K_d$$

where

SA = surface area of fracture (m^2)
Lv = volume of liquid in fracture (ml)
K_d = distribution coefficient (ml/m^2)

Sorption data are obtained using either laboratory or in situ field techniques. In situ field experiments such as pair hole sorbing tracer tests avoid the problems associated with reproducing in the laboratory the actual at depth conditions, thus avoiding many of the sources of uncertainty intrinsic to laboratory sorption experiments. In situ tests are considerably more expensive and time consuming; however, they have the potential to provide more representative data than laboratory experiments.

2.5.7.1 Sources of Uncertainty in In Situ Field Tests

Two potential sources of uncertainty in in situ tests are the proper selection of tracers and tracer solutions. The composition of the injected tracer solution should mimic the properties of the natural formation water, and neither alter the chemistry or surface properties of the matrix or formation water, nor cause the tracer to precipitate or become unstable under the conditions existing in the formation. The most useful tracers would be either the actual radionuclides of interest or short-lived isotopes of the waste elements of interest. If environmental concerns preclude the use of radioactive tracers, then analog tracers can be used. This analog approach, however, requires that laboratory experiments be performed to quantify the difference in behavior between the analog tracers and the radionuclides of interest.

An additional source of uncertainty is the extrapolation of data collected at one or more points to the entire flow path. This extrapolation requires the assumption that there is little or no spatial variability of sorption properties between points where in situ data are collected. This assumption, if applied to a non-isotropic or a heterogeneous water-bearing unit, can introduce uncertainties that will be difficult to quantify.

2.5.7.2 Sources of Uncertainty in Laboratory Sorption Experiments

Most laboratory derived K_d values for a given combination of radionuclide(s) and sorber are, at best, a rough approximation of the actual behavior of the facility. Sorption is known to be affected by many physiochemical parameters, such as fluid compositions, nuclide concentrations, pH, Eh, and temperature. It is difficult to ensure that a laboratory experiment is accurately reproducing these physiochemical conditions that exist at depth. The following sections discuss the effects of these parameters on sorption processes.

2.5.7.2.1 Fluid Composition

Groundwaters containing high concentrations of alkali and alkaline earth cations frequently result in lower K_d values than in comparable systems using low ionic strength groundwater. These dissolved cations in brines and bitterns compete with dissolved radionuclides for sites in the solid substrate (sorber) that control the sorption phenomenon. The fluids associated with the WIPP facility span a wide range of ionic strengths. The 17 Culebra wells sampled by the Water Quality Sampling Program have ionic strengths that range from 0.05 at H-08b to 2.65 at H-05b,[6] whereas some samples of WIPP brine collected as part of the Brine Sampling and

Evaluation Program have ionic strengths as high as 7.2. The K_d values most relevant to the WIPP facility are those obtained using carrier solutions of appropriate ionic strength for the particular portion of the flow path under investigation. Trace amounts of organics such as humic or fulvic acids, and dissolved gasses such as H_2S and CO_2 can produce significant changes in K_d due to the occupation of available sorption sites. Sorption experiments using small amounts of plywood extract yielded K_d values that were in some cases orders of magnitude lower than similar experiments performed without the plywood extract.[64]

2.5.7.2.2 Radionuclide Concentration

It is often assumed that sorption is dependent upon radionuclide concentration, resulting in linear sorption isotherms. However, that is not always the case. In the event of a breach scenario, it is likely that radionuclide concentrations in mobile aqueous solutions will change with time and distance from the repository due to decay, dilution, dispersion, and interactions with host rock, backfill, and other media. Therefore, the full range of concentrations that may be of interest in sorption determinations may be fairly wide. Unless it can be determined that the sorption isotherms are linear, the concentration of radionuclides in experimental solutions should reflect the concentrations estimated for the WIPP facility at specific points of interest along the flow path.

2.5.7.2.3 pH

The pH of groundwater can have a profound effect on sorption, affecting speciation, solubility, and the nature of the sorbing surfaces. The effect on speciation is especially pronounced for the actinide elements that undergo hydrolysis. In the case of americium, the effect is compounded by the fact that the solubility is controlled over a wide range of pH values by a hydroxide phase.[65] Small differences between laboratory and field pH conditions can produce large differences in K_d values for these elements.

2.5.7.2.4 Redox State

The sorption of multivalent elements is highly dependent on the particular redox state(s) of the elements. For example, the redox chemistry of plutonium is quite complex, having four redox states (III, IV, V, and VI) that can exist in the natural environment, and each redox state displays independent sorption behavior. Prior knowledge of the redox state of the natural system is required to reproduce those conditions in the laboratory, and natural redox states can be difficult to characterize accurately.

2.5.7.2.5 Experimental Design

The experimental design employed to determine K_d can also affect values obtained. Experimental designs employed are usually the batch method, or the dynamic or flow through method. The batch method permits continuous reactions between the solid and fluid phases for a specified period of time. Batch experiments are frequently run until approximately steady-state (concentrations are independent of time) conditions are observed. Often, the solid is powdered and agitated so that a relatively large surface area is exposed to the fluid compared to a coarse grained or fractured rock. The sorption characteristics of freshly crushed surfaces are usually quite different than natural fracture surfaces. Thus, experiments performed on powdered materials may not be directly relevant to natural fracture flow systems. The dynamic method evaluates the interaction of solution introduced in discrete volumes or by continuous, controlled flow through a column filled with a sorbing material. Migration studies using intact porous cores or fractured cores can be performed to verify data obtained through methods that utilize crushed or powdered material.

From this discussion it is important to recognize that a K_d value applies, strictly, only to the experimental system in which it was measured. Consequently, a simple, generic approach to radionuclide/ geologic media interaction and radionuclide migration is not forthcoming. Sorption must be considered as a site-specific issue, using experiments that utilize site-specific materials and consider the naturally occurring range of material properties. Experiments must be carefully designed to control environmental conditions that are known to affect the K_d results. It appears unlikely that experimental systems can reflect the actual geologic/hydrologic complexities of a repository site; however, a sufficiently large, well-controlled data base may permit modeling and approximations of radionuclide transport potential under a range of realistic environmental conditions.

The literature relating to sorption of radionuclides by geologic media and other materials is quite extensive; however, much of this available information is not site specific and does not directly pertain to the assessment of radionuclide transport at the WIPP facility. This information will not be discussed here. Data that are most applicable to the present effort include those that are related to:

Geologic and engineered barrier materials that will be present at the WIPP facility (as opposed to analogs) or are expected to be present in fluid-bearing zones that may be potential radionuclide transport routes. These materials would include: backfill; Rustler anhydrite or dolomite; Salado anhydrite, clays, or other clastic units interbedded with salt; and shaft seal and disturbed zone rock materials.

Fluids that reflect expected groundwater compositions at the WIPP facility. These will be solutions containing total dissolved solid concentrations that range from thousands to hundreds of thousands of milligrams per liter, similar to those sampled and analyzed as part of the Water Quality Sampling Program and the Brine Testing Program. Major cations include Na^+, Ca^{++}, Mg^{++}, and K^+; major anions are Cl^- and SO_4.

Effects of organic complexation on sorption. The presence of naturally occurring as well as waste inventory organics that are capable of forming organometallic complexes with radionuclides can reduce the retardation effects of sorption. The organic contents of Rustler and Salado fluids are currently being analyzed as part of the Water Quality Sampling Program and the Brine Sampling and Evaluation Program.Temperatures, Eh, and fluid pH that reflect the range of expected conditions at the WIPP facility along potential migration routes.

Solids that are prepared to reflect in situ conditions; e.g., geologic media that are fractured and will transmit fluids by fracture flow will not be accurately evaluated if experimental samples are powdered. Natural fractures are usually lined with materials that have different sorption characteristics than freshly fractured surfaces.

2.5.7.3 Sorption Data

Site-specific laboratory studies of sorption of radionuclides from brines by WIPP facility-related geologic media have been performed.[64,66] For the WIPP facility, laboratory measurements of K_d's by the batch method have been performed on samples from rock core taken in exploratory hole AEC-8. Included in the tests were samples from the Magenta Dolomite, Culebra Dolomite, Cowden anhydrite, Bell Canyon sands, and from halite, polyhalite, and clay horizons at the WIPP facility waste storage horizon. The rock samples were crushed and separated into size fractions. The surface areas of specific masses of the dolomite and Bell Canyon samples were measured using either a gas adsorption technique or the ethylene glycol method. Three different carrier solutions were prepared to match roughly the concentrations and pH of brines and the brackish water that would be derived from evaporites and the Rustler dolomites. The systems were open to the atmosphere. No other control on redox potential was applied.

Distribution coefficients were measured using solutions containing Eu-152, Ce-144, Sb-125, Sr-85, Cs-137, or Ru-106, with only one nuclide dissolved in each solution to eliminate competing ion effects. Europium and cesium can be used to estimate the behavior of other rare earth elements and some actinides present in the wastes. Tc-99, Np-237, Am-243, Pu-237, Pu-238, Pa-233, Cm-243, Cm-244, I-131, Gd-153, and U-235 were also used because they represent actinides and long-lived fission products in radioactive waste. Times for the tests ranged from 5 to 170 days.

The values of laboratory K_d's for several radionuclides and WIPP facility-related geologic materials are presented in Table 2.5-21. Generally, the K_d values for fission products are higher in the low ionic strength groundwater than in high ionic strength brines, confirming that singly and multiply charged ions in the brine and brackish fluids compete with the radionuclides for available exchange sites in the solid substrate. Also, the brines and brackish fluid more readily form complexes and ion pairs with radionuclides that increase the solubility of the radionuclides or reduce the ability of the substrate to remove them from solution.

The K_d measurements are also sensitive to the differences in the rocks' affinities for specific nuclides. It appears that the sandstone, dolomite, and limestone materials studied sorb alkali metals moderately and alkaline earth metals only slightly in groundwater similar to the composition of that found in the Rustler Formation. Clay layers in the Salado salt sorb many of the radionuclides investigated more effectively than the other geologic media, particularly in the low ionic strength solutions.

A general summary of the WIPP facility-specific laboratory K_d data is as follows:

Anionic species. TcO_4^- and I^- showed little or no tendency to absorb on any of the geologic media (K_d < 1) with the possible exception of a clay material from a halite stratum (K_d < 5).

Cs and Sr K_d's were also generally less than one, but values in the range of 10 to 20 were observed. Results show a strong dependence on the ionic strength of the carrier solution.

Ru K_ds ranged from 25 to 10^3, depending on the ionic strength of the solution and the sorbing material. Lowest K_ds were measured in the high ionic strength solutions, brine A. Higher final pH values in brine B and groundwater C relative to brine A may indicate that hydrolysis effects are important in the removal of Ru from solution. The highest K_d's were achieved using the clay substrate.

The lanthanide and actinide K_d's were typically $> 10^3$ for all materials and solutions. Only polyhalite showed significantly lower sorption.

These results must be examined in light of the experimental conditions under which they were determined. The following factors must be considered before extrapolating the referenced laboratory data to field conditions:

The laboratory experiments used crushed powders with grain sizes of 44 to 149 microns. Extrapolation of these data to flow through natural fractures will introduce uncertainties.

Single radionuclides were used in each experiment to eliminate competing ion effects. Extrapolation of these data to complex systems with multiple radionuclides may introduce uncertainties.

The redox state of the experiment was uncontrolled.

Because the uranium and neptunium used in these K_d determinations are alpha emitters, count rates are typically low, and large quantities of these nuclides had to be used for the alpha particles to be detected. This difficulty with uranium is noted in the laboratory report.[66] The use of 3 to 8 mg/l of uranium to facilitate counting probably saturated the sorption sites, thereby giving anomalously low K_d values. The initial concentration of neptunium in solution was second only to that of uranium in the experiments. It was two orders of magnitude less than that used for uranium and eight orders of magnitude more than that used for plutonium. The reported K_d value for neptunium, approximately 10 ml/g, may also have involved the saturation of sorption sites, especially in view of the small rock/solution ratio used.

The measurement of distribution coefficients by radioactivity counting techniques is not sensitive to speciation of the nuclide. In the particular case of uranium, for example, the known aqueous species U^{4+}, $U(OH)^{3+}$, UO_2^{+}, $UO_2(CO_3)_2(H_2O)_2^{2-}$, and $UO_2(CO_3)_3^{4-}$ all have the same specific activity, but would a priori be expected to have different sorption behavior. The behavior, but not the identification of species, is reflected in the radiometric determination of the degree of sorption. In nature, the dominance of a particular species and (therefore the degree of sorption) is sensitive to the immediate geologic environment. Speciation effects are also known to exist for neptunium. In the experiments conducted for the WIPP facility, uranium, neptunium, and plutonium species were in their most stable (oxidized) valance states for neutral groundwater in equilibrium with the atmosphere, and those tend to be mobile species. Under anoxic conditions, these species may be reduced, and less mobile species may be stable.

2.5.7.4 Application of Sorption Data for Performance Assessment

The discussion in Section 2.5.7 is intended to show that laboratory sorption data must be very judiciously applied in performance assessment. This conclusion reflects the variability of experimental results, the inability to reproduce the natural conditions in the laboratory, and, more importantly, the uncertainties related to the geologic, hydrologic, and geochemical conditions at the repository and its environs that are known to affect sorption. The site-specific laboratory data are inconclusive and limited in scope, and there is little justification for applying them to WIPP facility performance assessment and radionuclide migration analyses. The simplest and most conservative means to deal with sorption in radionuclide transport is to assume that sorption does not occur ($K_d = 0$) for all dissolved radionuclides, and that there is no retardation of radionuclide transport by geomechanical processes. If, by this assumption, radionuclide transport rates and release rates are within prescribed values, sorption need not be considered further.

Based upon this review of reported literature data and the interpretation of the results of the WIPP facility-specific experiments, the distribution on coefficients summarized in Table 2.5-21 should be considered an approximation tha which contain considerable uncertainties.

2.5.8 GROUNDWATER USE

Groundwater is used in the region for irrigation, municipal supplies, rural domestic supplies, livestock watering, a few industrial purposes and for secondary oil recovery (usually referred to as "waterflooding"). The Capitan aquifer is the largest source, but supplies are also taken from the Dockum Group and the Rustler Formation. A recent study has been completed on the local water usage and the water balance for an area of approximately 2000 mi^2 around the WIPP facility (Figure 2.5-9).[62] An extensive discussion of the modeling requirements for such a study is included in that report. Recent groundwater use data cited here are taken from a recently published report by the New Mexico State Engineer's office on water use in 1985.[67]

2.5.8.1 Regional Groundwater Use

Demand for water throughout the region increased steadily since the 1950s, and this trend had been expected to continue into the 1980s. Production from the Capitan aquifer alone increased from about 80,000 acre-feet in 1950 to about 700,000 acre-feet in 1970.[39] The increase has been fairly linear over the 20-year period. Most of the increased demand has been for oil field flooding which began in the early 1950s. The largest amount of pumping for this purpose is in Ward and Winkler counties, Texas and is primarily extracted from the Capitan aquifer. The other major source is the San Andres Limestone. According to Hiss,[39] the cumulative total of water produced from these aquifers for the period 1920-1969, in thousands of acre-feet, is as follows:

Use	Eddy County	Lea County	West Texas	Total
Industrial	65.4	--	--	65.4
Irrigation	151.0	--	223.7	374.7
Municipal	162.0	--	--	162.0
Secondary Recovery	0.6	2.8	293.0	296.4
TOTAL	379.0	2.8	516.7	898.5

According to the New Mexico State Engineer's office,[67] groundwater use in Eddy and Lea counties declined between 1980 and 1985. High rainfall, low crop prices, and the government Payment-in-Kind (PIK) program lowered groundwater use in 1985. The fall in oil and gas prices affected groundwater use in Eddy and Lea counties because oil refineries and gas processing plants in the area have cut back on production activities or shut down operations completely.

Table 2.5-22 illustrates the change in use of surface water and groundwater in the state between 1980 and 1985.

Table 2.5-23, modified from the State Engineer's Report,[67] lists water use, by user category, for Eddy and Lea counties. Seventy eight percent of the groundwater withdrawn in Eddy County went for irrigation while in Lea County, 67 percent of groundwater used was for irrigation.

The occurrence of large quantities of potable groundwater is restricted to the west of the Pecos River, and most of it is extracted from the Capitan aquifer. Municipal water supplies for the communities of Carlsbad and White's City are obtained from wells completed in the Capitan aquifer. Water pumped from the Capitan aquifer is used to irrigate about 2300 acres of farmland in the Pecos River valley in the immediate vicinity of Carlsbad.[39]

In addition to the above uses, water pumped from the Capitan aquifer in Carlsbad is transported by pipeline to a potash refining plant about 18 miles east of Carlsbad. About 3740 acre-feet of water per year were used to refine potash ore during the period 1965-1969. Approximately 31,962 acre-feet of groundwater was pumped in Eddy and Lea counties in 1985 to support industries extracting and processing minerals and fossil fuels. This includes all of the following activities: mine dewatering, oil and gas well drilling, secondary oil recovery, oil refineries, and gas processing plants.

2.5.8.2 Local Groundwater Use East of the Pecos River

East of the Pecos River in southeastern New Mexico, small amounts of groundwater are used for rural domestic supplies, watering livestock, gasoline plants, and gas stripping. The Artesia Group, the Dockum Group, and the Rustler Formation are the principal hydrologic units pumped for these purposes. In the area of Nash Draw, relatively large quantities of groundwater have been taken from the Rustler Formation for use in potash refining.

The future development of groundwater at the WIPP facility is limited by the paucity of good quality water and the low permeability of the formations present.

2.5.9 LONG-TERM HYDROGEOLOGIC PROCESSES

It is clear that geological processes have acted at different rates at different times during the geological history of the region. The present climate at the WIPP facility is semiarid. A change in climate could cause precipitation to increase or decrease and could result in a change of infiltration, groundwater gradients, and the rate of groundwater flow. The following discussion of the potential mechanisms for, and amount of dissolution that has occurred in the geologic past can possibly provide a basis for estimating current rates of dissolution. It is assumed that future variations in climate will fall within the range of past variations and could cause dissolution to occur in the future.

2.5.9.1 Dissolution of Salt in the Permian Evaporites

It has been proposed that as much as 50 percent of the original salt in the Delaware Basin evaporites has been removed either by surface erosion or by subsurface dissolution and transport by groundwater.[68] Purportedly, these processes have been in progress intermittently for more than 100 million years.[69,70] At least four periods, in which the removal of salt may have been accomplished, are recognized:

- Early Triassic time
- Jurassic through early Cretaceous time
- A late Cretaceous through mid-Tertiary period
- Post-Ogallala uplift and erosion

Two possible dissolution regimes have been suggested as occurring in the Delaware Basin. The most likely is dissolution by waters infiltrating from rainfall on the ground surface above the salt. Groundwater moving laterally through permeable beds removes soluble salts and leaves behind a residuum of insoluble material, which is referred to as a leached zone. The "brine aquifer" (Figure 2.5-15) beneath Nash Draw seems to be such a zone and is apparently the route of lateral migration of the leached salts that discharge into the Pecos River.

Salt removal by dissolution at considerable depth ("deep dissolution") within the Salado or Castile Formation evaporites has also been suggested.[71] The possible sources of the dissolving fluid and potential circulation pathways required to enable this process to occur are not readily apparent. Localized collapse features around the basin margin have been recognized[49], and a variety of processes has been proposed to explain the origin of these features.[72,73]

2.5.9.1.1 Near Surface Dissolution

Dissolution occurs in the western part of the Delaware Basin where the evaporites are exposed or near the surface. The depth to which it extends is highly variable, as shown by the elevation of the top of the salt (Figure 2.7-32). In Nash Draw, where the Rustler Formation is exposed, dissolution extends into the Salado to a depth of 400 feet, and the permeable residuum contains the brine aquifer.[61] Percolating groundwater seems to move laterally toward Nash Draw and eventually discharge to the Pecos River after becoming saturated with salt.

In the Rustler Formation, progressive dissolution of halite and hydration of anhydrite to gypsum occurs westwardly across the region of the WIPP facility.[46,74] Removal of salt results in thinning of the formation, and hydration of anhydrite results in increased thickness, thus contributing to the erratic isopach contours (Figure 2.7-11). Bachman states that, "The evaporitic and clastic members [of the Rustler] exhibit variations in facies and thickness. Some of these variations may be attributed to dissolution of the evaporites, but some are the direct result of deposition."[75] In the Waste Shaft, Holt and Powers[14] note that horizons of the Rustler previously identified as dissolution residues in nearby boreholes contain primary sedimentary structures; specifically, fine bedding, cross cutting relationships due to erosion, and sharp continuous claystone beds. Further, this exposure lacks evidence of post-lithification dissolution; no breccia, chaotic bedding, or karst features were observed.

In Nash Draw, where the Rustler Formation is exposed at the surface, dissolution has continued since late in Gatuna time (Middle Pleistocene).[76] At the WIPP facility the Rustler Formation is covered by about 550 feet of sediments, including the Dewey LakeRedbeds, which retard any infiltration of water from the surface. Infiltration is additionally retarded by the presence of a well-developed caliche, the Mescalero caliche.[76] The caliche formed over the last 510,000 years[70], and its presence indicates that during the time it was forming, the landscape surface was very stable (no net erosion or deposition) and that no significant moisture infiltrated beyond the base of caliche development (calcite deposition) to dissolve underlying salt.

The upper member of the Salado Formation thins to the west and north of the WIPP facility. The thinning is attributed to a combination of thickness changes inherent in the original deposition processes and thinning due to dissolution during the middle and late Cenozoic. Westward toward Nash Draw there is as much as a fourfold reduction in thickness of this member to as little as 150-170 feet in some places. This thickness includes the residue of a 500-foot thick section from which soluble materials have been leached by circulating groundwater. Wherever the upper member of the Salado is thinned by dissolution, the section of rock between the upper surface of the remaining salt and the upper surface of the formation consists of clay-sized material with crudely interlayered seams of broken and shattered gypsum (from rehydration of anhydrite) and fine grained sandstone.[49]

As dissolution progresses and soluble material is carried away, voids may develop, and the residue is weakened until it is no longer able to support the overlying material. Collapse of the residue can extend to the ground surface, resulting in a depression, termed a "collapse sink." An irregular topography created by solutional processes, consisting of numerous sinks, deranged surface drainage, caves and underground drainage systems, is termed "karst." The term "karst" is a genetic term and is properly used only when it is known that dissolution is the dominant landscape forming process. Karst topography is locally extensive in southeastern New Mexico where carbonates and/or evaporites are near or at the surface. It most commonly develops on limestone and gypsum substrata.

The nearest known karst topography to the WIPP facility is in Nash Draw, over four miles to the northwest of the WIPP facility. WIPP-33 was drilled in a small closed basin on the Livingston Ridge surface east of Nash Draw, about three miles west of the center of the WIPP facility. The thinning of the Rustler Formation (276 feet as compared with as much as 450 feet) in this hole may be attributed to dissolution of salt and gypsum cavities in the Forty-Niner Member of the Rustler. Cavities that may be solutional in origin have been observed through downhole cameras.[77] Late Pleistocene spring deposits along the eastern edge of Nash Draw have been interpreted as deposits formed from discharging waters that dissolved material in the vicinity of WIPP-33.[76]

Bachman reports that dolines (shallow sinks that develop on a soluble rock surface beneath the soil mantle) are very common in southeastern New Mexico and suggests that the course of the Pecos River southward from Carlsbad to the vicinity of the New Mexico-Texas state line lie in a major belt of collapsed sinks.[69,70] For example, along the east side of the Pecos River southeast of Carlsbad at Malaga Bend, a linear scarp is believed to have formed along a collapse structure now occupied by the river. Other major collapse features mentioned by Bachman include Clayton Basin and Nash Draw. According to Bachman, these features formed as coalescing sinks, probably during Pleistocene time.

Another large depression is San Simon Sink, 22 miles east of the WIPP facility, in the southeastern end of San Simon Swale. San Simon Swale probably originated from a combination of surface stream erosion and solution subsidence, because the area of collapse seems to be confined to the sink areas and is not pervasive over the entire swale. Collapse in the sink areas acted to steepen the local drainage gradient, resulting in headward erosion and widening of the swale.[72] Anderson[68,71] proposed dissolution and subsidence at the contact between the evaporite beds and the Capitan reef as the reason for the sink while Jones[45] believes that the sink formed by collapse due to halite removal from the Rustler. Lambert[72] indicates that the most likely origin of San Simon Sink involves collapse of overlying material into a phreatic cavity in the Capitan reef limestones. Other theories for the sink's origin have also been proposed, but no unequivocal interpretation has been developed. The last collapse of San Simon Sink occurred in the 1930s.[3] Many sinks along the Pecos River valley also collapsed in historic time.[69] As recently as 1973, a small collapse sink formed at Lake Arthur, New Mexico, about 50 miles north of Carlsbad.

2.5.9.1.2 Deep Dissolution

Anderson[68] correlated breccia beds in the western part of the basin with the salt beds that are intercalated with varved anhydrite beds that can be traced across the basin. Anderson inferred that dissolution has occurred deep within the lower Salado and upper Castile salt beds. Certain assumptions, however, are implicit in the interpretation that these wedges of sedimentary thinning are the result of deep dissolution. These assumptions include that all halite units were once of uniform thickness throughout the Delaware Basin, that they were deposited on a flat surface, and that all local variations (reductions) in thickness from a preselected value for a halite bed were caused by postdepositional dissolution and removal of halite.[72]

To evaluate the magnitude and distribution of thickness variations of the Castile Formation, 348 borehole logs from the northern DelawareBasin were examined.[72] In general, it was reported that there are no abrupt overall thinnings in the lower and middle Castile attributable to post depositional removal of halite by dissolution. This observation strongly suggests that variations in the thicknesses of individual beds are syndepositional or deformational, not dissolutional.[72] It is likely that the development of Castile dissolution breccias occurred during Permian time.

The Guadalupian aquifer system has been considered a possible source of water for dissolving the salt.[68,78] However, the thick anhydrite beds of the Castile Formation overlying the Capitan Reef and Bell Canyon sands act as an aquiclude preventing the upward movement of water into the salt beds. Even if the anhydrite should develop fractures, it has been shown that neither the Capitan nor Bell Canyon is capable of providing a source of unsaturated fluids or a sink for saturated fluids of sufficient efficacy to produce significant salt removal even over geologic time.[8] A more likely potential source of water for dissolving salt is water from outcrop areas on the western side of the basin moving along the contacts between beds.[72] If water enters the evaporites at areas of outcrop, the location of discharge of the salt saturated fluids is not apparent. The large dissolution depressions on the eastern side of the basin that are filled with Cenozoic sediments are probably the result of surface water infiltration reaching the deep salt beds prior to Cenozoic time.[69]

The most prominent small-scale (less than one mile across) dissolution features in the Delaware Basin are described as domal karst features.[79] They are described in Section 2.6.1. The subsurface projection of one of them, Dome C, was encountered by Mississippi Chemical Corporation at the level of the McNutt potash zone. It was found to be a chimney in the Salado Formation filled primarily with brecciated halite and anhydrite, with minor amounts of clay and silt sized material belonging to strata above the McNutt. A chimney containing cemented rubble was encountered in commercial exploratory drilling near the Wills Weaver Mine, but this chimney was not associated with a breached dome at the surface. Geophysical surveys of the region reveal that many of these domal features, including the "Wills Weaver pipe" and Dome C, are associated with electrical resistivity lows. The subsurface expressions of Domes A and C were explored by Sandia National Laboratories and the USGS in drillholes WIPP-31 and WIPP-16, respectively.

The WIPP-31 drillhole, located very near the center of Dome A, was deepened by coring from 810 feet to 1981 feet.[73] No rocks in normal stratigraphic position were encountered in this depth interval. Core recovered from this interval was comprised primarily of rock salt and anhydrite and other breccia in a clay and silt matrix. These sediments and evaporites are thought to come from the Dewey Lake Redbeds and the Rustler

Formation. Drill stem tests were made over various intervals in WIPP-31, and none showed significant inflow into the drill hole. The final depth of the hole (1981 feet) is definitely below the projected base of the Salado Formation, and it is thought that the "breccia chimney" must originate below the evaporites.[73]

Drillhole WIPP-16 was sunk near the edge of Dome C to a depth of about 1300 feet. The borehole penetrated brecciated rock of the Triassic Dockum Group and the Permian Dewey Lake Redbeds and part of the Rustler Formation. Although the Rustler has been downdropped and shattered, the beds, unlike the overlying rocks, are in recognizable stratigraphic order. The contact of the Rustler and the overlying Dewey Lake has been downdropped about 620 feet, as has the Culebra dolomite of the Rustler.[73] Hydrologic testing in WIPP-16 was not conducted because of the instability of the hole walls. Geophysical logging was conducted, however, and did not indicate the presence of water in the drill hole. Snyder and Gard[73] theorize that the breccia chimneys are the result of collapse into cavities in the Guadalupian carbonates, formed by dissolution by the Capitan aquifer. Davies[80] believes that these chimneys formed as a result of dissolution of salt by water from the Capitan aquifer at the base of and within the Salado Formation. Thus, occurrence of this type of breccia chimney is restricted to areas underlain by the Capitan aquifer. The Capitan aquifer does not extend beneath the WIPP facility.

The WIPP facility is in an area of the Delaware Basin that is free of features that typically have been associated with deep seated processes acting to erode rocks below the top of the Salado Formation. The nearest of these features is Dome D, located about 11 miles northwest of the center of the WIPP facility and one-half mile southeast of Dome C. Since the subsurface expression of Dome D has not been investigated, its actual characteristics have not been determined to be analogous to those of Dome C, one-half mile to the northwest. Based on the interpretation of a considerable number of geophysical logs from hydrocarbon and potash holes in the area, dissolution of the salt beds of the lower Salado Formation and Castile Formation is not occurring in the vicinity of the WIPP facility.[72] Additionally, seismic profiles on a grid spacing of less than 2500 feet show no evidence of dissolution or collapse features (Section 2.7.13).

2.5.9.2 Rates of Dissolution

For the Delaware Basin, two divergent opinions have developed regarding the timing of major evaporite dissolution.[72] Bachman[70] proposes that several episodes of dissolution have occurred since Triassic time, each characterized by evaporite exhumation and a wetter climate separated by episodes of evaporite burial and/or a drier climate. Anderson's[68] view is that most of the dissolution results from a continuing process that began in the late Cenozoic. Adoption of either view does not facilitate calculation of an average rate of halite removal from the Delaware Basin since the Permian.[72]

Various attempts have been made, however, to determine the current rate of halite dissolution in the basin. Present day dissolution rates estimated by Swenson[81] are based on the tonnage of salt dissolved and discharged by springs and streams along the many subsidiary basins. His study indicates that the salt dissolution rate is 955 ton/year from each square mile of drainage area. If the discharge of salt continues at that rate, 0.5 vertical foot of salt would be removed each thousand years, provided that the dissolution is distributed evenly over the area drained.

Calculations of the present rate of salt removal from the Rustler and Salado Formations in the Pecos Valley have also been made based on the rates and discharge of dissolved $NaCl$ and $CaSO_4$ into the Pecos River by brine seepage at Malaga Bend. Active dissolution of halite from the upper parts of the Salado Formation occurs in the solution breccia zone "brine aquifer" at the base of the Rustler Formation in Nash Draw.[46] The zone is thought to discharge into the Pecos River at Malaga Bend, and may also be discharging to the surface in Laguna Tonto, to the northeast of Nash Draw.[62]

Bachman[69,76] analyzed the rate of dissolution in Nash Draw since the development of the Mescalero caliche, which, measured by uranium series disequilibrium, is 510,000 years old.[76] Along Livingston and Quahada Ridges on the east and west sides of Nash Draw, respectively, the Mescalero caliche is undeformed at elevations above 3300 feet. Since the Mescalero is a pedogenic unit that formed parallel to the existing landscape, caliche surfaces that dip gently toward Nash Draw do not in themselves indicate collapse. Bachman[69,76] has shown that collapse sinks did begin to form near the end of Gatuna time. Part of Nash Draw is therefore a paleokarst feature that predates the development of the Mescalero caliche.

A cross section through potash exploratory holes in Nash Draw can be used to estimate the approximate maximum amount of salt dissolution if it is assumed that Nash Draw formed entirely after the Mescalero caliche. At one locality, the surface of Nash Draw is 180 feet below the projected altitude of the Mescalero caliche. If this difference of 180 feet is attributed entirely to subsidence by dissolution and the age of the caliche is 510,000 years, the maximum average rate at which dissolution lowered the landscape at this location can be calculated to be about 0.35 feet per 1000 years.

Since the climate has varied considerably during the Pleistocene, a major part of the dissolution may have occurred during periods that had greater precipitation than is experienced today. The rate of dissolution in Nash Draw is not an average rate for the region. For example, in the area of "The Divide," between Antelope and Livingston Ridges, the Mescalero caliche is relatively undisturbed, and probably no dissolution occurred there since Mescalero time.

More recent work by Bachman[82] has shown that the age of Nash Draw as previously proposed is too young. Evidence that the depression was formed, at least in part, prior to deposition of the caliche includes the presence of the Mescalero on the slopes and in the bottom of Nash Draw. This caliche has been weathered and eroded, but remnants of depositional morphology are present. Thus, the rate of dissolution estimated above is greater than the rate that must have actually prevailed in the past.

The rate at which the zone of dissolution in the Salado Formation has advanced eastward (laterally) was estimated to be about six to eight miles per million years.[69] This estimate was based on the assumption that at the end of Ogallala time, the salt-bearing Salado Formation extended to the Capitan reef escarpment on the western edge of the basin, and the salt was removed since the beginning of Pleistocene time, a period of extensive erosion. It is now recognized that at least some dissolution of this salt probably occurred during several episodes before Ogallala time. Thus, the average rate of lateral advancement is much less than the estimate given above and is indeterminate due to the long, complex history of dissolution in this region.

An alternative approach for determining the rate of advance was suggested by Anderson[68] based on estimates of the volume of lower Salado salts that were originally deposited and on assumptions that those salts were removed only by deep dissolution, and that the process did not begin until stripping of the Ogallala Formation began, estimated to be about four million years ago. Based on Anderson's estimate of the original volume, only one fourth of the lower Salado salt remains. Assuming a linear progression of salt dissolution, if three fourths of the salt were dissolved in four million years, the balance of salt in the lower Salado would be removed in the next million years.

Several assumptions in this estimate make it a very conservative, and possibly unrealistically, estimate of the minimum time involved. It is highly likely that Permian rocks in the western portion of the basin were exposed to erosion during the late Permian or early to middle Triassic.[82] Erosion was also dominant in Jurassic time, and removal of Ochoan strata during this period is very probable. Thus, estimating the rate of salt dissolution from the basin based on assumptions of the volume of salt remaining four million years ago is demonstrably not valid. Assuming no salt had been removed prior to Ogallala time seems to be highly unreasonable. Thus, estimating the volume of salt remaining four million years ago is difficult at best, and assuming no salt had been removed prior to Ogallala time appears unrealistic.

The geologic history since Jurassic time indicates that the most rapid rates of erosion and dissolution occurred during the Pleistocene, the period for which the rates of dissolution are calculated. Should the present arid climate change and a more humid climate develop in the future, the calculated rates provide a basis for evaluating the amount of dissolution that might occur in the vicinity of the WIPP facility.

If a vertical rate of dissolution of 0.5 feet per 1000 years is assumed, dissolution would take about two million years to reach the salt horizon of the waste storage area. In a lateral direction, dissolution of the waste storage horizon is more than 10 miles west of the WIPP facility. Thus, the conservative estimate of easterly advancement of the solution front of six to eight miles per million years indicates that it would take more than one million years for dissolution to reach the waste storage area.

2.5.10 ONGOING AND PLANNED HYDROGEOLOGIC PROGRAMS

Continuing activities in the WIPP hydrologic programs can be divided into long-term monitoring programs and testing expected to be continuing for site characterization. Monitoring programs include:

- Comprehensive water-level measurements
- Water quality sampling and analysis for the Environmental Monitoring Programs (Water Quality Sampling Program)
- Brine sampling and chemical analysis from the WIPP facility horizon (Brine Sampling and Evaluation Program)

Tests planned to provide a more complete analysis and interpretation of the hydrology are described in the planning document for the Test Phase and include:

- Interpretation and analysis:

  Final analysis of pressure transient tests

  Interpretation of the water chemistry of the Rustler Formation

  Interpretation of multi-pad interference tests

  Long term geologic performance assessment modeling (radionuclide transport analysis)

- Additional geophysical studies both on the surface and underground, to attempt to define the distribution of fluid, fractures, or both in the Rustler, Salado, and Castile Formations
- Additional brine, gas, and permeability testing in the WIPP underground facility
- Fielding of additional multi-pad interference tests
- Fielding of at least one multi-well tracer test
- Installation of additional hydrologic test wells

Due to the very complicated nature of the flow systems in the vicinity of the WIPP facility, additional programs may be deemed required for site characterization as a more thorough understanding of these systems is acquired.

Only the Water Quality Sampling Program (WQSP) and the Brine Sampling and Evaluation Program (BSEP) are of any significance to WIPP operations.

None of these programs is considered to be necessary from a safety standpoint since the hydrological characteristics of the WIPP facility, as described in Section 2.5, do not pose any operational safety hazards. These programs are conducted to extend the data base over longer periods of time and thereby provide useful information for post-operational hydrological performance assessments. Comparisons of operational data to preoperational data will be used to assess potential impacts that operating the facility may have on the hydrology. These, however, are expected to be minimal.

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Table 2.5-1

TRANSMISSIVITY AND STORAGE COEFFICIENT OF FLUID-BEARING ZONES ABOVE THE SALADO FORMATION*

[Transmissivity is expressed in ft- squared/d]

	Magenta Dolomite Member		Culebra Dolomite Member		Rustler/Salado Contact	
Test Hole	Transmissivity	Storage	Transmissivity	Storage	Transmissivity	Storage
H-1	0.05	-	0.07	10^{-4}	0.0003	-
H-2a	0.01	10^{-4}				
H-2b			0.40	10^{-9}		
H-2c					0.0001	-
H-3	0.10	10^{-5}	19.0	-	0.0003	10^{-4}
H-4a	0.06	10^{-6}				
H-4b			0.90	10^{-9}		
H-4c					0.0006	10^{-4}
H-5a	0.10	10^{-5}				
H-5b			0.20	10^{-5}		
H-5c					0.00003	10^{-3}
H-6a	0.30	10^{-5}				
H-6b			73.0	-		
H-6c					0.003	10^{-6}
H-7a	Unsaturated	-				
H-7b			1000 +	-		
H-7c					0.73	-
H-8a	0.006	10^{-5}				
H-8b			16.0	-		
H-8c					0.003	-
H-9a	1.0	10^{-9}				
H-9b			231	-		
H-9c					0.0002	-
H-10a	0.01	10^{-3}				
H-10b			0.07	10^{-4}		
H-10c					0.00009	-
P-14			140	-	0.05	-
P-15			0.07	10^{-4}	0.0004	-
P-17			1.0	10^{-6}	0.0002	10^{-4}
P-18			0.001	-	0.00003	10^{-5}
W-25	375	-	270	-	5.0	10^{-3}
W-26	Unsaturated	-	1250	-	0.40	-
W-27	53	-	650	-	0.0002	-
W-28	Unsaturated	-	18	-	0.87	-
W-29	Not Present		1000	-	8.0	-
W-30	0.004	-	0.3	10^{-4}	0.20	10^{-4}

*J. W. Mercer, Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico, U.S. Geological Survey, Water-Resources Investigations Report 83:4016, Table 7, p. 105 (1983).

RECORDS OF WELLS IN THE VICINITY OF THE WIPP FACILITY

	Water Level						
Location Number	Altitude Above Mean Sea Level, ft**	Depth of Well ft***	Diameter of Well Casing, in.	Depth Below Land Surface, ft.	Date of Measurement	Geologic Source****	Power, Use, and Remarks
19.32.34.424	3560	260	--	Dry	09-22-72	QTs,Trd, Trd(?)	Unused; 3 wells at this locality; no access for entering casing in the other 2 wells.
19.33.26.244	3609	--	6.0	90.58	09-25-72	QTs,Trd(?)	Electric submersible; stock.
26.244a	3609	101	--	90.93	09-25-72	QTs,Trd(?)	--
19.34.31.131	3620	53	6.0	Dry	09-25-72	QTs	Unused; 2 ft of water in bottom of hole-- probably does not represent true water level.
31.232	3632	12OR	6.0	--	09-25-72	QTs,Trd(?)	Windmill; stock; "Hardin Well," no access to enter casing.
20.31.13.412	3440	30	6.0	1.12	09-18-72	QTs	Unused.
15.130	3460	105	6.0	62.10	09-18-72	QTs(?),Trd	Unused.
15.130a	3460	79	6.0	63.39	09-18-72	QTs(?),Trd	Unused; 5 wells at this location of which only 1 is an operating well.
15.130b	--	--	--	--	--	QTs(?),Trd	Windmill; stock.
20.32. 1.312	3510	20	6.0	Dry	09-22-72	QTs	Unused; deepest of 4 wells at this location, all wells are dry.
24.333	3555	67	5.0	37.67	09-11-72	QTs	Unused.
24.333a	3555	--	--	--	--	QTs(?)	Windmill; stock.
27.144	3545	30	--	23.67	09-18-72	QTs	Unused; no casing present.

Reference: C.L. Jones, M.E. Cooley, and G.O. Bachman, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico, U.S. Geological Survey Open-File Report USGS-4339-7, Table 4, pp. 45-48 (1973)

**From topographic maps.

***All depths of wells were obtained in 1972; all depths to water in the wells measured in 1972 or before are listed; R, reported depth; P, pumping level; < , less than.

****Geologic Source: QTs, surficial deposits; Trd, Dockum Group; Pdl, Dewey Lake Redbeds; Pru, Rustler Formation above Culebra Dolomite; including Magenta Dolomite members; Prc, Culebra Dolomite member of Rustler Formation.

RECORDS OF WELLS IN THE VICINITY OF THE WIPP FACILITY

Location Number	Water Level: Altitude Above Mean Sea Level, ft**	Depth of Well ft***	Diameter of Well Casing, in.	Depth Below Land Surface, ft.	Date of Measurement	Geologic Source****	Power, Use, and Remarks
36.214	3585	--	--	P43.88	09-18-72	QTs	Windmill; stock; 3 wells at this location at Bingham Ranch, well pumping estimated at 2 gpm.
20.33. 4.432	3555	4		Dry	09-22-72	QTs	Unused.
18.123	3521	249	6.5	245.58	09-25-72	Trd	Unused.
21.111	3536	49	6.0	36.90	09-25-72	QTs	Unused.
24.124	3630	680	12.0	405.15	09-22-72	Trd,Trd(?)	Windmill; stock; "West Windmill." Watersand at about 300 ft as reported by driller.
20.34. 4.444	3633	200	8.0	P174.08	10-02-72	Trd	Windmill; stock; "Robert's Well," old oil test drilled before 1930.
14.133	3648	230	--	190.25	10-02-72	Trd	Windmill; stock.
17.334	3640	220	8.0	129.68	10-02-72	Trd	Windmill; stock; "City Service Well," possibly oil test.
22.224	3655	220	12.0	196.49	10-02-72	Trd	Windmill; stock; "North Well," old oil test.
34.432	3770	96	6.0	89.50	10-02-72	QTs	Windmill; stock.
21.30.18.333	3220	156	6.0	129.54	09-25-72	Pru	Unused.
22.423	3180	130	6.0	111.50	09-25-72	Pru	Unused.
21.31. 1.131	3580	30R	6.0	20.80	09-18-72	QTs	Windmill; domestic & stock; at Campbell Ranch
1.241	3600	--	--	--	--	--	"Grave Well."

Reference: C.L. Jones, M.E. Cooley, and G.O. Bachman, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico, U.S. Geological Survey Open-File Report USGS-4339-7, Table 4, pp. 45-48 (1973)

**From topographic maps.

***All depths of wells were obtained in 1972; all depths to water in the wells measured in 1972 or before are listed; R, reported depth; P, pumping level; < , less than.

****Geologic Source: QTs, surficial deposits; Trd, Dockum Group; Pdl, Dewey Lake Redbeds; Pru, Rustler Formation above Culebra Dolomite; including Magenta Dolomite members; Prc, Culebra Dolomite member of Rustler Formation.

RECORDS OF WELLS IN THE VICINITY OF THE WIPP FACILITY

Location Number	Water Level: Altitude Above Mean Sea Level, ft**	Depth of Well ft***	Diameter of Well Casing, in.	Depth Below Land Surface, ft.	Date of Measurement	Geologic Source****	Power, Use, and Remarks
2.221	3570	35	--	29.80	09-18-72	QTs	Windmill; stock.
7.331	3350	367	14.0	192.10	09-14-72	Pru,Prc(?)	Unused.
13.244	3600	68	6.0	Dry	09-13-72	QTs,Trd	Unused.
18.411	3310	--	6.0	158.32	09-14-72	Pru	Windmill, stock; "New Well."
30.421	3300	176	6.0	Dry	09-25-72	Pru	Unused.
21.32. 6.111	3598	54R	--	44.00R	09-18-72	QTs	Windmill; domestic & stock; at Allred Ranch; 2 wells at this location.
21.33. 2.231	3810	1150R	--	--	09-22-72	Trd	Unused; could not pass tape below 580 ft in 1972.
2.420	3770	94	6.0	79.58	09-22-72	QTs	Windmill, stock.
4.434	3805	147	--	129.66	10-02-72	QTs(?),Trd	Unused.
4.434a	3805	127	--	Dry	10-02-72	QTs(?),Trd	Unused.
18.114	3890	150	--	140.75	09-12-72	QTs	Windmill; stock.
18.114a	3890	175	--	142.88	09-12-72	QTs	Unused.
21.33.18.123	3855	--	--	--	09-12-72	QTs(?)	Windmill; stock.
18.123a	3885	145	8.0	117.30	09-12-72	QTs	Unused.
18.131	3895	11	--	Dry	09-12-72	QTs	Unused.
25.421	3670	67	--	56.58	09-22-72	QTs	Windmill; stock; "West Well."

Reference: C.L. Jones, M.E. Cooley, and G.O. Bachman, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico, U.S. Geological Survey Open-File Report USGS-4339-7, Table 4, pp. 45-48 (1973)

**From topographic maps.

***All depths of wells were obtained in 1972; all depths to water in the wells measured in 1972 or before are listed; R, reported depth; P, pumping level; < , less than.

****Geologic Source: QTs, surficial deposits; Trd, Dockum Group; Pdl, Dewey Lake Redbeds; Pru, Rustler Formation above Culebra Dolomite; including Magenta Dolomite members; Prc, Culebra Dolomite member of Rustler Formation.

RECORDS OF WELLS IN THE VICINITY OF THE WIPP FACILITY

Location Number	Altitude Above Mean Sea Level, ft**	Depth of Well ft***	Diameter of Well Casing, in.	Water Level: Depth Below Land Surface, ft.	Water Level: Date of Measurement	Geologic Source****	Power, Use, and Remarks
28.124	3688	210	8.0	179.00	09-22-72	Trd	Windmill; stock; "Standard Wells," 3 wells at this location.
22.30. 5.431	3120	225	14.0	53.25	09-19-72	Pru,Prc(?)	Unused.
6.444	3140	176	22.0	92.40	09-19-72	Pru	Unused.
7.244	3110	58	12.0	Dry	09-19-72	Pru	Unused.
10.311	3135	68	6.0	63.70	09-12-72	Pru	Unused; at Crawford Ranch.
20.120	3076	10	5.0	Dry	09-19-72	QTs, Pru	Unused.
32.111	3010	35	6.0	32.70	09-19-72	Pru	Unused.
22.31.15.130	3460	--	--	144.07	09-12-72	Trd(?),Pdl	Windmill; stock.
15.130a	3460	--	--	145.50	09-12-72	Trd(?),Pdl	Unused.
22.32.14.323	3717	380	--	367.80	09-13-72	Trd	Jenson Jack; stock; "Commanche Wells."
14.324	3720	380(?)	--	370.40	09-13-72	Trd	Windmill; stock; "Commanche Wells."
22.33. 5.321	3650	10	6.0	0.0	09-22-72	--	Windmill; stock; well on edge of Dagger Lake.
13.231	3515	490	6.0	388.05	09-21-72	Trd	Windmill; stock; "Rogers Well."
13.231a	3515	400	6.0	388.05	09-21-72	Trd	Windmill; stock.
20.244	3602	--	--	--	--	--	Unable to locate well in 1972.
23.30. 2.444a	3250	315	7.0	257.73	09-20-72	Prc	Windmill; stock; "Little Windmill," well 444 destroyed.
6.424	2980	--	6.0	0.0	09-20-72	--	Unused; "Nash Well," area flooded by lake.

Reference: C.L. Jones, M.E. Cooley, and G.O. Bachman, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico, U.S. Geological Survey Open-File Report USGS-4339-7, Table 4, pp. 45-48 (1973)

**From topographic maps.

***All depths of wells were obtained in 1972; all depths to water in the wells measured in 1972 or before are listed; R, reported depth; P, pumping level: < less than.

****Geologic Source: QTs, surficial deposits; Trd, Dockum Group; Pdl, Dewey Lake Redbeds; Pru, Rustler Formation above Culebra Dolomite; including Magenta Dolomite members; Prc, Culebra Dolomite member of Rustler Formation.

Table 2.5-2

RECORDS OF WELLS IN THE VICINITY OF THE WIPP FACILITY

Location Number	Water Level: Altitude Above Mean Sea Level, ft**	Depth of Well ft***	Diameter of Well Casing, in.	Depth Below Land Surface, ft.	Date of Measurement	Geologic Source****	Power, Use, and Remarks
19.123	3045	--	7.0	68.55	09-20-72	Prc	Windmill; stock.
21.122	3165	--	5.0	--	09-20-72	Pru,Prc(?)	Windmill; stock; "Indian Well," no access for water level measurement.
		204	5.0	179.25	04-06-59	Pru,Prc(?)	
22.234	3210	244	--	227.32	09-20-72	Pru,Prc(?)	Unused.
33.244	3438	696	--	--	--	Pru,Prc	Abandoned; at Gnome Site, plugged 6-25-69, USGS No. 5.
34.133	3413	518	--	433.91	09-25-72	Pru,Prc	Observation; at Gnome Site, USGS No. 4
				433.67	12-12-61	Pru,Prc	
34.133a	3413	--	--	427.03	09-25-72	Pru,Prc	Unused; at Gnome Site, USGS No. 8.
34.234	3401	568	6.0	415.70	04-14-62	Pru,Prc	Observation at Gnome Site, USGS No. 6, drilled to 1499 ft & plugged back to 568 ft.
23.30.34.234a	3402	563	6.0	418.10	04-16-62	Pru,Prc	Observation; at Gnome Site, USGS No. 7, drilled to 1507 ft & plugged back to 563 ft.
34.324	3426	567	--	441.67	09-25-72	Pru,Prc	Observation; at Gnome Site, USGS No. 1.
				442.40	09-22-60	Pru,Prc	
23.31. 6.320	3300	213	8.0	144.72	02-04-59	Pdl	Windmill; domestic.
6.320a	3300	400R	--	--	--	Pdl,Pru	Windmill; domestic; tape will not pass 222 ft. in 1972.

Reference: C.L. Jones, M.E. Cooley, and G.O. Bachman, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico, U.S. Geological Survey Open-File Report USGS-4339-7, Table 4, pp. 45-48 (1973)

**From topographic maps.

***All depths of wells were obtained in 1972; all depths to water in the wells measured in 1972 or before are listed; R, reported depth; P, pumping level; < , less than.

****Geologic Source: QTs, surficial deposits; Trd, Dockum Group; Pdl, Dewey Lake Redbeds; Pru, Rustler Formation above Culebra Dolomite; including Magenta Dolomite members; Prc, Culebra Dolomite member of Rustler Formation.

Table 2.5-2

RECORDS OF WELLS IN THE VICINITY OF THE WIPP FACILITY

Location Number	Water Level: Altitude Above Mean Sea Level, ft**	Depth of Well ft***	Diameter of Well Casing, in.	Depth Below Land Surface, ft.	Date of Measurement	Geologic Source****	Power, Use, and Remarks
6.444	3310	--	6.0	106.35	09-20-72	Pdl	Windmill; domestic.
7.240a	3315	--	6.0	62.27	09-20-72	Pdl	Windmill; stock.
17.310	3305	--	--	--	09-20-72	Pdl,Pru	Windmill; stock.
26.340	3451	--	6.0	250.47	09-20-72	Pdl	Windmill; stock.
29.113	3335	--	4.0	139.90	09-20-72	Pdl	Windmill; stock.
23.32. 3.311	3660	550R	8.0	--	09-13-72	Trd	Windmill; stock.
3.311a	3660	--	10.0	204.18	09-13-72	Trd	Unused.
21.241a	3680	515	--	480.75	09-21-72	Trd	Windmill; stock.
		550	6.0	510.00R	04-13-59	Trd	
23.33.12.312	3530	388	12.0	351.45	09-21-72	Trd	Windmill; stock; "Allred Well."
17.423	3702	650(?)	8.0	504.40	09-21-72	Trd(?),Trd	Submersible; stock; "Graham Wells."
26.421	3645	173	6.0	165.15	09-21-72	Trd	Windmill; stock; "Tip Top Wells."
26.421a	3645	189	6.0	P184.00	09-21-72	Trd	Windmill; stock; "Tip Top Wells."
28.334	3675	544(?)	--	500.00R	11-27-53	Trd(?),Trd	Windmill; stock & domestic; at Brinninstool Ranch, 2 wells at this location, tape will not pass 220 ft in either well.

**From topographic maps.

***All depths of wells were obtained in 1972; all depths to water in the wells measured in 1972 or before are listed; R, reported depth; P, pumping level;, less than.

****Geologic Source: QTs, surficial deposits; Trsr, Santa Rosa Sandstone; Pdl, Dewey Lake Redbeds; Pru, Rustler Formation above Culebra Dolomite; including Magenta Dolomite members; Prc, Culebra Dolomite member of Rustler Formation.

Table 2.5-3

SUMMARY OF HYDROLOGIC WORK AND TESTING

(1981-1986)

Hydropad/ Well	Work or Testing Completed	Dates	Aquifer Zones*	Reference
H-02	H-02c, Tracer test	07-07-80 - 04-07-81	C	28
	H-02b2, Pump test	11-08-83 - 11-21-83	C	29
	H-02, Slug test	08-28-84 - 09-04-84	C	29
	H-02a, H-02b1, H-02b2, H-02c slug test	08-28-84 - 09-07-84	M, C, R/S	29
	H-02a, Water Quality Sampling	04-04-86 - 04-21-86	C	6
	Borehole deviation survey	06-26-86 - 07-08-86	NA	30
H-03	H-03b3, Tracer test	04-18-84 - 06-12-84	C	5
	H-03b3, Water Quality Sampling	01-29-85 - 02-04-85	C	6,29
	H-03b1, Water Quality Sampling	06-17-85 - 07-02-85	M	6,29
	H-03b2, Step-drawdown test	06-20-85 - 07-08-85	C	29
	H-03b2, Multipad pump test	10-15-85 - 12-16-85	C	5
	H-03b3, Water Quality Sampling	04-25-86 - 05-05-86	C	30
	Borehole deviation survey	06-26-86 - 07-08-86	NA	30
	H-03b1, Water Quality Sampling	09-05-86 - 09-16-86	M	30
H-04	Interference pump tests	05-21-81 - 10-02-81	C	28
	H-04c, Convergent-flow tracer test	09-30-82 - 10-15-84	C	29
	H-04b, Water Quality Sampling	07-08-85 - 07-25-85	C	6,29
	H-04c, Acid treatment, swabbing, and slug test	07-16-86 - 08-05-86	C	t,30
	H-04c, Installed bridge plug, perforate Magenta	08-21-86	M	30
	H-04c, Water Quality Sampling	10-29-86 - 11-04-86	M	30
	H-04b, Water Quality Sampling	11-06-86 - 11-13-86	C	**
H-05	Interference pump tests	05-27-81 - 11-11-81	C	28
	H-05b, Water Quality Sampling	08-01-85 - 09-03-85	C	6,29
	H-05b, Water Quality Sampling	05-09-86 - 05-21-86	C	**
	H-05c, Installed bridge plug, perforate Magenta	08-21-86 - 08-22-86	M	30
	H-05c, Water Quality Sampling	10-02-86 - 10-24-86	M	**
H-06	Interference pump tests	05-01-81 - 06-05-81	C	28
	H-06c, Convergent-flow tracer test	08-19-81 - 09-11-81	C	28
	H-06c, Convergent-flow tracer test	09-30-82 - 10-15-82	C	28
	H-06c, Convergent-flow tracer test	10-24-82 - 11-29-82	C	28
	H-06b, Two-well recirculating tracer test	04-15-83 - 05-14-83	C	28
	H-06b, Two-well recirculating tracer test	06-17-83 - 07-26-83	C	28
	H-06b, Water Quality Sampling	09-04-85 - 09-16-85	C	6,29
	H-06b, Water Quality Sampling	07-11-86 - 07-28-86	C	30
	H-06c, Installed bridge plug, perforate Magenta	08-22-86	M	30
	H-06c, Water Quality Sampling	09-18-86 - 10-01-86	M	30

Table 2.5-3 Page 2 of 4

SUMMARY OF HYDROLOGIC WORK AND TESTING

(1981-1986)

Hydropad/ Well	Work or Testing Completed	Dates	Aquifer Zones*	Reference
H-07	H-07b, Pump test	02-18-86 - 02-24-86	C	5
	H-07b, Water Quality Sampling	03-20-86 - 03-27-86	C	6
H-08	H-08a, Water Quality Sampling	10-10-85 - 10-21-85	M	6,29
	H-08b, Pump test	12-06-85 - 12-18-85	C	5
	H-08b, Water Quality Sampling	01-09-86 - 01-23-86	C	6
H-09	H-09b and H-09c pump tests	08-11-83 - 12-21-83	C	29
	H-09b, Water Quality Sampling	10-30-85 - 11-14-85	C	6,29
H-11	H-11, Slug test	09-16-84 - 09-18-84	C	29
	H-11b2, Well development	10-01-84	C	30
	H-11b3, Well development	10-02-84 - 10-08-84	C	30
	H-11b1, Well development	10-09-84 - 10-11-84	C	30
	H-11b1, Well development	10-10-84 - 10-11-84	C	30
	H-11b3, Pump test, Water Quality Sampling	05-13-85 - 06-04-85	C	6,29
	H-11b3, Water Quality Sampling	05-28-86 - 06-24-86	C	29
H-12	Pump test	01-07-84 - 01-12-84	C	29
	Water Quality Sampling	08-03-85 - 08-09-85	C	6,29
H-14	Drill stem test	10-21-86 - 10-22-86	C	+
H-15	Drill stem test	11-11-86 - 11-13-86	C	+
DOE-1	Pumping interference test	05-06-83 - 06-11-83	C	28
	Water Quality Sampling	04-12-85 - 04-25-85	C	6,29
	Water Quality Sampling	06-20-86 - 07-13-86	C	30
DOE-2	Drill stem tests	09-14-84 - 10-15-84	D, M, C, R/S	5
	Pump test, Water Quality Sampling	02-18-85 - 03-12-85	C	6,29
	Drill stem tests (Salado, Bell Canyon)	05-18-85 - 07-13-85	NA	5
	Reset packer and perforate Culebra	04-01-86 - 04-02-86	C	5,30
	Well development	04-16-86 - 04-24-86	C	30
	Acid treatment	05-27-86	C	30
	Well development	06-13-86	C	30
	100-hour pump test	06-30-86 - 07-04-86	C	30
	Water Quality Sampling	08-12-86 - 08-27-86	C	30
P-14	Water Quality Sampling	02-18-86 - 02-27-86	C	6
P-17	Well development and cleaning	06-11-85 - 07-12-85	C	29
	Water Quality Sampling	03-04-86 - 03-17-86	C	6
	Water Quality Sampling	12-03-86 - 12-18-86	C	**
	Slug Test	11-20-86	C	+

Table 2.5-3

SUMMARY OF HYDROLOGIC WORK AND TESTING

(1981-1986)

Hydropad/ Well	Work or Testing Completed	Dates	Aquifer Zones*	Reference
WIPP-12	Well perforations	10-14-85	C	30
	Step-drawdown pump test	05-01-86	C	30
	Acid treatment	05-21-86	C	30
WIPP-13	Well perforations	10-26-85	C	30
	Well development	04-04-86 - 04-14-86	C	30
	Acid treatment	06-12-86	C	30
	50-hour pumping test	08-04-86 - 08-09-86	C	30
WIPP-18	Reaming, casing, and perforations	10-03-85 - 10-11-85	C	30
	Well development pumping	05-10-86 - 05-14-86	C	30
	Slug test	05-20-86	C	30
	Bailed 500 gallons	08-27-86	C	30
WIPP-19	Reaming, casing, and perforations	09-28-85 - 10-09-85	C	30
	Well development pumping	05-29-86	C	30
	Slug test	06-01-86 - 06-04-86	C	30
	Bailed 500 gallons	08-22-86	C	30
WIPP-21	Reaming, casing, and perforations	09-18-85 - 10-06-85	C	30
	Well development pumping	06-28-86 - 07-01-86	C	30
	Slug test	07-11-86	C	30
	Bailed 300 gallons	08-24-86	C	30
	Bailed 500 gallons	08-27-86	C	30
WIPP-22	Reaming, casing, and perforations	09-23-85 - 10-08-85	C	30
	Well development pumping	06-12-86 - 06-17-86	C	30
	Slug test	06-19-86	C	30
	Bailed 500 gallons	08-26-86	C	30
WIPP-25	Water Quality Sampling	02-05-86 - 02-13-86	C	6
WIPP-26	Water Quality Sampling	11-15-85 - 11-25-85	C	6,29
WIPP-29	Water Quality Sampling	11-26-85 - 12-15-85	C	6
Cabin Baby-1	Well development	10-10-86 - 10-20-86	C	+
Engle	Well development	06-11-85 - 07-12-85	C	29
	Pump test	11-04-83 - 11-11-83	C	+
	Water Quality Sampling	02-25-85 - 03-05-85	C	+,6
ERDA-9	Well development	10-01-86 - 11-26-86	C	+
	Slug test	11-24-86	C	+
Ranch	Water Quality Sampling	06-12-86 - 06-18-86	D	**

Table 2.5-3

SUMMARY OF HYDROLOGIC WORK AND TESTING

(1981-1986)

Hydropad/ Well	Work or Testing Completed	Dates	Aquifer Zones*	Reference
Twin Wells	Water Quality Sampling	01-24-86 - 02-02-86	D	6

* D = Dewey Lake, M = Magenta Dolomite, C = Culebra Dolomite, R/S = Rustler/Salado Contact

** Reference: D. W. Uhland and W. S. Randall, "1987 Annual Water Quality Data Report for the Waste Isolation Pilot Plant," DOE-WIPP 87-006 (1987).

+ R. L. Beauheim, "Interpretations of Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987," Sandia National Laboratories Report, No. SAND87-0039 (1987).

Table 2.5-4

PACKER PERMEABILITY TESTS IN SHALLOW BORINGS

Hole No.	Ground Surface Elev. ft	Depth Interval Tested, ft	Formation Tested	Hydraulic Conductivity, ft/d*
B-1	3412.2	29.0 - 58.2	Gatuna/Dockum Group	1.2
		39.0 - 58.2	Dockum Group	0.2
B-3	3415.3	25.0 - 29.0	Gatuna	0
B-5	3917.0	23.0 - 32.3	Gatuna	1.2
B-6	3422.0	16.0 - 26.3	Gatuna	0
B-8	3408.6	16.0 - 50.0	Gatuna/Dockum Group/Dewey Lake	0.3
		31.0 - 50.0	Gatuna/Dockum Group/Dewey Lake	0.5
		34.5 - 39.5	Gatuna/Dockum Group	0.9
		36.0 - 50.0	Dockum Group/Dewey Lake	0.8
		41.0 - 50.0	Dewey Lake	0
B-9	3410.5	31.9 - 38.3	Gatuna	1.3
B-10	3413.0	20.1 - 32.0	Gatuna	0.8
		25.8 - 32.0	Gatuna	1.5
B-11	3414.3	19.9 - 30.0	Gatuna	5.0
B-13	3403.9	23.0 - 28.3	Gatuna	0.5
B-14	3406.6	18.0 - 24.5	Gatuna	0.7
B-18	3419.2	24.7 - 32.3	Gatuna	0.2
B-20A	3403.5	18.0 - 34.2	Gatuna	0.6
		25.5 - 34.2	Gatuna	0.9
B-22	3406.9	13.0 - 27.8	Gatuna	1.7
		15.0 - 27.8	Gatuna	0.8
		19.5 - 27.8	Gatuna	0.6
B-24	3417.9	16.5 - 29.3	Gatuna	1.1
		20.5 - 29.3	Gatuna	0.8
B-27	3400.2	18.5 - 25.8	Gatuna	1.5
B-35	3402.6	19.0 - 32.0	Gatuna	2.2
		24.5 - 32.0	Gatuna	0.4
B-36	3422.0	22.0 - 27.8	Gatuna	2.1
B-37	3438.9	19.5 - 27.5	Gatuna	0.7
		22.0 - 27.5	Gatuna	1.2
B-38	3429.9	18.2 - 23.2	Gatuna	0.3
		20.0 - 35.0	Gatuna	0.4
		35.0 - 40.0	Gatuna	0.3
		40.0 - 45.0	Dockum Group/Dewey Lake	0.1
		45.0 - 50.0	Dewey Lake	0
B-39	3422.1	18.5 - 27.6	Gatuna	0.7
B-40	3438.5	18.5 - 27.9	Gatuna	1.3
B-52	3385.5	15.0 - 20.0	Gatuna/Dewey Lake	0
		21.5 - 30.0	Dewey Lake	0.7
B-53	3386.7	23.2 - 30.2	Gatuna/Dewey Lake	0.5

*Zero values indicate no measurable water inflow; test method not effective for conductivities less than 0.003 ft/d.
Reference: J. K. Register, "Subsurface Hydrology of Strata Overlying the Salado Formation at the Waste Isolation Pilot Plant Plant Site, Eddy County, New Mexico," TME-3059, Waste Isolation Pilot Plant, Carlsbad, NM (1980)

Table 2.5-5

WELL PERMEAMETER TESTS IN SURFICIAL SANDS

Test No.	WIPP Site Coordinates North	East	Ground Surface Elevation, ft	Depth Interval Tested, ft	Hydraulic Conductivity, ft/d
E-19-1	499255	666665	3408	0.5 - 3.0	6.8
E-19-2	498895	666765	3406	0.5 - 2.5	12.9
E-19-3	498245	668170	3410	0.5 - 3.0	3.2
E-19-4	499154	669349	3425	0.5 - 3.0	4.8
E-19-5	499155	669683	3430	0.5 - 3.0	9.2
E-19-6	499157	670017	3436	0.5 - 3.0	17.7
E-19-7	496661	665463	3386	0.5 - 3.0	12.2

Reference: Bechtel National, Inc., "Waste Isolation Pilot Plant Title I Design Report," Volume IX-A, Calculations, Calculation Numbers CS-22-V-005 and CS-22-V-006, 1980.

Table 2.5-6

DOE-2 HYDRAULIC TEST RESULTS

Zone	Depth (ft)	Test	kh (md-ft)	k (md)	T (ft^2/day)	K (ft/day)	S	s	h_{ext} (ft msl)
Dewey Lake	539-641	Constant-Head	--	--	--	--	--	--	--
Forty-Niner	664-686	FBU	1.1	4.9×10^{-2}	2.5×10^{-3}	1.1×10^{-4}	--	--	<3187
		Slug	4.5	0.21	1.1×10^{-2}	4.8×10^{-4}	--	--	--
Magenta	700-722	FBU	0.6	0.03	1×10^{-3}	7×10^{-5}	--	--	<3178
Tamarisk	796-817	FBU	--	--	--	--	--	--	--
Culebra(I)	824-846	Slug	--	--	--	--	--	--	3034
Culebra(Ia)		Pumping							
DOE-2	824-846	Recovery	>8500	>380	>22	>1.0	--	31	3045
H-6b	604-627	DD & Rec	21 500	930	61	2.7	6×10^{-6}	--	--
Culebra (1986)		Pumping							
DOE-2	824-846	DD & Rec	31 100	1410	89	4.0	--	-4.7	3045
H-6b	604-627	DD & Rec	21 500	930	61	2.7	6×10^{-6}	--	--
WIPP-13	701-724	DD & Rec	25 200	1100	72	3.1	3×10^{-6}	--	--
Rustler-Salado	945-967	Slug	--	--	--	--	--	--	--
MB 138-139	2195-2309	FBU	$< 3 \times 10^{-2}$	$< 3 \times 10^{-4}$	$< 6 \times 10^{-5}$	$< 6 \times 10^{-7}$	--	--	2160
Salado	1040-3095	Pulse	--	--	--	--	--	--	--
Ramsey	4138-4180*	FBU	2.4	8.4×10^{-2}	5.4×10^{-3}	1.9×10^{-4}	--	1.2	--
		SBU	2.5	8.8×10^{-2}	5.7×10^{-3}	2.0×10^{-4}	--	1.0	<3092
		Slug	2.6	9.4×10^{-2}	6.0×10^{-3}	2.1×10^{-4}	--	--	--
Olds	4177-4218#	FBU	3.1	0.10	7.0×10^{-3}	2.3×10^{-4}	--	2.0	--
		SBU	2.9	9.8×10^{-2}	6.6×10^{-3}	2.2×10^{-4}	--	2.0	<3111
		Slug	3.3	0.11	7.6×10^{-3}	2.5×10^{-4}	--	--	--
Hays	4220-4325+	FBU	240	2.4	0.56	5.6×10^{-3}	--	0.8	--
		SBU	230	2.3	0.53	5.3×10^{-3}	--	0.6	<3077
		Slug	240	2.4	0.55	5.5×10^{-3}	--	--	--

* Effective thickness 4144-4172 ft
# Effective thickness 4187-4217 ft
+ Effective thickness 4255-4325 ft
Reference: Beauheim, 1986, Table 7-2.

Table 2.5-7

SUMMARY OF CABIN BABY-1 DST RESULTS

Test	Depth Interval (ft)	Unit Name	Analytical Method	k (md)	K (ft/day)	P_{ext} (psia)[2]	Remarks
DST-4178/FBU	4178.0-4298.6	Hays	Horner	0.57	1.3×10^{-3}	1894[3]	
/SFL			Slug	1.7	3.9×10^{-3}	NA	
/SBU			Horner	0.71	1.7×10^{-3}	1891[3]	
/SLUG			Slug	0.94	2.2×10^{-3}	NA	
DST-4138/FBU	4138.5-4170.9	Olds	Horner	2.2×10^{-2}	4.5×10^{-5}	1945[4]	
/SFL			Slug	6.7×10^{-2}	1.4×10^{-4}	NA	
/SBU			Horner	3.5×10^{-2}	7.2×10^{-5}	1921[4]	
/SLUG			Slug	8.2×10^{-2}	1.7×10^{-4}	NA	
DST-4100/FBU	4100.5-4132.9	Ramsey	Horner	2.3×10^{-2}	4.7×10^{-5}	1927[5]	
/SFL			Slug	8.2×10^{-2}	1.7×10^{-4}	NA	
/SBU			Horner	2.9×10^{-2}	6.0×10^{-5}	1903[5]	
/SLUG			Slug	8.7×10^{-2}	1.8×10^{-4}	NA	
DST-4044/FBU	4044.2-4097.4	Lamar	Horner	6.0×10^{-4}	1.0×10^{-6}	1897[6]	
DST-765/SBU	765.0-2725.4	Salado	Horner	9.0×10^{-6}	2.0×10^{-8}	402[7]	maximum k
/SLUG			Slug	8.0×10^{-5}	2.0×10^{-7}	NA	poor data fit to type curve

(1)All depths are relative to kelly bushing.

(2)psig = psia - 10.6 psi

(3)Pressures measured at depth 4165.4 feet

(4)Pressures measured at depth 4125.9 feet

(5)Pressures measured at depth 4087.9 feet

(6)Pressures measured at depth 4031.6 feet

(7)Pressures measured at depth 752.4 feet

Reference: Beauheim et al., Table 6, 1983.

Table 2.5-8

AQUIFER CHARACTERISTICS OF THE GUADALUPIAN HYDROLOGIC SYSTEM

Rock Core Analysis Data for Eddy and Lea Counties, New Mexico and Winkler and Ward Counties, Texas

Geologic Unit	Average Hydraulic Conductivity, ft/day	Average Porosity, %	No. of Samples Analyzed Conductivity	Porosity
Tansill Formation	0.006	4.23	399	381
Yates Formation	0.026	9.74	11,287	11,387
Seven Rivers Formation	0.140	6.56	4,367	4,485
Queen Formation	0.029	7.79	7,324	7,648
Grayburg Formation	0.032	7.15	1,971	1,973
Grayburg-San Andres (Und.)	0.033	5.76	7,062	7,313
Glorietta Sandstone	0.027	9.16	3,128	3,115
Delaware Mt. Group	0.016	15.65	4,549	4,493

Reference: W. L. Hiss, Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas, Ph D Dissertation, University of Colorado,

Hydrology, Table 6, p. 158 (1975).

Pumping Tests

Geologic Unit	Location	Average Hydraulic Conductivity, ft/day	Type of Test
San Andres	T.20S, R.38E, Sec. 7	0.20	(Drawdown test)
San Andres	T.20S, R.38E, Sec. 7	0.20	(Recovery test)
San Andres	T.22S, R.37E, Sec. 29	0.30	(Drawdown test)
Capitan	T.21S, R.27E, Sec. 5	2.4	(Recovery test)
Capitan	T.21S, R.28E, Sec. 30	16.0	(Recovery test)
Capitan	T.21S, R.35E, Sec. 24	3.0	(Specific capacity)
Capitan	T.21S, R.35E, Sec. 14	1.7	(Specific capacity)
Capitan	T.21S, R.35E, Sec. 14	3.5	(Drawdown test)
Capitan	T.21S, R.35E, Sec. 14	1.9	(Drawdown test)
Capitan	T.21S, R.34E, Sec. 14	1.4	(Recovery test)
Capitan	T.24S, R.36E, Sec. 4	24.0	(Drawdown test)
Capitan	T.24S, R.36E, Sec. 4	25.0	(Specific capacity)
Capitan	T.24S, R.36E, Sec. 16	4.4	(Specific capacity)

Reference: W. L. Hiss, Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas, Ph D Dissertation, University of Colorado,

Hydrology, Table 7, p. 160-162 (1975).

Table 2.5-9

HYDRAULIC CONDUCTIVITY, STATIC BOTTOM HOLE PRESSURE, AND FLUID DENSITY, UPPER BELL CANYON FORMATION

Test Hole	Date of Test	Tested Interval (feet below ground level)	Hydraulic Conductivity (ft/day)	Static Bottom Hole Pressure (extrapolated, psig)	Fluid Density (gm/cc)
AEC-7	04-27-79	4597-4702 (Ramsey)	4×10^{-2}	1,883	1.130
	04-28-79	4481-4702 (Upper Bell Canyon)	4×10^{-2}	1,811	1.130
AEC-8	08-15-77	4832-4848 (Pre-Ramsey lower sand)	2×10^{-2}	2,037	1.147
	09-27-77	4809-4815 (Pre-Ramsey upper sand)	7×10^{-3}	2,044	1.060
	07-24-76	4292-4393 (Lamar)	2×10^{-6}	1,813	--
ERDA-10	09-19-77	3847-3914 (Lamar)	4×10^{-4}	1,783	--
	09-29-77 09-30-77	4127-4430 (Ramsey)	5×10^{-2}	1,820	1.165

Reference: J. W. Mercer, Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico, U.S. Geological Survey, Water-Resources Investigation Report 83:4016, Table 4, p. 102 (1983).

Table 2.5-10

TRANSMISSIVITY OF THE CULEBRA DOLOMITE

Observation Well	$[m^2/s]$	Log $[m^2/s]$
H-01	7.5×10^{-8}	-7.125
H-02	6.0×10^{-7}	-6.222
H-03	4.0×10^{-6}	-5.398
H-04a	1.4×10^{-6}	-5.854
H-04b	1.0×10^{-6}	-6.000
H-04c	1.1×10^{-6}	-5.959
H-05a	1.8×10^{-7}	-6.745
H-05b	2.1×10^{-7}	-6.678
H-05c	1.1×10^{-7}	-6.959
H-06a	7.8×10^{-5}	-4.108
H-06b	8.1×10^{-5}	-4.092
H-06c	7.8×10^{-5}	-4.108
H-07b	1.2×10^{-3}	-2.921
H-08b	7.2×10^{-6}	-5.143
H-09b	1.8×10^{-4}	-3.745
H-10b	7.5×10^{-8}	-7.125
H-11b3	1.1×10^{-5}	-4.959
H-12	4.5×10^{-8}	-7.347
DOE-1	3.6×10^{-5}	-4.444
DOE-2	3.9×10^{-5}	-4.409
P-14	2.5×10^{-4}	-3.602
P-15	8.9×10^{-8}	-7.051
P-17	1.8×10^{-6}	-5.745
P-18	2.1×10^{-9}	-8.678
WIPP-25	2.9×10^{-4}	-3.538
WIPP-26	1.3×10^{-3}	-2.886
WIPP-27	7.0×10^{-4}	-3.155
WIPP-28	1.9×10^{-5}	-4.721
WIPP-29	1.1×10^{-3}	-2.959
WIPP-30	3.2×10^{-7}	-6.495

Reference: Haug et al., "Modeling of Groundwater Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site in Southeastern New Mexico: Interim Report," Sandia National Laboratories Report No. SAND86-7167, Table 3.5, pp. 69-70 (1986).

Table 2.5-11

CHEMICAL QUALITY DATA

(reported in milligrams per liter, except as noted)

Monitor Well;	Date of Sample	pH (Units)	Hardness (As $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicar-bonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
<u>Magenta Dolomite</u>										
H-1	76-06-04	7.4	3300	890	270	5700	70	92	0	3900
H-2A	77-02-22	8.6	2700	820	170	2700	81	74	0	2400
H-3	77-05-10	8.0	5000	1200	480	9300	250	51	0	3400
H-4A	78-12-14	8.0	2200	210	410	7000	130	63	--	7000
H-5A	78-12-14	7.8	1300	240	170	1500	53	50	--	3200
H-6A	78-12-20	7.3	2000	520	160	1100	46	51	--	2700
H-8A	80-02-12	9.3	2200	870	17	2400	84	--	--	2100
H-9A	80-02-05	8.5	2100	550	170	800	28	--	--	2700
H-10A	80-03-21	7.1	17000	2500	2600	93000	510	--	--	2700
WIPP-25	80-09-04	7.5	3300	910	240	3100	0.8	--	--	1900
WIPP-27	80-07-24	6.8	11000	1100	1900	34000	1800	--	--	9400
	80-09-20	6.5	17000	3600	2000	43000	10000	--	--	2900
WIPP-30	80-09-24	8.8	2400	690	170	5500	190	--	--	3200
<u>Culebra Dolomite</u>										
H-1	76-06-02	7.6	3100	780	280	9400	190	105	0	7400
H-2B	77-02-22	8.4	2400	690	160	2100	91	59	5	3000
H-3	77-03-17	7.4	6500	1500	670	19000	630	115	0	5700
H-4B	78-12-14	7.6	2200	180	430	5800	180	59	--	4000
H-5B	78-12-19	6.8	8700	360	1900	53000	1400	41	--	810

Reference: Mercer, J. W., <u>The Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico,</u> U. S. Geological Survey Water Resources Investigations Report 83-4016, Table 2, p. 99 (1983).

Table 2.5-11

CHEMICAL QUALITY DATA

(reported in milligrams per liter, except as noted)

Monitor Well;	Date of Sample	pH (Units)	Hardness (As $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicar- bonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
H-6B	78-12-20	7.3	7000	1200	970	18000	500	--	--	3800
H-7B	80-03-20	7.0	2000	590	130	210	1.4	--	--	1900
H-8B	80-02-11	7.3	2100	570	170	82	4.7	--	--	2000
H-9B	80-02-05	7.3	2100	580	150	210	1400	--	--	2000
H-10B	80-03-21	8.3	8100	1600	1000	21000	520	--	--	5600
P-14	77-03-14	6.0	11000	3100	760	7600	600	357	0	1400
P-15	77-05-10	--	2200	770	63	6900	1700	63	24	3200
P-17	77-05-10	7.4	11000	1700	1600	30000	120	77	0	5000
P-18	77-05-10	7.2	80000	5600	16000	9200	6200	310	0	980
WIPP-25	80-08-14	7.3	3300	920	250	5100	0.9	--	--	2400
WIPP-26	80-08-18	6.9	4400	1200	340	3600	2	--	--	2300
WIPP-27	80-08-22	6.4	16000	3100	2000	39000	714	--	--	3900
WIPP-28	80-08-21	6.4	4900	1200	470	21000	4	--	--	3200
WIPP-29	80-08-20	6.1	26000	810	5700	79000	150	--	--	13000
WIPP-30	80-08-13	6.8	6300	1100	870	37000	888	--	--	5050
Rustler/Salado Contact										
H-1	77-02-23	7.9	160000	13000	30000	56000	17000	675	0	520
H-2C	77-02-23	5.9	130000	9200	25000	66000	9100	199	0	1300
H-3	77-02-23	7.6	150000	18000	25000	59000	14000	467	0	370
H-4C	79-03-16	--	130000	8300	27000	66000	8600	1	0	1400
H-5C	79-05-16	--	340000	2100	82000	14000	21000	300	--	2000
H-6C	79-04-09	--	97000	4200	21000	80000	8000	--	--	2000
H-7C	80-03-20	6.8	10000	2600	910	22000	210	--	--	2900
H-8C	80-09-06	7.6	4800	1200	430	46000	660	--	--	5300

Table 2.5-11

CHEMICAL QUALITY DATA

(reported in milligrams per liter, except as noted)

Monitor Well;	Date of Sample	pH (Units)	Hardness (As $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicar-bonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
H-9C	80-05-20	7.0	6800	1300	870	130000	1200	--	--	2600
H-10C	80-05-19	6.3	49000	1500	11000	100000	4000	--	--	3300
P-14	77-02-24	7.2	6400	570	1200	120000	1300	222	0	10000
P-15	79-04-03	--	3400	770	350	24000	1400	--	--	2800
P-17	79-05-11	--	200000	15000	40000	23000	8800	--	--	1200
P-18	79-05-11	5.4	--	10000	37000	48000	12000	--	--	480
WIPP-25	80-03-19	7.2	15000	650	3200	90000	2400	--	--	12000
WIPP-26	80-03-18	8.5	12000	2700	1300	52000	1000	--	--	7600
WIPP-27	80-05-21	7.8	--	1160	1040	102000	2570	--	--	5190
WIPP-28	80-03-20	7.0	--	615	2070	65000	2070	--	--	11000
WIPP-29	80-03-18	7.3	10000	850	2000	32000	1000	--	--	12000
WIPP-30	80-03-19	7.0	12000	850	2300	120000	1500	--	--	7000

Monitor Well	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Solids, Residue at 105°C	Nitrite + Nitrate (N)	Sulfide (S)	Boron (B), ug/l
<u>Magenta Dolomite</u>							
H-1	8000	2.8	1.3	18900	--	0.0	2200
H-2A	4100	--	6.0	12000	0.04	--	220
H-3	15000	1.8	6.4	32000	0.08	--	13000
H-4A	7500	2.5	6.4	22300	0.01	--	13000
H-5A	880	2.8	9.0	--	0.01	--	11000
H-6A	1200	1.4	7.7	--	0.03	--	2500
H-8A	3500	0.7	0.9	9410	0.06	--	3100
H-9A	750	1.8	3.3	5460	0.02	--	2600

Table 2.5-11

CHEMICAL QUALITY DATA

(reported in milligrams per liter, except as noted)

Monitor Well	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Solids, Residue at 105° C	Nitrite + Nitrate (N)	Sulfide (S)	Boron (B),ug/l
H-10A	160000	1.3	1.9	270000	0.03	--	3900
WIPP-25	5600	1.5	25.0	18700	0.64	1.2	1900
WIPP-27	61000	0.0	1.7	106000	0.32	--	26000
	85000	0.4	13.0	173000	0.40	1.8	230
WIPP-30	8700	1.9	0.7	19000	0.00	0.0	12000
<u>Culebra Dolomite</u>							
H-1	12000	5.1	2.7	30100	--	0.0	2400
H-2B	2800	2.0	1.7	9700	0.01	--	9500
H-3	29600	0.5	1.2	62000	0.07	--	20000
H-4B	7500	1.9	5.2	18100	0.02	--	19000
H-5B	86000	1.4	2.1	144000	0.01	--	36000
H-6B	28000	1.5	8.5	52600	0.02	--	9500
H-7B	350	1.4	39.0	3610	0.40	--	780
H-8B	57	2.4	19.0	3200	0.95	--	580
H-9B	320	3.0	26.0	3590	0.13	--	780
H-10B	36000	1.3	1.5	69200	0.01	--	13000
P-14	20000	0.9	33.0	38000	0.01	--	700
P-15	11000	1.2	1.6	24000	0.04	--	4700
P-17	54000	1.5	1.0	97000	0.06	--	1700
P-18	80000	1.2	1.0	420000	0.81	--	100000
WIPP-25	8300	1.4	29.0	22100	0.67	0.8	1900
WIPP-26	8200	1.5	20.0	23800	3.50	0.0	1800
WIPP-27	77000	0.5	13.0	186000	4.00	0.0	1900
WIPP-28	30000	1.1	28.0	74000	0.09	10.0	5400

Table 2.5-11
CHEMICAL QUALITY DATA

(reported in milligrams per liter, except as noted)

Monitor Well	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Solids, Residue at 105° C	Nitrite + Nitrate (N)	Sulfide (S)	Boron (B),ug/l
WIPP-29	140000	0.7	11.0	239000	0.02	0.0	45000
WIPP-30	64000	0.5	2.9	110000	1.20	0.0	64000
Rustler/Salado Contact							
H-1	210000	--	< 0.1	480000	0.29	--	110000
H-2C	200000	--	2.0	450000	1.10	--	150000
H-3	210000	--	1.0	327000	0.77	--	1900
H-4C	210000	1.7	1.3	322000	0.27	--	360000
H-5C	290000	< 0.1	1.6	412000	--	--	67000
H-6C	200000	1.0	1.4	316000	--	--	200000
H-7C	41000	0.8	7.2	79800	0.03	--	3100
H-8C	70000	0.4	0.8	130000	0.00	0.6	1300
H-9C	190000	0.1	3.8	326000	1.10	--	19000
H-10C	190000	0.7	3.2	323000	0.84	--	120000
P-14	180000	--	2.0	350000	0.34	--	1700
P-15	38000	1.3	1.3	--	--	--	3700
P-17	180000	3.8	15.0	--	0.04	--	880
P-18	220000	2.3	0.4	--	0.06	0.0	160000
WIPP-25	130000	0.0	2.6	252000	0.04	--	35000
WIPP-26	88000	0.0	2.5	153000	0.05	--	30000
WIPP-27	154000	0.2	0.1	363000	--	--	1300
WIPP-28	102000	0.2	6.0	--	--	--	54000
WIPP-29	49000	0.9	3.5	129000	0.23	--	21000
WIPP-30	170000	0.0	3.5	302000	0.04	--	77000

Table 2.5-11

MAJOR ANIONS AND CATIONS IN WATER FROM TEST HOLES COMPLETED IN THE UPPER PART OF THE BELL CANYON FORMATION

(Concentration in milligrams per liter)

Test Hole	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Chloride (Cl)	Sulfate (SO_4)
AEC-7	9700	2600	55000	970	110000	1800
AEC-8	10000	2500	55000	860	120000	240
ERDA-10	5300	1300	89000	720	150000	2400

Table 2.5-12

CHEMICAL COMPOSITION OF FLUIDS BELL CANYON FORMATION - CABIN BABY-1

Sample	Units	Hays Sandstone DST-4178[1] SWAB #34[2]	Olds Sandstone DST-4138[3] SWAB #4[4]	Upper Bell Canyon PIP-4041[5] SWAB #24[6]	Upper Bell Canyon PIP-4041[5] SWAB #26[7]	PIP-4039[8] SWAB #5[9]
FIELD DETERMINATIONS:						
Temperature	°C	32[10]	24[11]	--	22	--
pH	Standard Units	6.5-7.0	6.5	--	6-7	--
Specific Conductance	µmhos/cm |25°3C	--	320,000	--	370,000	--
Thiocyanate[12]	mg/l	2.2	16	1.4	1.9	--
LABORATORY DETERMINATIONS:						
pH	Standard Units	7.00	7.35	--	6.62	--
Specific Conductance	µmhos/cm @25°C	320,000	430,000	360,000	330,000	610,000
Specific Gravity	--	1.120/1.134	1.160/1.177	1.117	1.128	1.255
Total Dissolved Solids[13]	mg/l	191,000	263,000	--	188,000	--
Total Suspended Solids[14]	mg/l	1,330	13,500	--	12,600	--
Viscosity	cp	1.300	1.538	1.457	1.498	2.673
Cations:						
Barium	mg/l	127	137	--	137	--
Calcium	mg/l	11,400	2,300	--	9,300	--
Cesium	mg/l	<2	<2	--	2	--
Lithium	mg/l	21	12	--	22	--
Magnesium	mg/l	2,300	3,400	--	2,300	--
Potassium	mg/l	1,400	5,300	--	1,500	--
Sodium	mg/l	62,000	98,000	--	60,000	--
Strontium	mg/l	255	33	--	200	--
Anions:						
Bicarbonate	mg/l	94	220	--	148	--
Bromide	mg/l	60	72	--	70	--
Chloride	mg/l	115,000	160,500	--	117,500	--
Fluoride	mg/l	0.3	0.3	--	0.3	--
Iodide	mg/l	2	2	--	2	--
Sulfate	mg/l	1,375	3,925	--	2,525	--
Thiocyanate[12]	mg/l	2.0	17	3.6	4.3	80
Nutrients:						
Ammonia (as Nitrogen)	mg/l	299	159	--	299	--
Nitrate (as Nitrogen)	mg/l	0.15	0.95	--	0.1	--
Phosphate (as Phosphorus)	mg/l	3.5	2.0	--	9.5	--

CHEMICAL COMPOSITION OF FLUIDS BELL CANYON FORMATION - CABIN BABY-1

Sample	Units	Hays Sandstone DST-4178[1] SWAB #34[2]	Olds Sandstone DST-4138[3] SWAB #4[4]	Upper Bell Canyon PIP-4041[5] SWAB #24[6]	PIP-4041[5] SWAB #26[7]	PIP-4039[8] SWAB #5[9]
FIELD DETERMINATIONS:						
Other Elements:[15]						
Aluminum	mg/l	0.28	0.28	--	0.28	--
Boron	mg/l	53	42	--	48	--
Copper	mg/l	0.47	0.49	--	0.27	--
Iron	mg/l	36	3.69	--	41	--
Manganese	mg/l	4.9	4.0	--	5.1	--
Silicon (as SiO_2)	mg/l	5.3	5.9	--	4.9	--
Zinc	mg/l	23	34	--	1.9	--

NOTES:
(1)Test interval 4178.0-4298.6 feet below KB.
(2)Sample collected on 34th swab after≅ 6400 gallons (12 test-interval volumes) removed.
(3)Test interval 4138.5-4170.9 feet below KB.
(4)Sample collected on 4th swab after ≅550gallons (3.7 test-interval volumes) removed.
(5)Test interval 4040.8-4298.6 feet below KB.
(6)Sample collected on 24th swab after ≅4220 gallons (3.6 test-interval volumes) removed.
(7)Sample collected on 26th swab after≅ 4450 gallons (3.8 test-interval volumes) removed.
(8)Test interval 4038.9-4298.6 feet below KB.
(9)Sample represents drilling fluid in borehole.
(10)Downhole temperature averaged 31°C during DST-4178.
(11)Downhole temperature averaged 31°C during DST-4138.
(12)Thiocyanate added as tracer to drilling fluid. Presence of thiocyanate in samples indicates contamination.
(13)Solids, residue on evaporation at 180°C, dissolved, gravimetric.
(14)Solids, residue at 105°C, suspended, gravimetric.
(15)Flow through drill tubing may have contaminated samples with metals.
"--" = Parameter not analyzed.
Reference: Beauheim et al., "Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico," WTSD-TME-020, Table 7 (1983).
* Quantities are approximate

Table 2.5-13

SUMMARY OF CHEMICAL ANALYSIS RESULTS FROM THE FIRST ROUND OF THE WATER QUALITY SAMPLING PROGRAM

Well No.	Zone Monitored	Date	Specific Gravity (Value @ Temperature and Date Taken)	pH (Units)	Calcium (Ca) mg/l	Magnesium (Mg) mg/l
H-03b3	CULEBRA	02/04/85	--	7.6	1500	780
Engle Well	CULEBRA	03/04/85	--	6.5	590	150
DOE-2	CULEBRA	03/12/85	--	7.08	2000	1100
DOE-1	CULEBRA	04/25/85	--	6.94	1700	1600
H-11b3	CULEBRA	06/04/85	1.091 @ 22.6°C (05/23/85)	7.18	1700	1300
H-03b1	MAGENTA	07/01/85	1.006 @ 21.4°C (07/02/85)	7.57	1000	290
H-04b	CULEBRA	07/25/85	1.015 @ 21.1°C (07/25/85)	7.59	690	430
DOE-2	BELL CANYON	07/23/85	--	6.72	5900	1300
H-12	CULEBRA	08/09/85	1.096 @ 24.0°C (08/09/85)	7.33	1900	1400
H-05b	CULEBRA	08/27/85	1.105 @ 21.6°C (08/27/85)	7.04	1300	1700
H-06b	CULEBRA	09/15/85	1.042 @ 23.5°C (09/16/85)	7.19	1900	740
H-09b	CULEBRA	11/14/85	1.003 @ 22.6°C (11/04/85)	7.5	560	140
WIPP-26	CULEBRA	11/15/85	1.012 @ 21.8°C (11/25/85)	7.35	1800	370
WIPP-29	CULEBRA	12/14/85	1.216 @ 20.8°C (12/15/85)	6.57	630	6300
H-08a	MAGENTA	10/21/85	--	--	560	11
H-08b	CULEBRA	01/22/86	1.002 @ 21.8°C (01/22/86)	7.9	540	170
Twin Wells (Pasture)	DEWEY LAKE	01/30/86	0.998 @ 21.6°C (01/31/86)	8	82	24
WIPP-25	CULEBRA	02/12/86	1.010 @ 21.85°C (02/13/86)	7.72	1200	350
P-14	CULEBRA	02/27/86	1.019 @ 21.3°C (02/27/86)	7.01	3900	760
P-17	CULEBRA	03/17/86	1.065 @ 21.22°C (03/17/86)	7.02	1700	1600
H-07b2	CULEBRA	03/27/86	1.001 @ 21.45°C (03/27/86)	7.5	540	130
H-02a	CULEBRA	04/21/86	1.009 @ 21.65°C (04/21/86)	7.83	700	170

Well No.	Zone Monitored	Date	Sodium (Na) mg/l	Potassium (K) mg/l	Chloride (Cl) mg/l	Specific Conductance µmhos/cm @ 25°C
H-03b3	CULEBRA	02/04/85	18000	430	30000	82000
Engle Well	CULEBRA	03/04/85	200	5.6	230	3700
DOE-2	CULEBRA	03/12/85	18000	410	35000	78900
DOE-1	CULEBRA	04/25/85	46000	1100	74000	146000
H-11b3	CULEBRA	06/04/85	40000	940	66000	135000
H-03b1	MAGENTA	07/01/85	1500	34	3400	11900
H-04b	CULEBRA	07/25/85	5900	210	7400	23600
DOE-2	BELL CANYON	07/23/85	50000	880	90000	132000
H-12	CULEBRA	08/09/85	45000	1500	80000	140000
H-05b	CULEBRA	08/27/85	48000	1300	87000	131000

Adapted from: Uhland and Randall, 1986

Table 2.5-13

SUMMARY OF CHEMICAL ANALYSIS RESULTS FROM THE FIRST ROUND OF THE WATER QUALITY SAMPLING PROGRAM

Well No.	Zone Monitored	Date	Sodium (Na) mg/l	Potassium (K) mg/l	Chloride (Cl) mg/l	Specific Conductance μmhos/cm @ 25°C
H-06b	CULEBRA	09/15/85	15000	480	34000	80400
H-09b	CULEBRA	11/14/85	150	7.7	200	3860
WIPP-26	CULEBRA	11/15/85	4200	350	10000	25800
WIPP-29	CULEBRA	12/14/85	89000	23000	180000	330000
H-08a	MAGENTA	10/21/85	1800	57	3000	--
H-08b	CULEBRA	01/22/86	51	3.7	33	3270
Twin Wells (Pasture)	DEWEY LAKE	01/30/86	26	3.7	47	682
WIPP-25	CULEBRA	02/12/86	3400	110	6200	20800
P-14	CULEBRA	02/27/86	3700	44	14000	42300
P-17	CULEBRA	03/17/86	29000	800	51000	120000
H-07b2	CULEBRA	03/27/86	210	7	700	3390
H-02a	CULEBRA	04/21/86	3600	97	5300	18500

Well No.	Zone Monitored	Date	Bicarbonate (HC03) mg/l	Carbonate (CO3) mg/l	Sulfate (SO4) mg/l	Residue Filterable @ 180°C
H-03b3	CULEBRA	02/04/85	--	--	4800	55000
Engle Well	CULEBRA	03/04/85	--	--	2000	3450
DOE-2	CULEBRA	03/12/85	--	--	4000	58000
DOE-1	CULEBRA	04/25/85	--	--	7400	130000
H-11b3	CULEBRA	06/04/85	--	--	7200	122000
H-03b1	MAGENTA	07/01/85	--	--	2300	8800
H-04b	CULEBRA	07/25/85	--	--	5500	20000
DOE-2	BELL CANYON	07/23/85	--	--	2000	160000
H-12	CULEBRA	08/09/85	56	0	5900	143000
H-05b	CULEBRA	08/27/85	47	0	6300	144000
H-06b	CULEBRA	09/15/85	100	0	3000	58000
H-09b	CULEBRA	11/14/85	120	0	1600	3300
WIPP-26	CULEBRA	1[illegible]85	130	0	2000	18000
WIPP-29	CULEBRA	1[illegible]85	170	0	17000	330000
H-08a	MAGENTA	10[illegible]/85	--	--	1700	--
H-08b	CULEBRA	01/22/86	94	0	1700	3100
Twin Wells (Pasture)	DEWEY LAKE	01/30/86	230	0	270	400
WIPP-25	CULEBRA	02/12/86	120	0	2400	14000
P-14	CULEBRA	02/27/86	100	0	1700	26000
P-17	CULEBRA	03/17/86	54	0	6400	88000
H-07b2	CULEBRA	03/27/86	130	0	2300	3400
H-02a	CULEBRA	04/21/86	56	0	3300	13000

Adapted from: Uhland and Randall, 1986

Table 2.5-14 Page 1 of 3

CONFIGURATION OF OBSERVATION - WELL IN THE WIPP FACILITY MONITORING NETWORK

Well	Total Depth of Hole Feet Below Ground Surface	Geologic Unit	Interval From - To Feet Below Ground Surface	Completion Type	Access Available As of 04/01/87
H-01	856	MAG	563 - 589	PERF.	YES
		CUL	676 - 699	PERF.	YES
		R/S	808	PERF.	NO
H-02a	672	CUL	623 - 654	SCREEN	YES
H-02b1	661	MAG	515 - 540	PERF.	YES
		CUL	624 - 642	OPEN	YES
H-02b2	660	CUL	621 - 643	SCREEN	YES
H-02c	795	CUL	624 - 642	PERF.	YES
		R/S	764	OPEN	NO
H-03b1	902	MAG	560 - 584	PERF.	YES
		CUL	670 - 694	PERF.	NO
		R/S	820	PERF.	NO
H-03b2	725	CUL	676 - 700	OPEN	YES
H-03b3	730	CUL	673 - 696	OPEN	YES
H-04a	532	MAG	375 - 400	OPEN	NO
		CUL	496 - 520	OPEN	YES
H-04b	529	CUL	490 - 516	OPEN	YES
H-04c	661	MAG	377 - 403	PERF.	YES
		CUL	490 - 516	OPEN	NO
		R/S	626	OPEN	NO
H-05a	930	MAG	783 - 810	OPEN	NO
		CUL	897 - 920	OPEN	YES
H-05b	925	CUL	897 - 920	OPEN	YES
H-05c	1076	MAG	788 - 812	PERF.	YES
		CUL	899 - 924	OPEN	NO
		R/S	1041	OPEN	NO
H-06a	637	MAG	492 - 511	OPEN	NO
		CUL	604 - 627	OPEN	YES
H-06b	640	CUL	604 - 627	OPEN	YES
H-06c	741	MAG	490 - 514	NONE	YES
		CUL	604 - 627	PERF.	NO
		R/S	NOT PICKED	OPEN	NO
H-07a	154	MAG	NOT PICKED	OPEN	YES
H-07b1	286	CUL	NOT PICKED	OPEN	YES
H-07b2	295	CUL	232 - 280	SCREEN	YES
H-07c	420	CUL	237 - 274	PERF.	NO
		R/S	283	OPEN	YES

Table 2.5-14 Page 2 of 3

CONFIGURATION OF OBSERVATION - WELL IN THE WIPP FACILITY MONITORING NETWORK

Well	Total Depth of Hole Feet Below Ground Surface	Geologic Unit	Interval From - To Feet Below Ground Surface	Completion Type	Access Available As of 04/01/87
H-08a	505	MAG	NOT PICKED	OPEN	YES
H-08b	624	CUL	NOT PICKED	OPEN	YES
H-08c	808	R/S	733	OPEN	YES
H-09a	692	CUL	647 - 677	SCREEN	YES
H-09b	708	CUL	NOT PICKED	OPEN	YES
H-09c	816	CUL	NOT PICKED	PERF.	YES
		R/S	NOT PICKED	OPEN	NO
H-10a	1318	MAG	NOT PICKED	OPEN	YES
H-10b	1398	CUL	NOT PICKED	OPEN	YES
H-10c	1538	R/S	NOT PICKED	OPEN	YES
H-11b1	785	CUL	730 - 756	OPEN	YES
H-11b2	776	CUL	733 - 757	OPEN	YES
H-11b3	787	CUL	734 - 759	OPEN	YES
H-12	1001	CUL	823 - 850	OPEN	YES
H-14*	589	CUL	545 - 572	OPEN	YES
H-15*	900	CUL	861 - 883	OPEN	YES
DOE-1	4057	MAG	714 - 737	NONE	NO
		CUL	821 - 843	PERF.	YES
		SAL/CAS	NOT PICKED	OPEN	NO
DOE-2	4325	CUL	822 - 848	PERF.	YES
		SAL/CAS	NOT PICKED	OPEN	NO
		BELL CAN	4138 - 4325	OPEN	NO
P-14	1545	CUL	573 - 595	PERF.	YES
		R/S	687	PERF.	NO
P-15	1465	CUL	413 - 435	PERF.	YES
		R/S	542	PERF.	NO
P-17	1660	CUL	558 - 583	PERF.	YES
		R/S	715	PERF.	NO
P-18	1998	CUL	909 - 938	PERF.	YES
		R/S	1088	PERF.	NO
WIPP-12	3928	CUL	810 - 835	PERF.	YES
		SAL/CAS	NOT PICKED	OPEN	NO
WIPP-13	3856	CUL	703 - 726	PERF.	YES
WIPP-18	1060	CUL	787 - 808	PERF.	YES
WIPP-19	1040	CUL	756 - 779	PERF.	YES
WIPP-21	1045	CUL	729 - 753	PERF.	YES
WIPP-22	1452	CUL	742 - 764	PERF.	YES

Table 2.5-14

CONFIGURATION OF OBSERVATION - WELL IN THE WIPP FACILITY MONITORING NETWORK

Well	Total Depth of Hole Feet Below Ground Surface	Geologic Unit	Interval From - To Feet Below Ground Surface	Completion Type	Access Available As of 04/01/87
WIPP-25	651	MAG	302 - 328	PERF.	YES
		CUL	447 - 472	PERF.	YES
		R/S	565	PERF.	NO
WIPP-26	503	MAG	70 - 99	PERF.	YES
		CUL	186 - 209	PERF.	YES
		R/S	309	PERF.	NO
WIPP-27	592	MAG	175 - 193	PERF.	YES
		CUL	292 - 318	PERF.	YES
		R/S	421	PERF.	NO
WIPP-28	801	MAG	285 - 310	PERF.	YES
		CUL	420 - 446	PERF.	YES
		R/S	531	PERF.	NO
WIPP-29	377	CUL	12 - 42	PERF.	YES
		R/S	143	PERF.	NO
WIPP-30	913	MAG	513 - 537	PERF.	YES
		CUL	631 - 653	PERF.	YES
		R/S	748	PERF.	NO
AEC-8	4911	BELL CAN	4821 - 4827	PERF.	NO
		BELL CAN	4844 - 4860	PERF.	YES
ERDA-9	2875	CUL	705 - 729	PERF.	YES
		SAL/CAS	2883	OPEN	NO
CABIN	4291	CUL	461 - 479	PERF.	YES
BABY-1		SAL/CAS	2696	OPEN	NO
		BELL CAN	4037 - 4291	OPEN	NO

*References for H-14 and H-15: R. L. Beauheim, "Interpretations of Single-Well Hydraulic Tests Conducted at and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987," Figures 3-4 and 3-5 (1987).

Reference: D. J. Winstanley and R. C. Carrasco, "Annual Hydrologic Data Report: 1985/1986," DOE-WIPP 86-004, Table C, pp. 11-77 (1986).

NOTE: DL = Dewey Lake Redbeds; MAG = Magenta; CUL = Culebra; R/S = Rustler/Salado Contact; BC = Bell Canyon; SAL = Salado; CAS = Castile.

Table 2.5-15

MEASURED AND DENSITY-CORRECTED WATER LEVELS IN SELECTED TEST HOLES

MAGENTA DOLOMITE

Test hole	Altitude of land surface, in feet above sea level	Water level: Feet below land surface	Water level: Altitude, in feet above sea level	Density, in grams per cubic centimeter	Freshwater equivalent corrected water level: Feet below land surface	Freshwater equivalent corrected water level: Altitude, feet above sea level
H-1	3,397.7	246.50	3,151	1.021	240	3,158
H-2a	3,377.9	233.07	3,145	1.012	230	3,148
H-3	3,389.5	238.30	3,151	1.010	234	3,155
H-4a	3,332.9	189.3	3,144	1.017	186	3,147
H-5a	3,506.2	344.5	3,162	1.008	342	3,165
H-6a	3,347.3	289.8	3,056	1.007	287	3,059
H-7a	-	-	-	-	-	-
H-8a	3,433.0	405.1	3,028	1.008	404	3,029
H-9a	3,405.4	282.0	3,123	1.004	281	3,124
H-10a	3,686.5	586.8	3,100	1.171	469	3,218
W-25	3,212.5	159.0	3,054	1.010	158	3,055
W-27	3,177.2	102.0	3,075	1.095	93	3,084
W-28	3,346.8	202.8	3,144	1.048	198	3,149

Reference: J. W. Mercer, Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico, U.S. Geological Survey Water Resources Investigations Report 83-4016, Table 10, p. 113 (1983).

Table 2.5-16

WATER LEVELS IN SHALLOW OBSERVATION WELLS

Well No. (Ground Elev.)	Zone Monitored	Monitored Interval Depth, Ft.	Water Level, Depth Below Surface, ft 4/80	5/80	6/80	7/80	8/80
B-1 (3,412.2)	Dockum Group	48.7-53.0	53.45	53.45	53.45	53.41	53.48
B-1A (3,412.5)	Sand Dunes	8.9-10.9	11.02	11.02	11.02	11.08	11.04
B-4 (3,417.2)	Gatuna	27.1-32.1	31.92	31.81	31.83	31.77	*
B-4A (3,417.1)	Sand Dunes	9.7-11.7	12.32	12.27	12.27	12.23	12.27
B-13 (3,403.9)	Gatuna	21.8-26.8	26.43	26.42	27.43	26.37	*
B-16 (3,409.9)	Gatuna	23.8-28.8	29.38	29.35	29.41	29.32	29.39
B-18 (3,419.2)	Gatuna	25.6-35.6	35.95	35.97	35.99	36.00	36.00
B-20 (3,403.7)	Sand Dunes	7.8-9.8	10.04	10.03	10.04	10.00	10.05
B-38 (3,429.9)	Dockum Group	41.0-45.0	45.05	45.05	45.06	45.00	45.05
B-54 (3,408.6)	Dewey Lake	170.0-195.0	195.02	195.02	195.04	195.03	195.01

*Water level altered by bailing test.

Reference: J. K. Register, Subsurface Hydrology of Strata Overlying the Salado Formation at the Waste Isolation Pilot Plant Site, TME-3059, Table 5 (1980).

Table 2.5-17

BEST ESTIMATE OF THE UNDISTURBED FRESHWATER HEADS IN THE CULEBRA DOLOMITE

Observation Well	Elevation of the Culebra Dolomite Center [m.a.s.l.]	Freshwater Head [m.a.s.l.]
H-01	825.8	921.6
H-02b	836.0	923.6
H-03b1	824.9	917.3
H-04b	861.9	913.2
H-05b	791.6	934.4
H-06b	832.3	932.2
H-07b	886.1	912.3
H-08b	862.6	911.5
H-09b	836.0	906.9
H-10b	704.6	920.0
H-11*	811.7	911.1
H-12	788.6	912.0
DOE-1	802.1	913.7
DOE-2	787.4	934.0
P-14	846.2	927.4
P-15	879.5	917.4
P-17	842.4	911.2
WIPP-25	838.8	930.3
WIPP-26	900.4	918.8
WIPP-27	874.6	940.7
WIPP-28	888.2	933.2
WIPP-29	899.0	905.6
WIPP-30	848.1	929.4

*Average values from H-11b1, H-11b2, and H-11b3

Reference: Haug et al., "Modeling of Groundwater Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site in Southeastern New Mexico: Interim Report," Sandia National Laboratories Report No. SAND86-7167, Table 3.7, p.72 (1986).

Table 2.5-18

BEST ESTIMATE OF THE UNDISTURBED FORMATION-WATER DENSITIES IN THE CULEBRA DOLOMITE

Well or Hydropad	Density [g/cm^3]
H-01	1.020
H-02	1.010
H-03	1.040
H-04	1.015
H-05	1.100
H-06	1.040
H-07	1.000
H-08	1.000
H-09	1.000
H-10	1.045
H-11	1.085
H-12	1.095
DOE-1	1.090
DOE-2	1.040
P-14	1.015
P-15	1.015
P-17	1.060
P-18	1.090
WIPP-25	1.010
WIPP-26	1.010
WIPP-27	1.090
WIPP-28	1.035
WIPP-29	1.215
WIPP-30	1.020

Reference: Haug et al., "Modeling of Groundwater Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site in Southeastern New Mexico: Interim Report," Sandia National Laboratories Report No. SAND86-7167, Table 3.8, p.73 (1986).

Table 2.5-19

MEASURED AND DENSITY-CORRECTED WATER LEVELS IN TEST HOLES

RUSTLER - SALADO CONTACT

Test hole	Altitude of land surface, in feet above sea level	Water level: Feet below land surface	Water level: Altitude, in feet above sea level	Density, in grams per cubic centimeter	Freshwater equivalent corrected water level: Feet below land surface	Freshwater equivalent corrected water level: Altitude, feet above sea level
H-2c	3,377.7	343.0	3,035	1.225	258	3,120
H-4c	3,333.5	411.0	2,923	1.215	365	2,969
H-6c	3,347.9	410.5	2,937	1.210	345	3,003
H-7c	3,163.5	205.7	2,958	1.048	197	2,967
H-8c	3,433.0	463.0	2,970	1.129	421	3,012
P-14	3,359.6	389.0	2,971	1.126	351	3,009
P-15	3,309.5	313.9	2,996	1.160	278	3,032
P-17	3,335.9	365.0	2,971	1.193	297	3,039
W-25	3,212.5	238.4	2,974	1.093	206	3,007
W-26	3,151.9	191.7	2,960	1.189	168	2,984
W-27	3,177.2	192.0	2,985	1.207	126	3,051
W-28	3,346.8	303.0	3,044	1.152	259	3,088
W-29	2,977.0	17.6	2,959	1.129	12	2,989
W-30	3,427.5	307.0	3,121	1.204	218	3,210

Reference: J. W. Mercer, Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico, U.S. Geological Survey Water Resources Investigations Report 83-4016, Table 6, p. 104 (1983).

Table 2.5-20

BRINE RESERVOIRS ENCOUNTERED IN DELAWARE BASIN IN CASTILE FORMATION*

Well Name	Flow (bbl/day)	Depth (ft)	Pressure (psi)
MASCHO-#2	3,000	3298	1740 **
MASCHO-#1	8,000	3322	1800 **
CULBERTSON	2,000	3515	1858 **
TIDEWATER	No Data	3730	2325 **
SHELL	20,000	3671	1941 **
GULF	Conflicting Data	3600	1972 +
BELCO-FEDERAL	12,000	2802	2075 +
ERDA-6	685	2711	2048 +
POGO	1200-1440	3322	2519 **
UNION	720	2810	1460 **
WIPP-12	12,000	3017	1831 +
H&W Danford 1	No Data	1930	1018 **
Bilbrey	6,000	3090	1630 **

* R. S. Popielak, R. L. Beauheim, S. R. Black, W. E. Coons, C. T. Ellingson, R. L. Olsen, Brine Reservoirs in the Castile Formation, Southeastern New Mexico, TME-3153, WIPP Technical Support Contractor, Albuquerque, NM, Table H.1, March 1983.

** Minimum pressure needed to discharge weighted mud or brine fluid to surface; data should not be used as static formation pressure.

\+ Shut-in pressure measured.

Table 2.5-21

DISTRIBUTION COEFFICIENTS
WIPP FACILITY BATCH-METHOD MEASUREMENTS, ml/g*+

Rock Type and Sample Depth§	Solution**	Cs	Sr	I, Tc	Eu, Gd	Ru	Pu	Am	Cm	Ce	Sb
Magenta Dolomite	Brine A	<1	1	0-1.5	$>5x10^3$	40-50					
(727 & 734)	Brine B	<1	1	<1	$>5x10^3$	500-600	$5.4x10^3$	$3.1x10^2$	$1.3x10^3$		
	Ground Water C	4	5	0-1.5	$>10^4$	400-550	$2.4x10^3$	$2.4x10^3$	$4.2x10^4$		
Culebra Dolomite	Brine A	<1	<1	<1	$>10^4$	25-35					
(852 & 853)	Brine B	1.2	1-2	<1	$>10^4$	640-660	$2.1x10^3$	$2.6x10^3$	$1.2x10^4$		
	Ground Water C	7-10	4-5	<1	$>10^4$	240-400	$7.3x10^3$	$2.2x10^4$	$1.1x10^5$		
Clay in halite	Brine A	<1	<1	<2	$<2.5x10^3$	150-180					
(2186) AEC-8	Brine B	4-6	<1	<1	$<10^4$	$>2x10^3$	$4x10^4$	$1.1x10^3$	$1.9x10^4$		
	Ground Water C	80-120	3-6	<1	$<10^4$	$>1x10^3$	$1.8x10^5$	$3.5x10^3$	$4.2x10^5$		
Polyhalite	Brine A	<1	5-10	<1§§	10-20++					10-20	<1
(2304) ERDA-9	Brine B	<1	19-22	<1§§	430-700++					50-55	0.9-1.5
	Ground Water C	<1	35-40	<1§§	100-200++					40-60	3-4
Cowden anhydrite	Brine B	<1			$>10^3$		$6.7x10^3$	$2.9x10^2$	$4.2x10^3$	$<10^3$	
(2562) AEC-8	Ground Water C	<1					$7.7x10^4$	$2.2x10^3$	$1.8x10^5$		
Clay in halite	Brine A	4-9	<1		$>2.8x10^2$	90-120					
(2725) AEC-8	Brine B	3-6	<1		$>10^4$	$>10^3$	$7.2x10^4$	310	$2.7x10^3$		
	Ground Water C	34-40	30-45		$>3x10^3$	$>10^3$	$4.0x10^4$	$2.3x10^3$	$1.6x10^5$		
Bell Canyon sand	Brine B	14-16	<1	<1§§	$>10^4$++						5-8
(4823) AEC-8	Ground Water C	130-140	1-5	<1§§	$>10^4$++						20-25

References:

*R. G. Dosch and A. W. Lynch, Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) Site in New Mexico, Sandia Laboratories Report SAND78-0297, Tables 6-13, pp. 33-38 (1978).

+R. J. Serne, D. Rai, M. J. Mason, and M. A. Molecke, Batch K_d Measurements of Nuclides to Estimate Migration Potential at the Proposed Waste Isolation Pilot Plant in New Mexico, Battelle Pacific Northwest Laboratories Report PNL-2448 (1977).

§Samples are from core taken in exploratory hole AEC-8 and ERDA 9 at depth (in feet) indicated.

**Brine A composition is that expected from contact with potash deposits in the vicinity of the WIPP site. Brine B composition is that expected from contact with halite deposits at the storage level. Ground water composition is based on analyses of ground water samples from aquifers above the evaporites.

++Values for Eu, only.

§§Values for Tc, only.

Table 2.5-22

TOTAL GROUNDWATER WITHDRAWALS IN EDDY AND LEA COUNTIES, NM, IN 1980 AND 1985

	WITHDRAWALS IN KAF[1]			
Water Use Category	**1980**	**1985**	**Change**	**(%)**
Urban	230.6	245.8	15.2	6.6
Rural	31.7	37.8	6.1	19.2
Irrigated Agriculture	3,432.2	3,161.9	-270.3	-7.9
Livestock	21.6	20.5	-1.1	-5.1
Stockpond Evaporation	35.7	35.7	0.0	0.0
Commercial	7.8	8.2	0.4	5.1
Industrial	0.9	0.8	-0.1	-11.1
Minerals	108.9	91.6	-17.3	-15.9
Military	13.2	11.7	-1.5	-11.4
Power	72.4	65.7	-6.7	-9.2
Fish and Wildlife	36.9	43.3	6.4	17.3
Recreation	13.1	12.1	-1.0	-7.6
Reservoir Evaporation	379.6	423.5	43.9	11.6
TOTAL	**4,384.6**	**4,158.6**	**-226.0**	**-5.2**

[1]KAF = thousands of acre-feet

Surface water withdrawals decreased 26,159 acre-feet (AF) or 1.1 percent from 2,482,690 AF in 1980 to 2,456,531 AF in 1985. Groundwater withdrawals decreased 200,537 AF, or 10.5 percent from 1,902,620 AF in 1980 to 1,702,083 AF in 1985.

Reference: B. Wilson, "Water Use in New Mexico in 1985," New Mexico State Engineer Office Technical Report 46, p. 8 (November 1986).

Table 2.5-23

GROUNDWATER USERS IN EDDY AND LEA COUNTIES, NM, IN 1985

	DATAYEAR = 1985: COUNTY = EDDY				COUNTY = LEA			
	WITHDRAWALS				WITHDRAWALS			
Category	**SW**	**GW**	**Total**	**%**	**SW**	**GW**	**Total**	**%**
URBAN	0	13700	13700	5.8	0	12818	12818	8.7
RURAL	0	1207	1207	0.5	0	949	949	0.6
IRRIGATED AG.	99235	82131	181366	76.9	0	98409	98409	67.1
LIVESTOCK	364	399	763	0.3	310	417	727	0.5
STOCKPOND EVAP.	498	0	498	0.2	279	0	279	0.2
COMMERCIAL	0	38	38	0.0	0	1111	1111	0.8
INDUSTRIAL	238	104	342	0.1	0	0	0	0.0
MINERALS	0	5909	5909	2.5	0	25783	25783	17.6
MILITARY	0	0	0	0.0	0	0	0	0.0
POWER	0	0	0	0.0	0	5708	5708	3.9
FISH AND WILDLIFE	0	543	543	0.2	0	0	0	0.0
RECREATION	565	737	1302	0.6	285	602	887	0.6
RESERVOIR EVAP.	30285	0	30285	12.8	0	0	0	0.0
TOTALS	**131185**	**104768**	**235953**	**100.0**	**874**	**145797**	**146671**	**100.0**

KEY:

AF = Acre-feet
SW = Surface water
GW = Groundwater
% = Percent of total

Modified from Wilson, B., "Water Use in New Mexico in 1985," New Mexico State Engineer Technical Report 46, Table 3, pgs. 25 and 30 (November 1986).

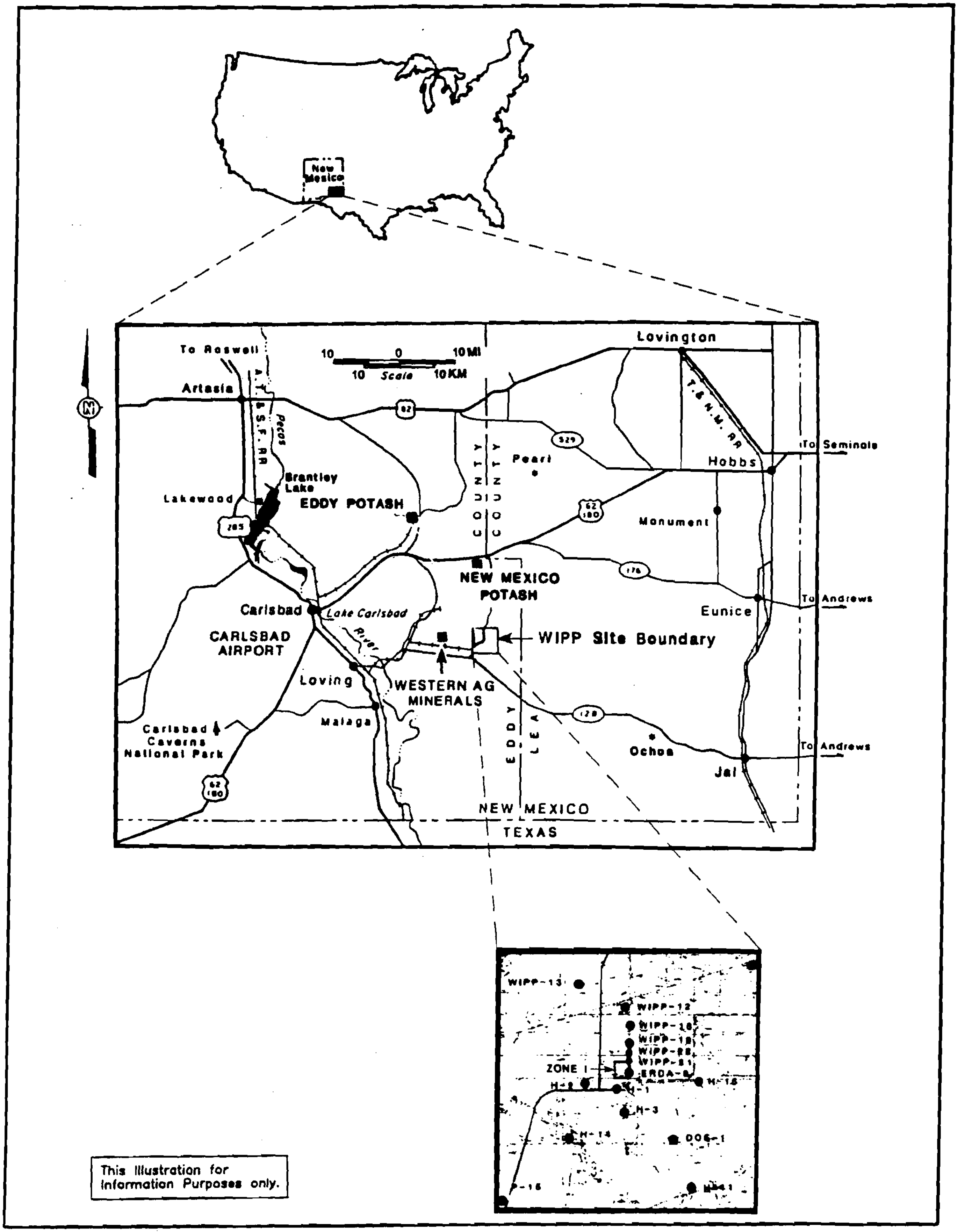


FIGURE 2.5-1
WIPP Location Map

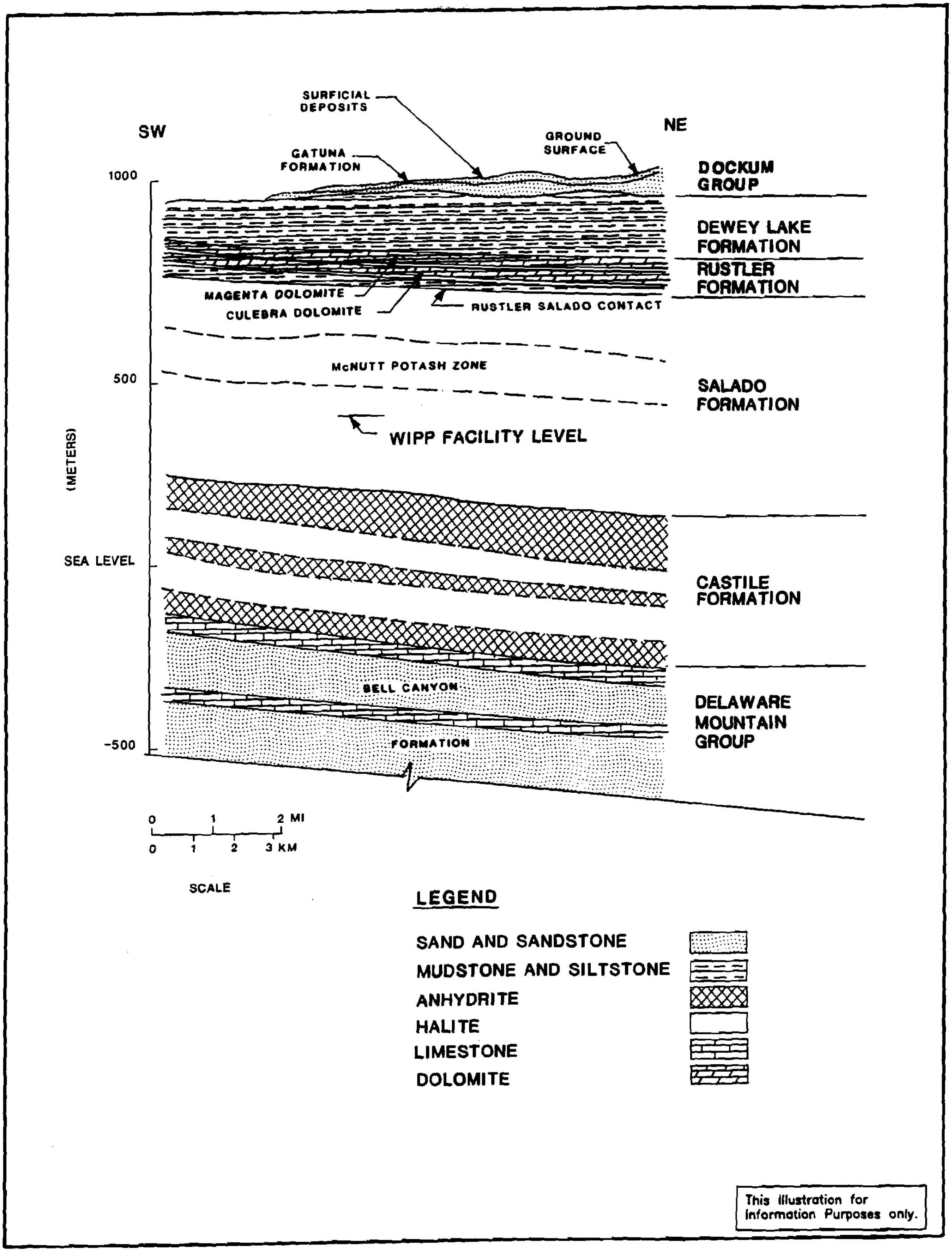


FIGURE 2.5-2
Generalized Stratigraphic Cross Section

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATERNARY	PLEISTOCENE		MESCALERO CALICHE	
			GATUNA	
TERTIARY	PLIOCENE		OGALLALA	
TRIASSIC		DOCKUM	UNDIVIDED	
PERMIAN	OCHOAN		DEWEY LAKE RED BEDS	
			RUSTLER	Forty-Niner
				Magenta
				Tamarisk
				Culebra
				Unnamed
			SALADO	Upper
				McNutt
				Lower
			CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON	
			CHERRY CANYON	
			BRUSHY CANYON	

Geologic Column Representative of WIPP Facility Area

Reference:

(After Powers et al., 1978 and Cooper and Glanzman, 1971)

This illustration for Information Purposes only.

FIGURE 2.5-3
Geologic Column Representative of WIPP Facility Area

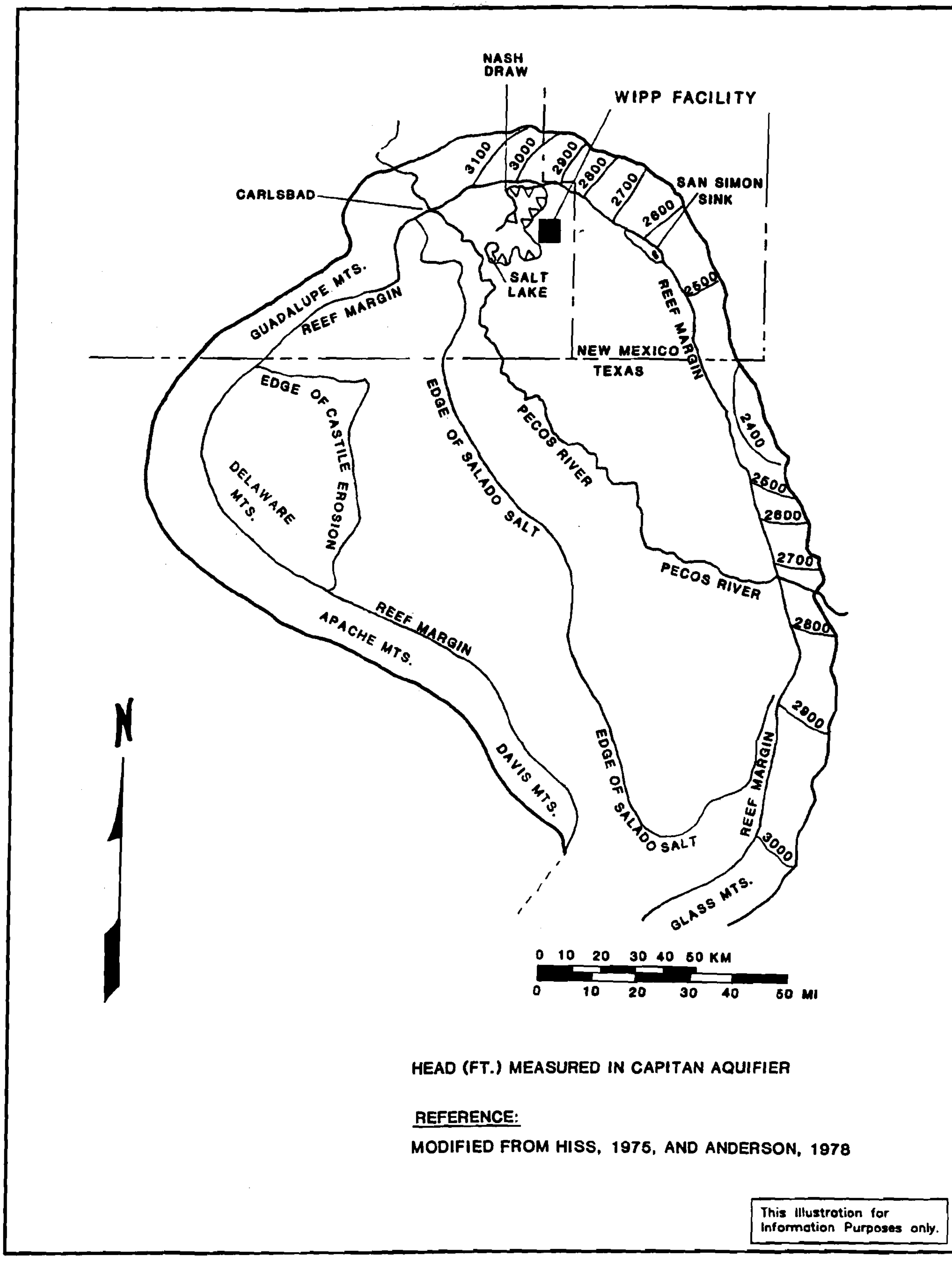
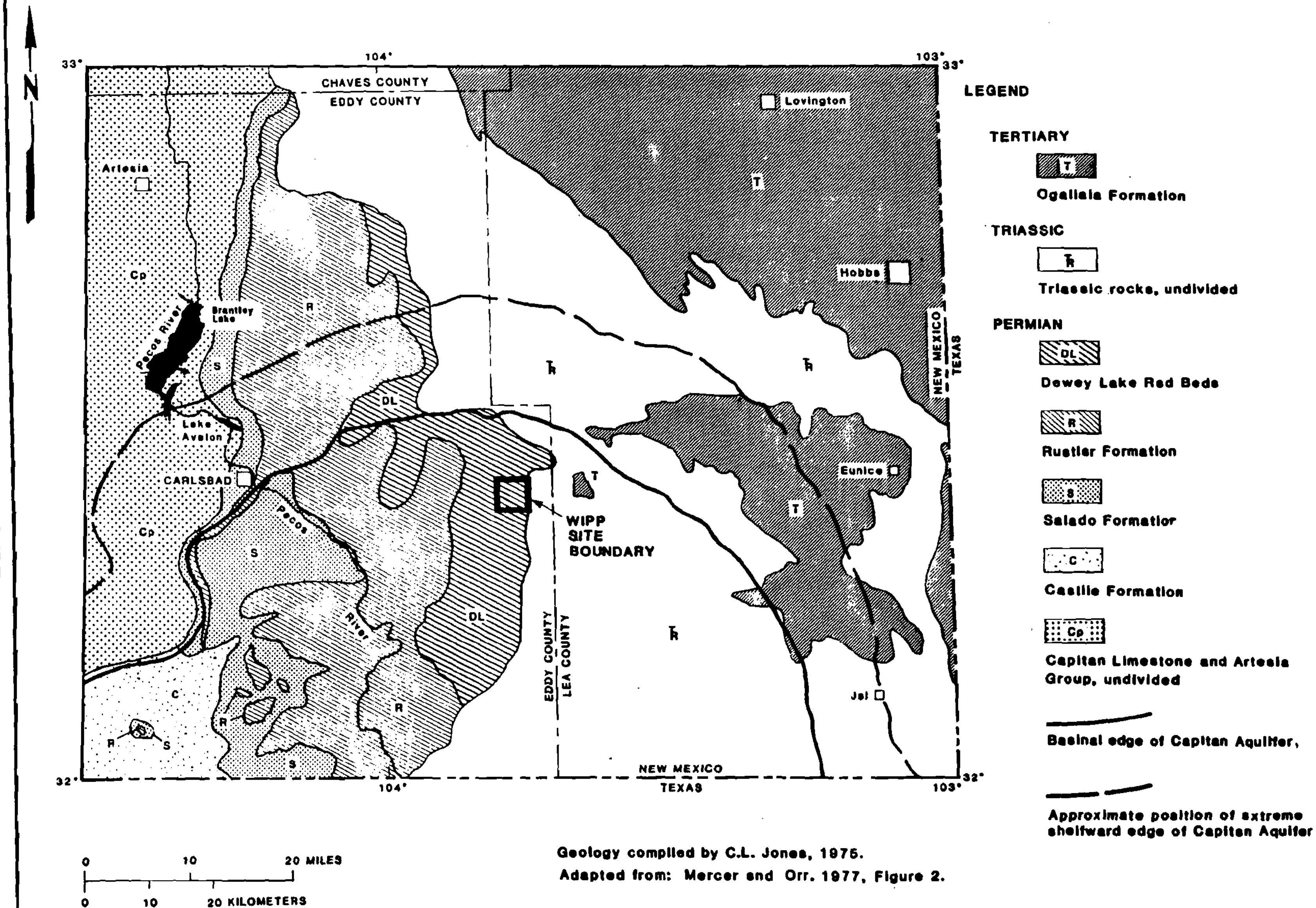


FIGURE 2.5-4
Location of the Capitan Limestone Aquifer and Approximate Post-development Potentiometric Surface

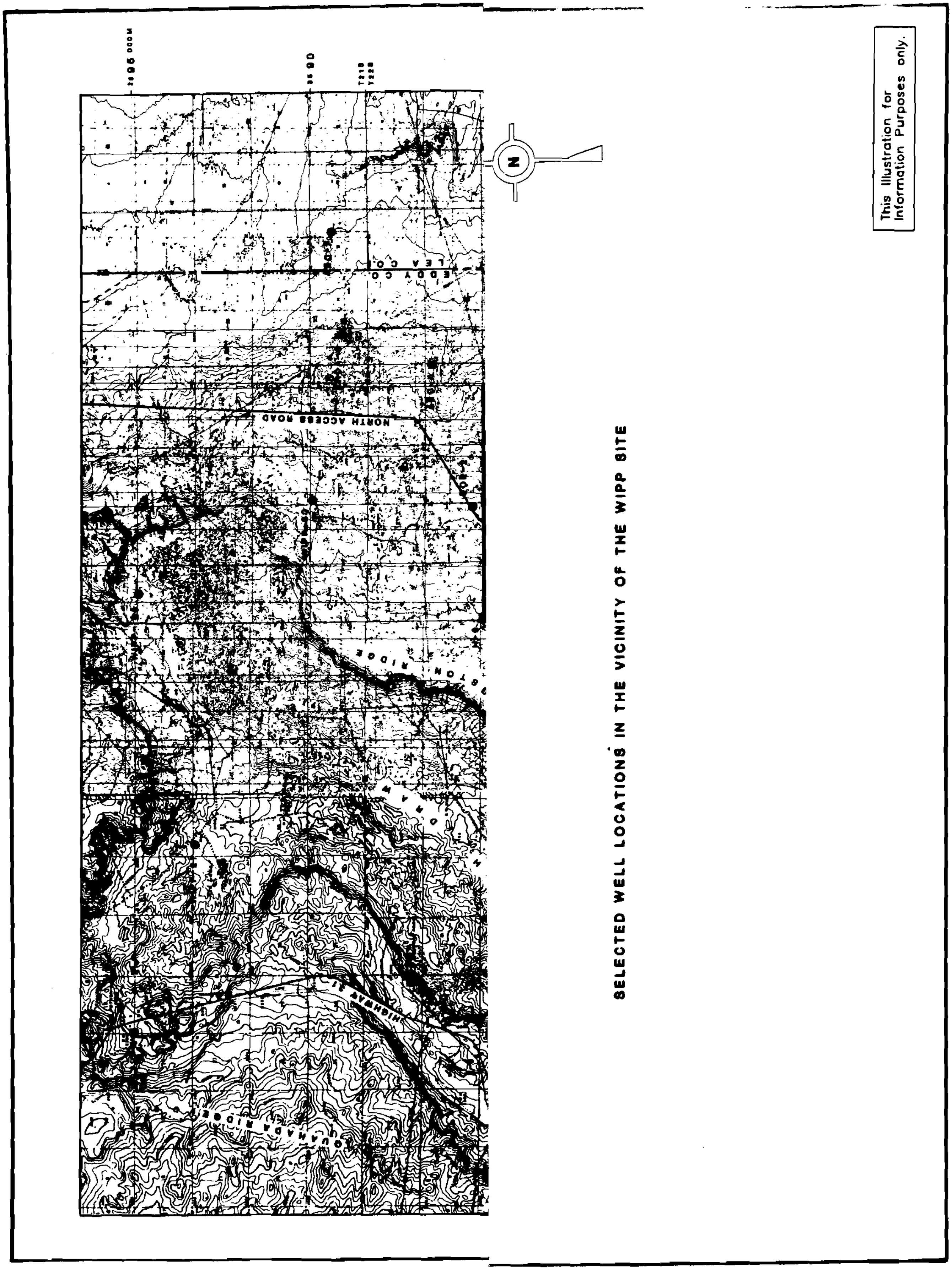


Geology compiled by C.L. Jones, 1975.
Adapted from: Mercer and Orr, 1977, Figure 2.

This Illustration for Information Purposes only.

FIGURE 2.5-5
Geologic Map of Los Medaños Area and Vicinity

GG69.2



IGURE 2.5-6
/ell Locations in the Vicinity of
he WIPP Facility

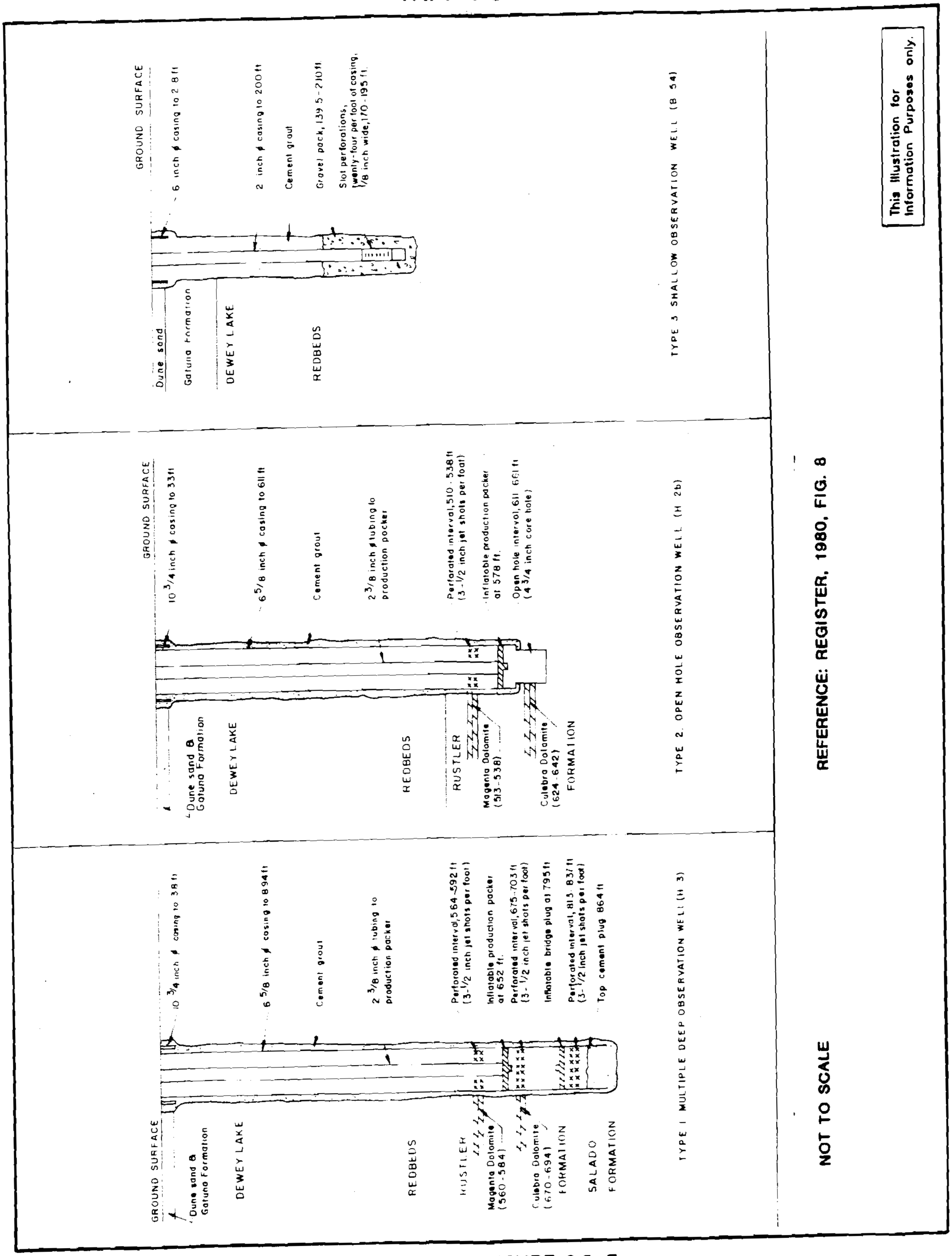
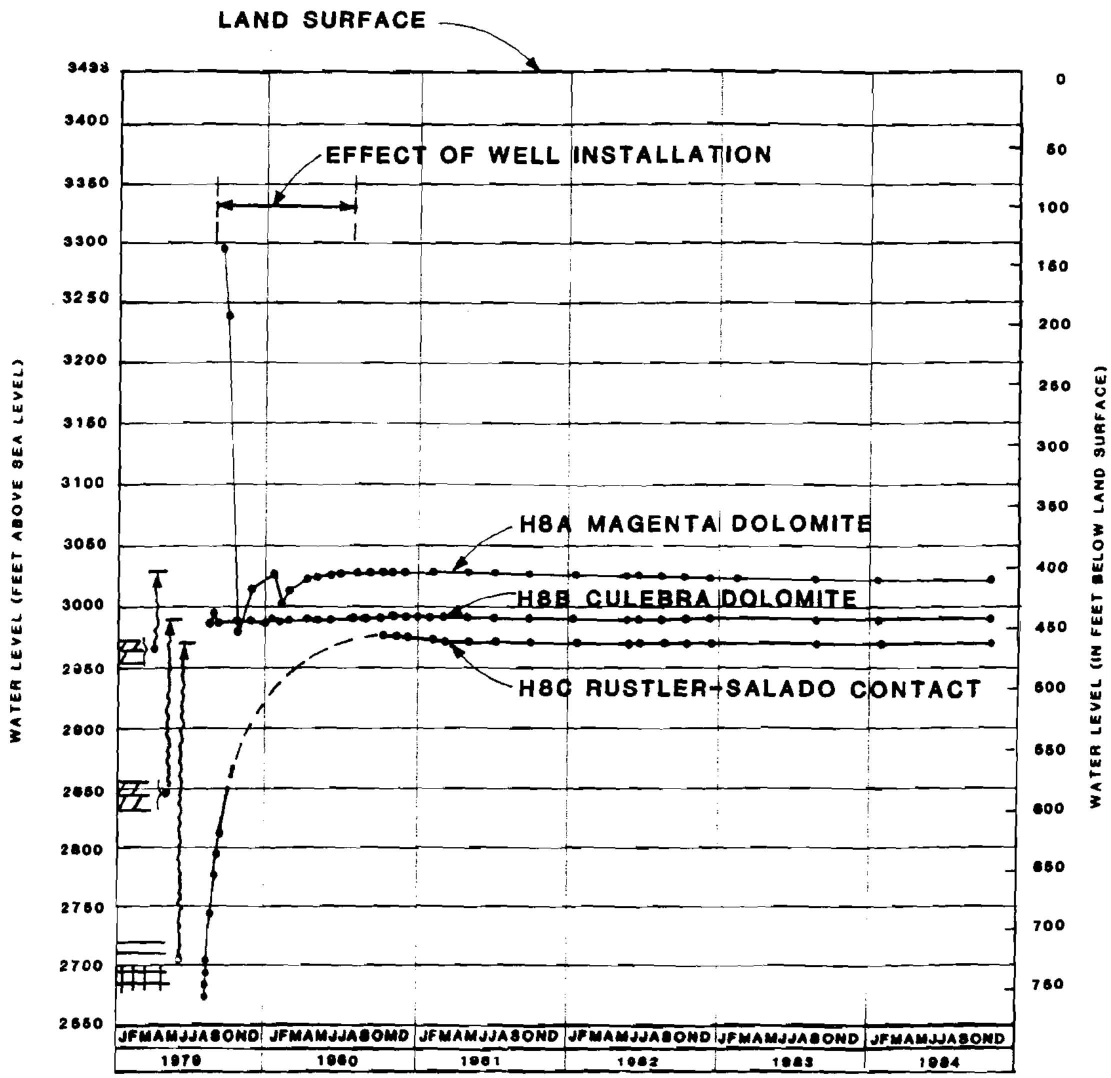


FIGURE 2.5-7
Examples of Observation Well Construction



Sources: U.S. Geological Survey

This Illustration for Information Purposes only.

FIGURE 2.5-8

Example of Fluid Levels in H-8 Observation Wells

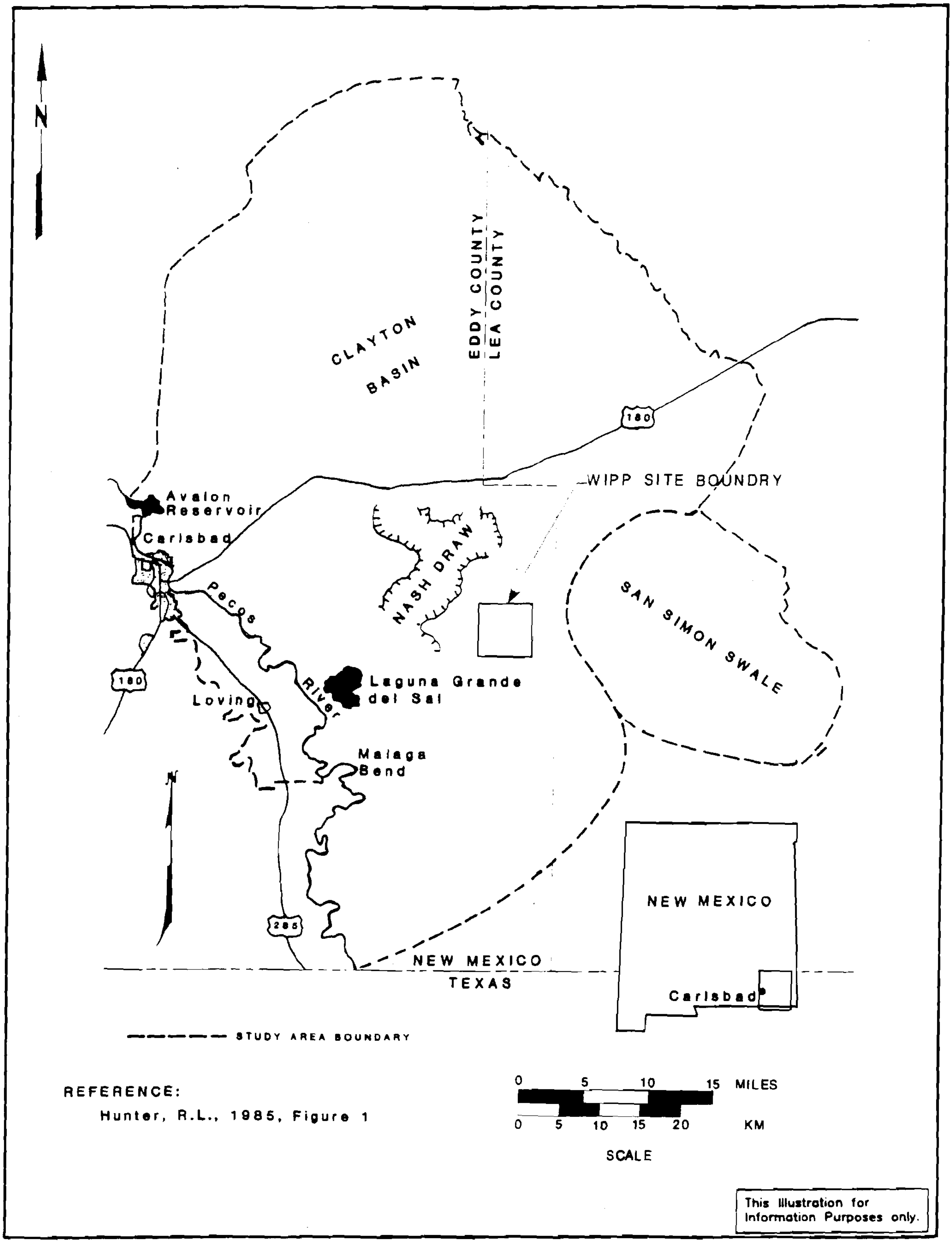


FIGURE 2.5-9
Generalized Physiographic Setting of the WIPP Facility Showing the Area of the WIPP Water Balance Study

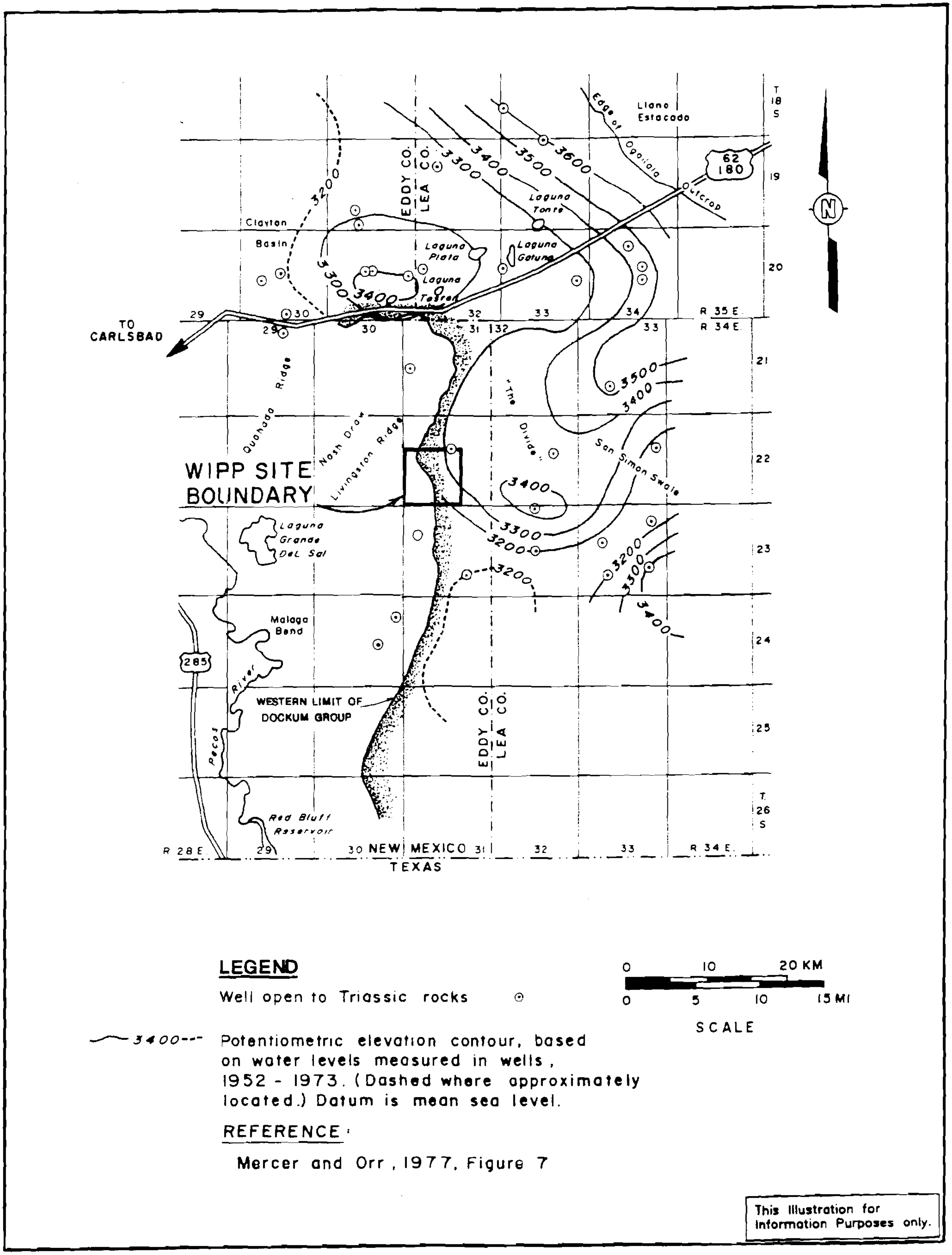
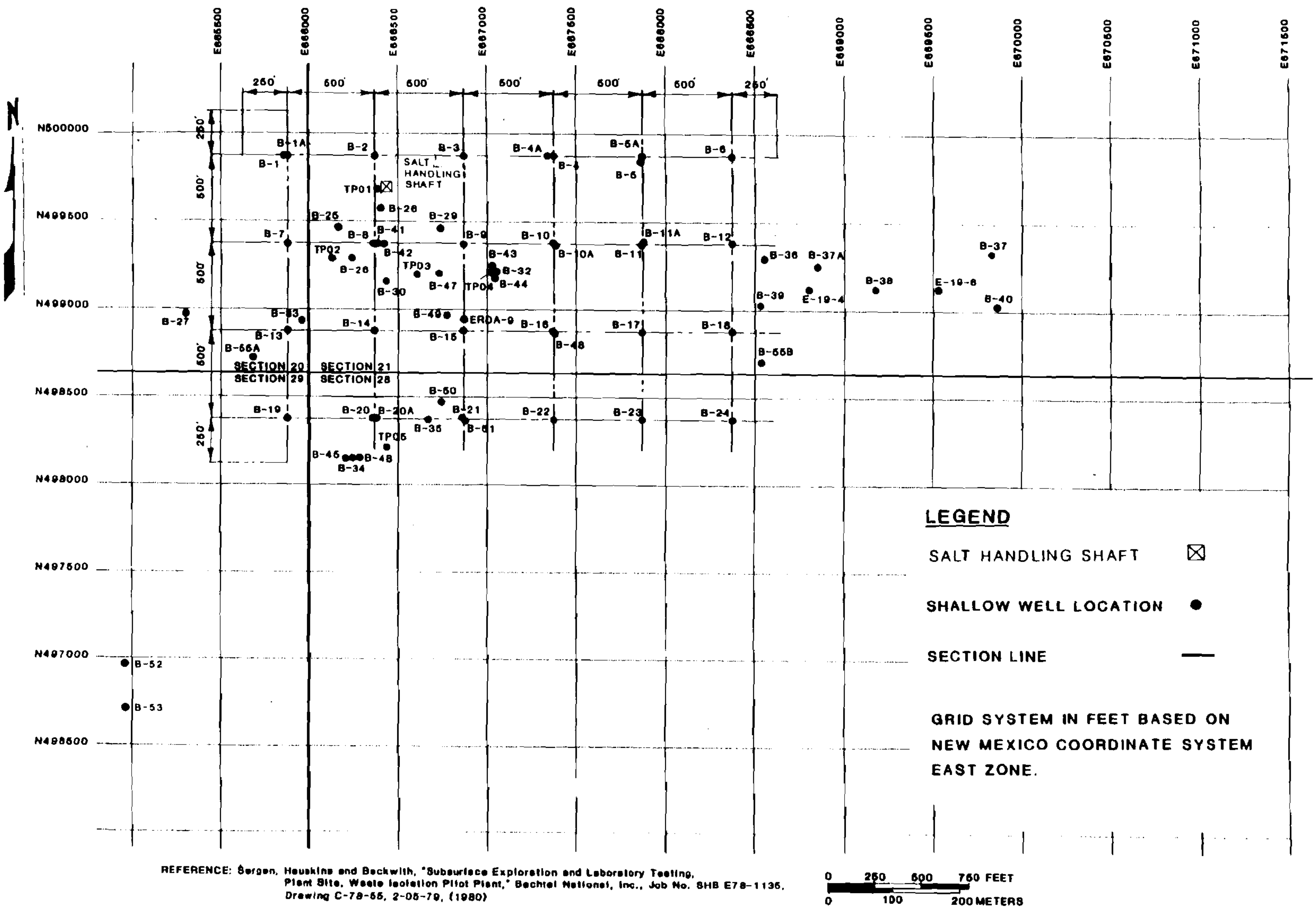


FIGURE 2.5-10
Potentiometric Surface of the Dockum Group Water-bearing Unit



REFERENCE: Sergen, Hauskins and Beckwith, "Subsurface Exploration and Laboratory Testing, Plant Site, Waste Isolation Pilot Plant," Bechtel National, Inc., Job No. SHB E78-1136, Drawing C-78-55, 2-05-79, (1980)

This illustration for Information Purposes only.

FIGURE 2.5-11
Location of Shallow Observation Wells at the WIPP Facility

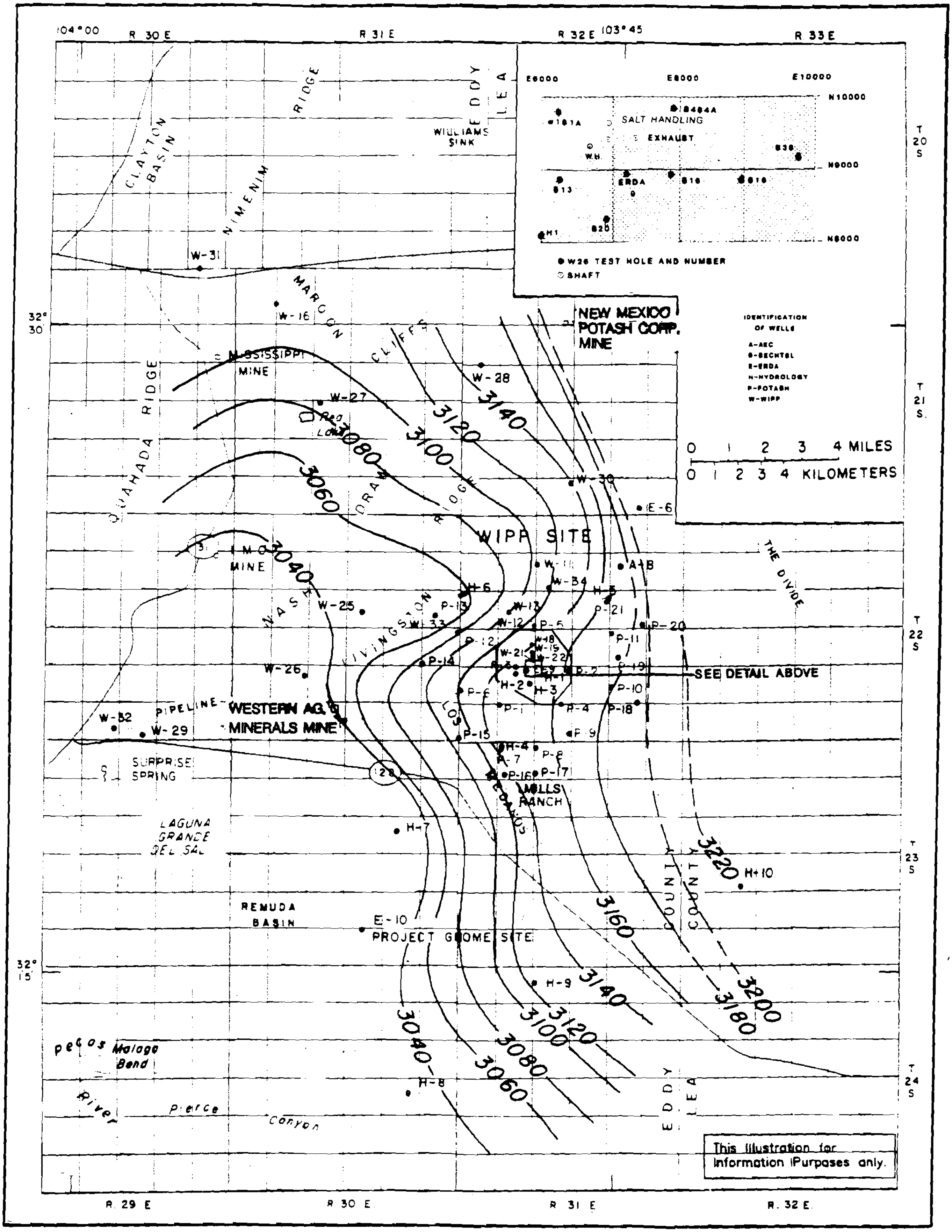


FIGURE 2.5-12
Equivalent Potentiometric Surface of the Magenta Dolomite Water-bearing Unit in the Rustler Formation

NOTE

POTENTIOMETRIC CONTOUR SHOWS ALTITUDE AT WHICH WATER HAVING A DENSITY OF 1.0 GRAM PER CUBIC CENTIMETER WOULD HAVE STOOD IN A TIGHTLY CASED WELL. DASHED WHERE APPROXIMATELY LOCATED. CONTOUR INTERVAL 20 FEET. DATUM IS SEA LEVEL.

MODIFIED FROM

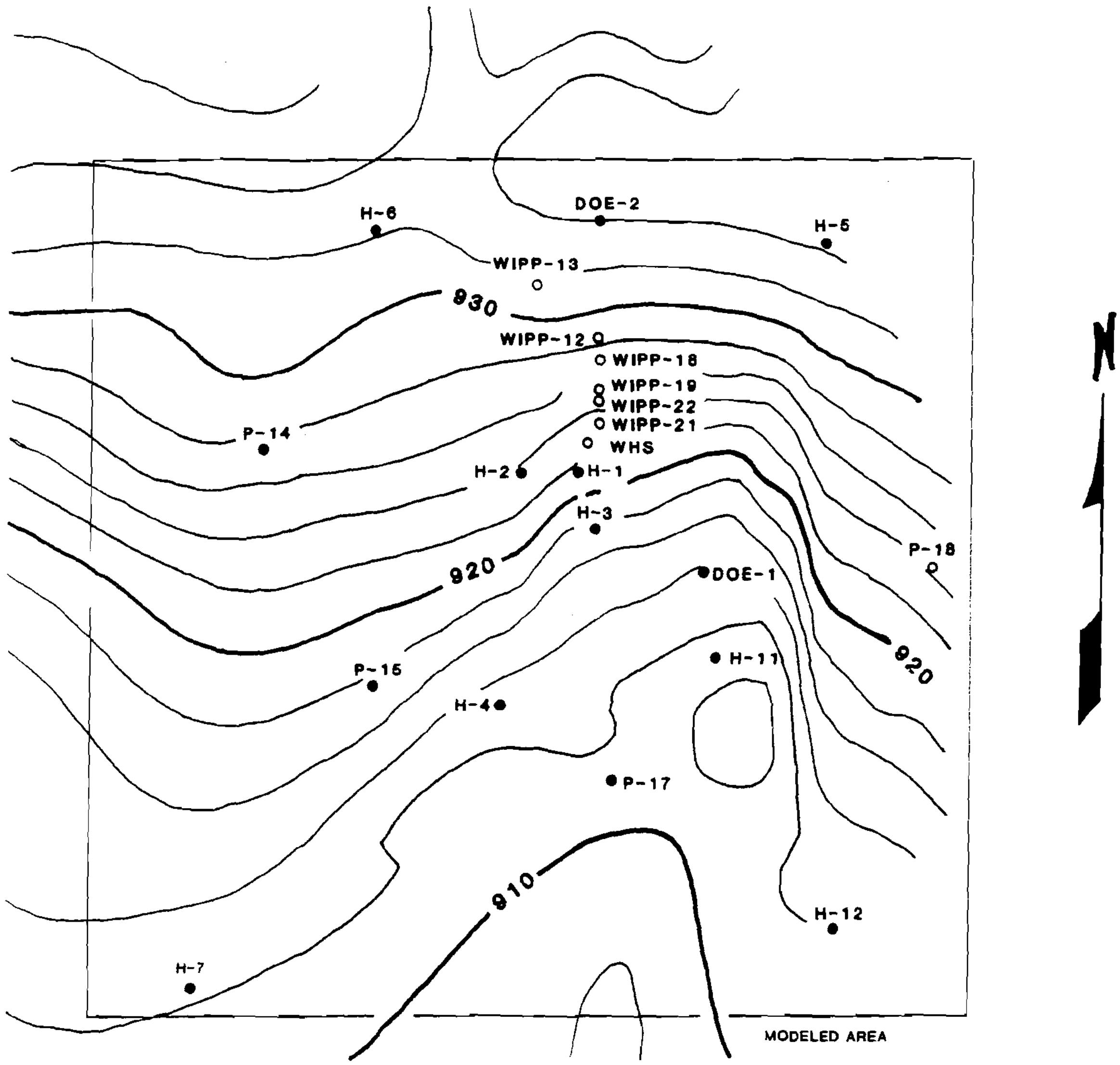
MERCER,J.W.1983,FIG20

LEGEND

WELL IDENTIFIER AND NUMBER
EXAMPLE: W-28 = WIPP WELL, NUMBER 28.

This Illustration for Information Purposes only.

Explanation to Figure 2.5-12



LEGEND

Data Point ●

Observation Well ○

NOTE

1. Freshwater Heads in m a.s.l.
2. Contour Scale: Linear
3. Contour Interval: 2 m

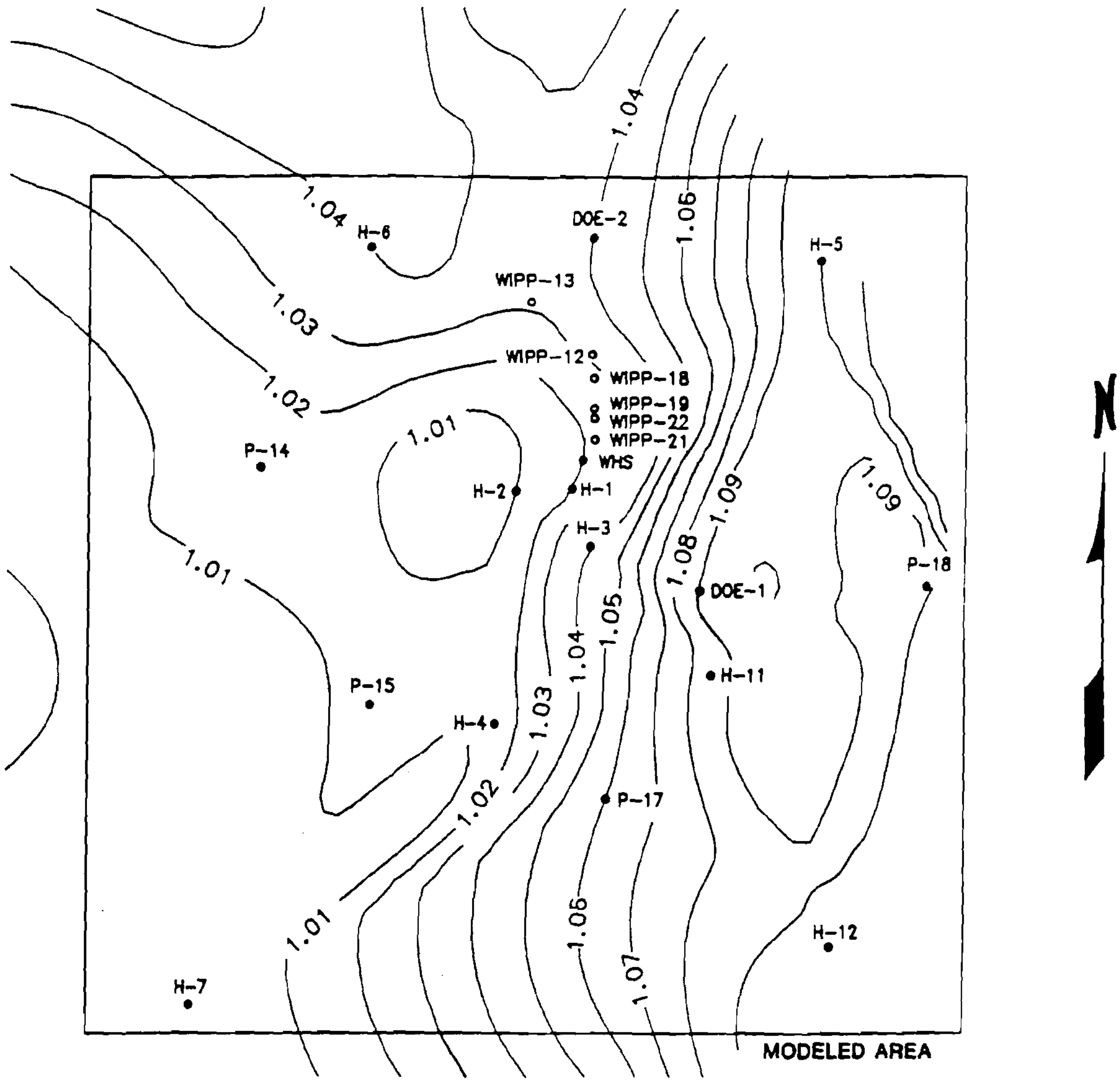
0	1	2	MILES

0	1	2	3	KM

Adapted from: Haug, et.at., 1986, Figure 3.9.

This illustration for Information Purposes only.

FIGURE 2.5-13
Best Estimate of the Undisturbed Freshwater Heads in the Culebra Dolomite



LEGEND

Data Point •

Observation Well ○

NOTES

1. Formation-Water Densities in g/ccm
2. Contour Scale: Linear
3. Contour Interval: 0.01 g/ccm

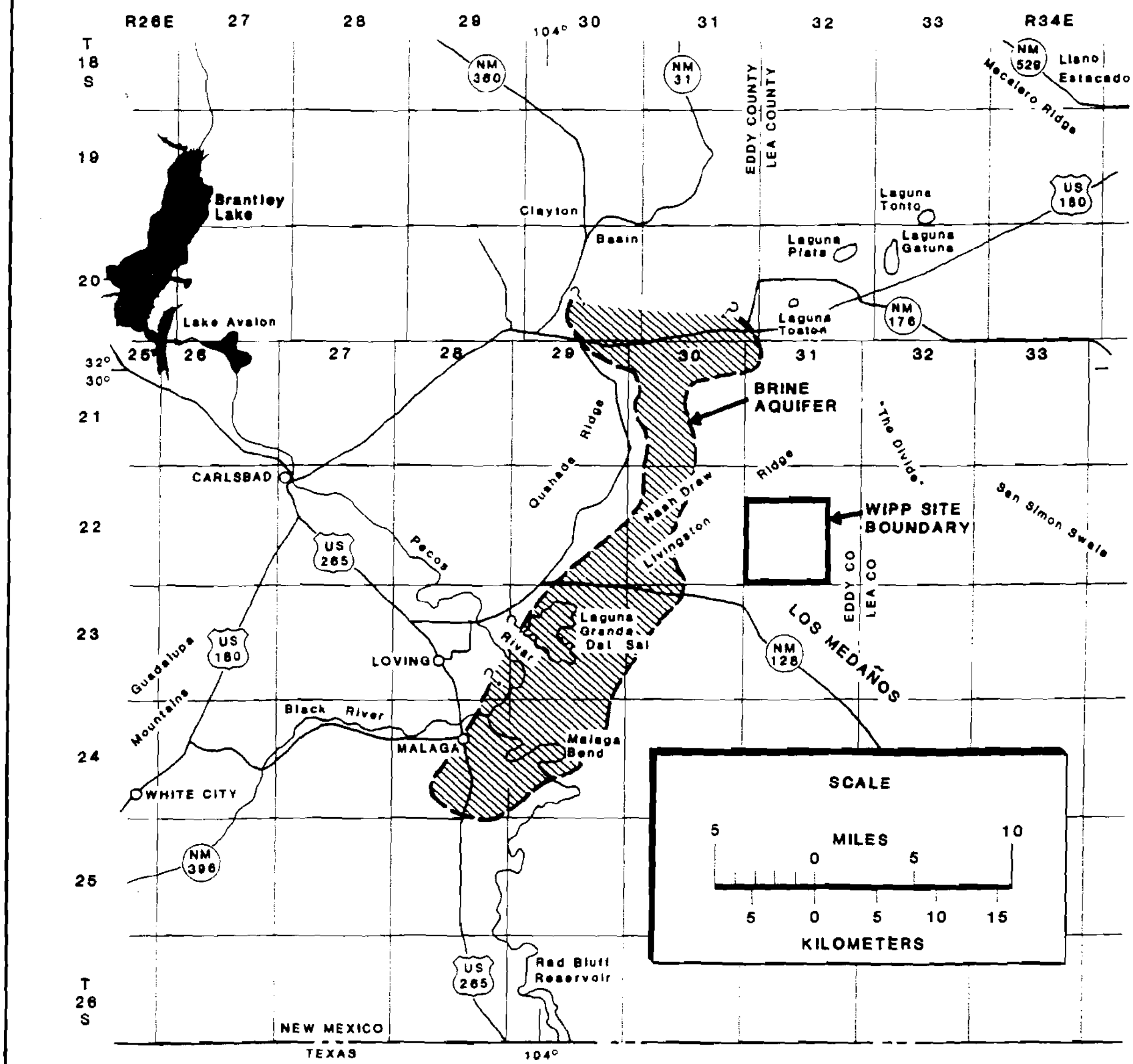
Adapted From: Haug, et. al., 1986, Figure 3.10.

0	1	2		MILES
0	1	2	3	KM

SCALE

This Illustration for Information Purposes only.

FIGURE 2.5-14
Observed Formation - Water Densities in the Culebra Dolomite



Adapted from Mercer and Orr, 1977, and Hale, et. al., 1954.

This Illustration for Information Purposes only.

FIGURE 2.5-15
Aerial Extent of the Rustler/Salado "Brine Aquifer"

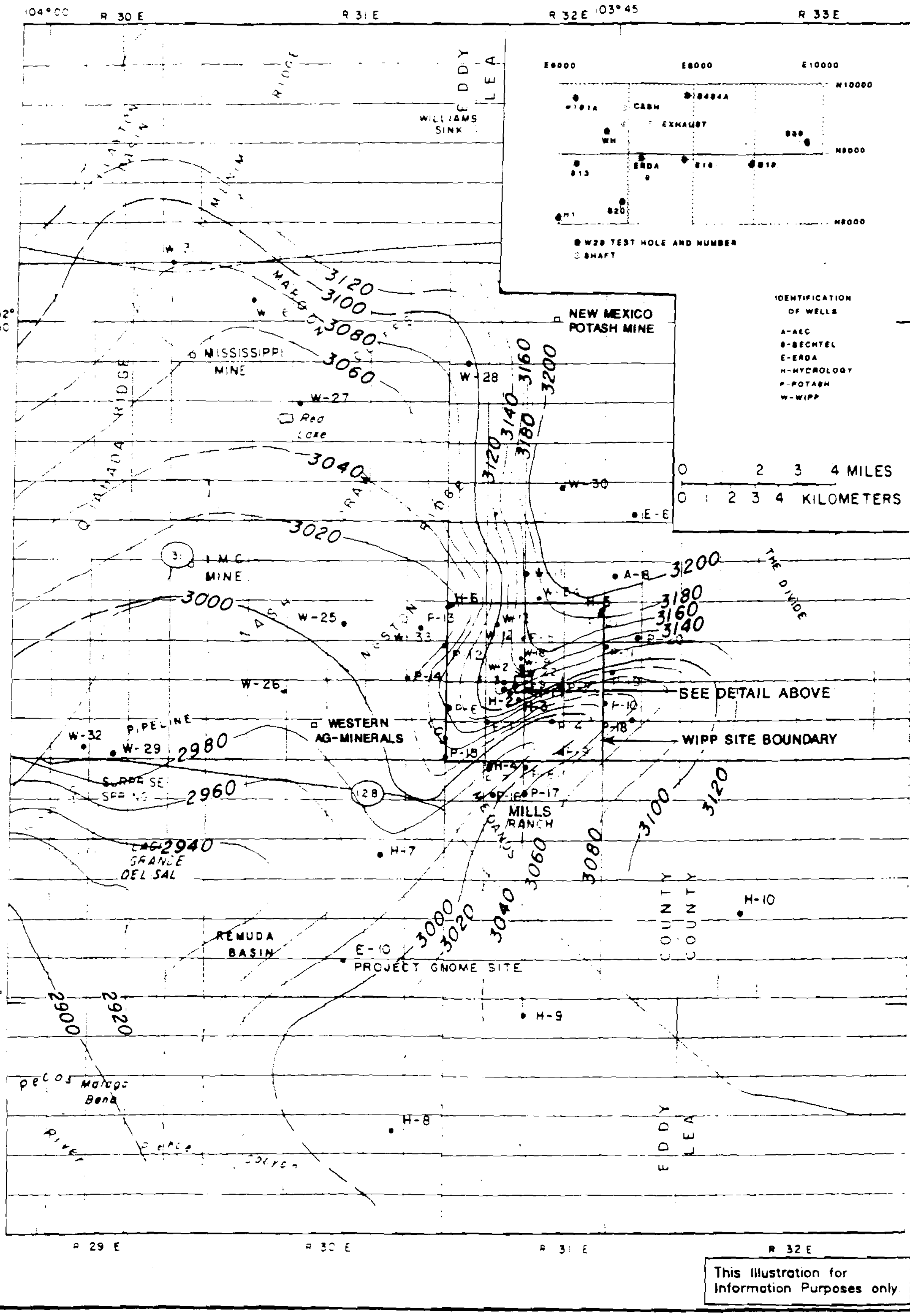


FIGURE 2.5-16

Equivalent Potentiometric Surface of the Water-bearing Unit along the Rustler/Salado Contact

NOTE

POTENTIOMETRIC CONTOUR SHOWS ALTITUDE AT WHICH WATER HAVING A DENSITY OF 1.0 GRAM PER CUBIC CENTIMETER WOULD HAVE STOOD IN A TIGHTLY CASED WELL. DASHED WHERE APPROXIMATELY LOCATED. CONTOUR INTERVAL 20 FEET. DATUM IS SEA LEVEL.

MODIFIED FROM

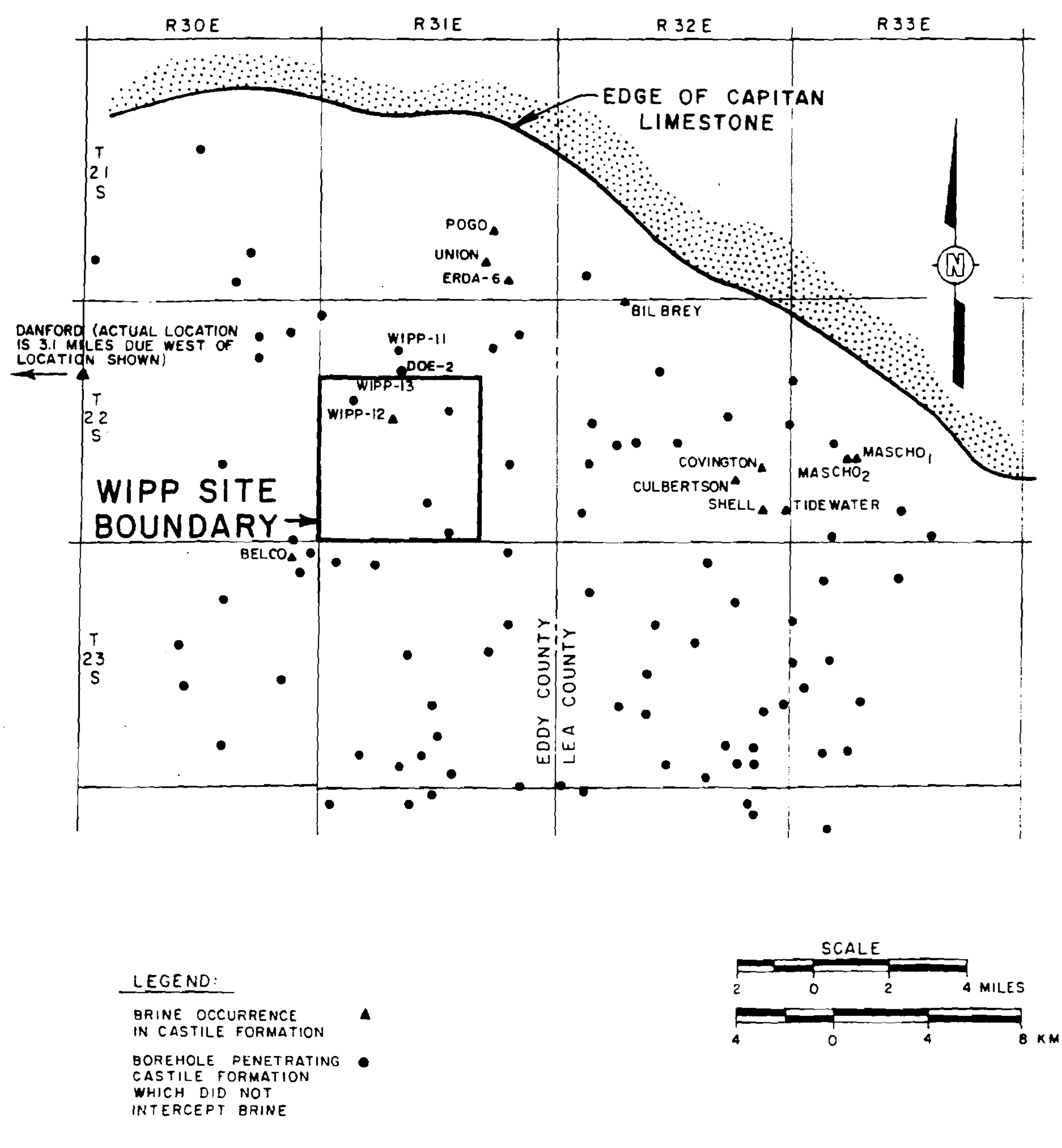
MERCER,J.W.1983,FIG15

LEGEND

WELL IDENTIFIER AND NUMBER
EXAMPLE: W-28 = WIPP WELL, NUMBER 28.

This illustration for Information Purposes only.

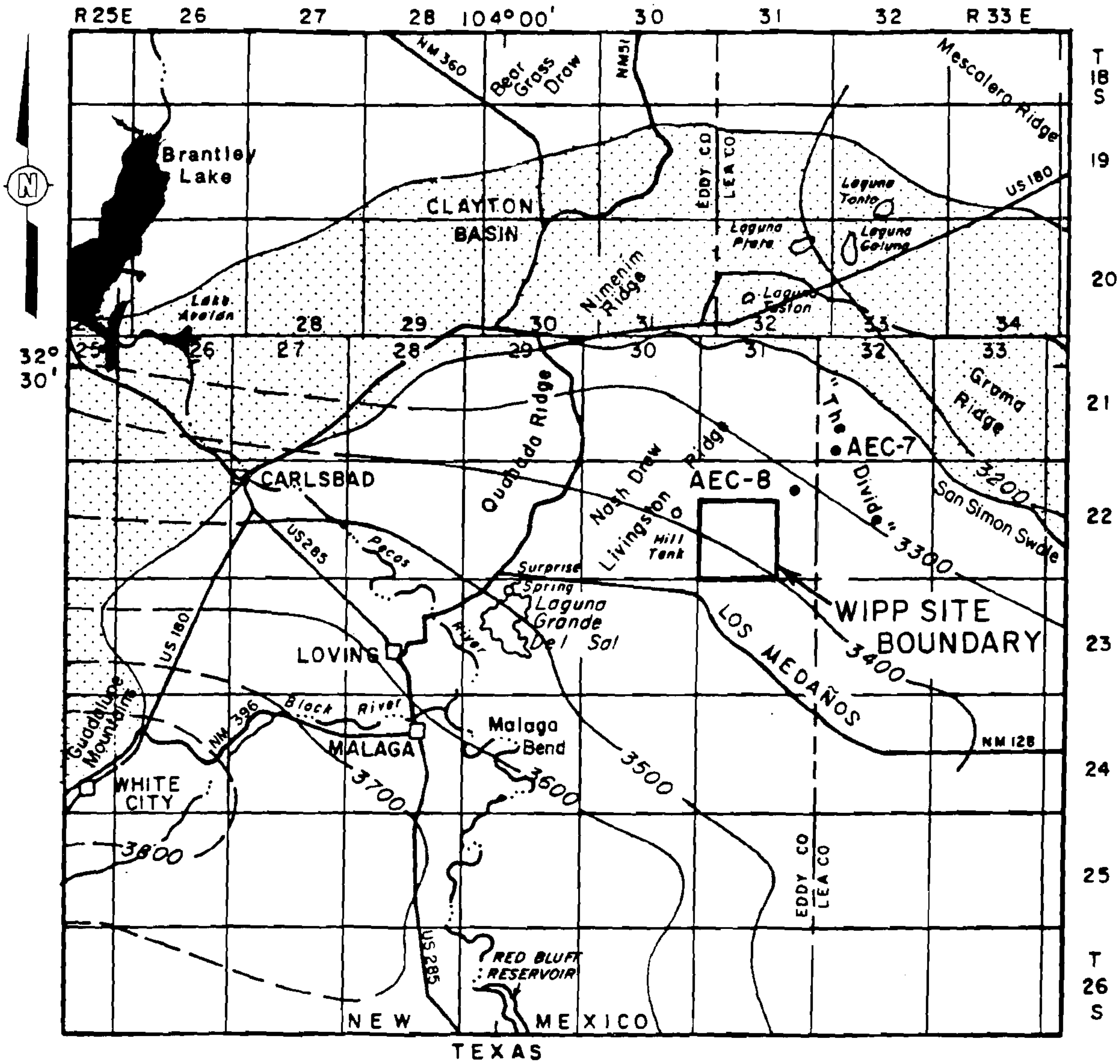
Explanation to Figure 2.5-16



Modified from: Popielak, R.S. et al., 1983, Figure G-11

This illustration for Information Purposes only.

FIGURE 2.5-17
Location Map of Boreholes Penetrating the Castile Formation in the WIPP Facility Vicinity

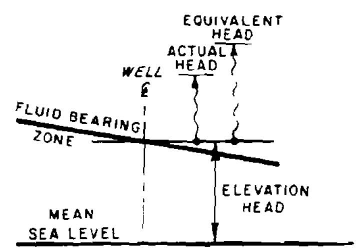


LEGEND

GUADALUPIAN REEF COMPLEX

TEST HOLE AND NUMBER — AEC-8

EQUIVALENT POTENTIOMETRIC CONTOUR interpolated between equivalent (adjusted) potentiometric heads in individual boreholes. For fluids with densities different from 1 g/cm^3, the equivalent head indicates altitude at which water having a density of 1.000 g/cm^3 would stand in a tightly cased well (i.e., pressure head adjustment). No density adjustment has been made for elevation heads. Contour interval 100 feet. Datum is mean sea level. — 3700



SCHEMATIC OF DATA RELATIONSHIP IN A SINGLE WELL

Modified from: Mercer, J.W., 1983, Figure 9

0 5 10 MI

0 5 10 KM

This illustration for Information Purposes only.

FIGURE 2.5-18

Equivalent Potentiometric Surface of the Hydrologic Unit in the Upper Part of the Bell Canyon Formation (Delaware Mountain Group)

2.6 REGIONAL GEOLOGY

The WIPP facility is located in the southwestern portion of the southern Great Plains physiographic province[1]. This province is a broad highland belt that slopes gently eastward from the Rocky Mountains and Basin and Range province on the north and west to the central lowlands province on the east side (Figure 2.6-1). The majority of the terrain in southeastern New Mexico is characterized by a gentle southwesterly slope and hummocky surface marked by karst features, caliche, and sand dunes. The major permanent drainage of the area is the north-south flowing Pecos River, located 14 mi west of the WIPP facility.

The basement rock in the WIPP facility region consists of Precambrian metasedimentary and igneous strata. This basement is overlain by a late Cambrian through Cenozoic sedimentary sequence consisting primarily of carbonates and evaporites with a small quantity of redbeds and terrestrial clastics. The lower and mid-Paleozoic sediments were deposited on a slowly subsiding continental shelf. They consist predominantly of carbonates with minor sand, shale, and chert. The upper Paleozoic section was deposited in a rapidly developing basin and shelf environment. The Delaware Basin, in which the WIPP facility is located, was one of the basins to form at this time. Reefs eventually grew around the margins of the Delaware Basin and reached a peak in the mid to late Permian. Their growth eventually restricted the water circulation in the basin and led to the accumulation of a thick section of upper Permian evaporites. The Mesozoic and Cenozoic sections consist of redbeds and scattered patches of limestone, sandstone, and conglomerate, all of which are overlain by caliche and windblown sand. These meager deposits are the result of the periodic and long-term emergent conditions that existed throughout the Mesozoic and Cenozoic Eras.

Structurally, the WIPP facility is situated at the southwestern margin of the central stable region of North America. It lies within a fairly undeformed area, north and west of the Ouachita Tectonic Belt, which is characterized by broad arches, basins, platforms, and shelves.[2] The immediate structural setting of the area around the WIPP facility is the northern Delaware Basin (Figure 2.6-2). Structural development of this basin began in the Pennsylvanian and ceased in the late Permian, when it was filled with evaporites and covered by younger sediments.[3,4] Since that time it has undergone only broad regional tilting.

2.6.1 REGIONAL PHYSIOGRAPHY AND GEOMORPHOLOGY

The Delaware Basin, bordered by the Diablo Platform, Northwestern Shelf, and Central Basin Platform (Figure 2.6-2), is located within the Pecos Valley section of the Great Plains physiographic province (Figure 2.6-1). The boundary between this province and the basin and range province is located approximately 60 mi west of the WIPP facility (heavy line on Figure 2.6-2). Altogether there are portions of seven physiographic sections within 200 mi of the WIPP facility. They are the Pecos Valley, High Plains, Edwards Plateau, and Central Texas sections of the Great Plains province, the Mexican Highlands and Sacramento sections of the basin and range province, and the Osage Plains section of the Central Lowlands province (Figure 2.6-1).

The Mexican Highlands and Sacramento sections are located to the west of the Pecos Valley section and consist of alternating basins and north-to-northwest trending late Tertiary to Quaternary-age mountain ranges. The Mexican Highlands section, which extends from the Colorado Plateau southward into Mexico, is composed of almost equal areas of faulted mountains and basins. Half of the basins are bolsons, and half drain or slope toward major rivers. The eastern portion of the Mexican Highlands contains the Rio Grande Rift, which extends from northern Mexico into Colorado (Figure 2.6-2). The rift consists of an en echelon series of basins and intervening ranges, which formed as a result of Laramide deformation and Miocene or late Cenozoic rifting.[2] The rift zone increases in width to the south, where it consists of several parallel grabens and horsts. The western portion of the Rio Grande Rift is known to be a region of high heat flow.[5,6] East of the Mexican Highlands are the faulted and sloping plateaus of the Sacramento section,[1] a narrow north-south trending strip about 300 mi long and 70 mi wide. This section, bordered on the west by the Rio Grande Rift and on the east by the Great Plains, is characterized topographically by two major bolsons, the Estancia Basin (Sandoval Bolson) in the north and the Salt Basin in the south (Figure 2.6-2). The bolsons are separated by a series of mountains that have bold western scarps and gently dipping eastern slopes.

The sections of the southern Great Plains physiographic province generally form a broad highland belt, which slopes gradually eastward from the Basin and Range province to the Central Lowlands. The Great Plains province represents the western extent of the Interior Plains, a major physiographic division.[7,1]

The High Plains section (Figure 2.6-1), 45 mi east of the WIPP facility, extends from South Dakota to near the Pecos River in Texas. The High Plains are the remnants of a great fluvial plain that originated from the deposition of the late Tertiary Ogallala Formation. A hard caliche layer mantles the sediments and helps preserve the plain's surface. East of the WIPP facility this plain has been preserved as an almost completely flat surface known as the Llano Estacado. Northward, the land is more dissected, and as a result, the original surface is preserved only along stream divides. Sand dunes and shallow depressions derived from dissolution, blowouts, animal wallowing, and differential compaction comprise the few topographic features in the High Plains section.

The Edwards Plateau section borders the High Plains and Pecos Valley sections on the south (Figure 2.6-1). The plateau is a flat-lying area underlain by resistant limestone, which dips gently to the south and east. It is bordered in most places by an escarpment up to 1000 ft high. The original plateau surfaces are narrow and highly dissected in the wetter eastern part of the section. In the drier western section, however, the plateau becomes a broad-valleyed plain similar to the Llano Estacado. Some shallow sinkholes, formed by the dissolution of the underlying limestone, are present in this section.

The Central Texas section lies adjacent to the Edwards Plateau, forming its northeastern boundary (Figure 2.6-1). The plateau-forming limestones of the Edwards Plateau have largely been removed from this region and the resistant nature of the older strata creates a land surface of strong relief.

The Osage section of the Central Lowland province, located north of the Central Texas section (Figure 2.6-1), is a long plain of low relief stretching from Kansas to Texas. The plain is interrupted at intervals by east-facing escarpments that indicate the presence of resistant Pennsylvanian and Permian strata within a great mass of nonresistant west or northwest dipping rocks. Along the western boundary of the section is an east-facing escarpment, several hundred feet high and deeply scalloped into the Texas panhandle by the wide valleys of east-flowing streams. This is the erosional edge of the late Tertiary fluvial plain.[8]

The Pecos Valley physiographic section, within which the WIPP facility is located (Figure 2.6-1), is dominated by the Pecos and upper Canadian River valleys. These river systems receive almost all of the surface drainage and a large part of the subsurface drainage in southeastern New Mexico. Together, these valleys form a long, north-south trending trough carved into the High Plains section. This trough, which varies from 5 to 30 mi in width, lies between 500 and 1000 ft below the surface of the High Plains.

The Pecos River, which flows 14 mi west of the WIPP facility, apparently originated in the Edwards Plateau[9] sometime after the Pliocene. The Pecos River apparently cut its way north by headward erosion through the Ogallala sediments, capturing and reversing the drainage of the eastward-flowing streams in the area. According to Bachman,[10,11] the present course of the Pecos was formed, at least in part, through the coalescence of trains of solution sinks. It became entrenched in this course through the processes of solution subsidence, headward cutting, and stream piracy. The age of entrenchment has been estimated as either early Pleistocene[12] or post mid-Pleistocene.[13]

The immediate valley of the Pecos is bordered on the east by an almost continuous series of bluffs, along which are located three Pleistocene to Holocene terraces. These terraces are located between approximately 10 and 80 ft above the stream channel (Sections 2.6.3.4.2 and 2.6.6.2). Beyond the bluffs is an extensive gently sloping surface known as the Mescalero Plain. This plain probably formed during a period of stability following the deposition of the Gatuna Formation in the early to mid-Pleistocene.[13] The Mescalero Plain rises eastward from 150 ft above the Pecos River to as much as 400 ft above the river at the base of the Llano Estacado[10,14] (located in the High Plains province). This area includes many low mesas, bluffs, and wide draws and is locally dissected by intermittent streams, playa pans, and small sinks.[15] The surface of the Mescalero Plain is covered with gravel and sand dunes. There also appear to be at least two distinct layers of sand cemented by caliche.

Taken as a whole, the land surface of the Pecos Valley section slopes gently eastward, reflecting the attitude of the underlying strata. The average elevations within the section range from over 6000 ft above sea level in the northwest to 2000 ft in the south. The land surface present beneath the alluvium and sand is an uneven rock floor, which formed through the differential erosion of limestone, sandstone, shale, and gypsum. Blowouts, formed by wind erosion, are particularly conspicuous some 15 mi north of the WIPP facility. Linear depressions, which may result from the leaching of carbonate cement and subsequent wind deflation, are found within the Ogallala Formation on the Mescalero Plain.[16,17]

Much of the surface of the Pecos Valley section exhibits a karst topography pitted by numerous sinks and other karst features. Bachman[11] and Lambert[18] indicate that many of these features often appear on LANDSAT imagery as water-filled depressions or ponds. Most of these are located north of the WIPP facility (near Roswell) and east of the Pecos River. They appear to be absent in the immediate vicinity of the WIPP facility.[19] Karst features and dissolution of the salt is discussed at length in Section 2.5.9.1.

2.6.2 REGIONAL GEOLOGIC AND STRUCTURAL HISTORY

The geologic history of southeastern New Mexico and west Texas is recorded in rocks ranging in age from 1400 million years to the present. The Precambrian basement (contoured in Figure 2 of Hills[3]) is overlain by an almost continuous sequence of Paleozoic marine strata and an extremely discontinuous sequence of Mesozoic and Cenozoic shallow water and terrestrial strata. This geologic record suggests a history of sedimentation and orogenic activity followed by erosion and the onset of mild epeirogenic movement. The development of a shelf and basin setting in the late Paleozoic resulted in a massive accumulation of clastics, carbonates, and evaporites. By the end of the Paleozoic, the area had stabilized and, except for a fairly brief period in the Cretaceous, remained emergent. Since that time, the Delaware Basin region has undergone only slight east-southeast tilting as a result of the late Tertiary uplift of the Guadalupe and Delaware Mountains. Figure 2.6-3 provides an outline of the major events that affected the southeastern New Mexico region. The structural elements discussed below are shown in Figure 2.6-2.

Very little is known about the Precambrian history of the region; however, the variety of Precambrian sedimentary rocks and intrusive and extrusive igneous rocks does suggest that the area had a complex history of sedimentation, mountain building, igneous episodes, and erosional cycles.[14,20,21,22] Wasserberg et al.[23] dated Precambrian igneous and metamorphic rocks from several regions in west Texas (the Franklin Mountains, Hueco Mountains, Pump Station Hills, Carrizozo Mountains, and Van Horn Mountains). The Rb/Sr and K/Ar dates obtained throughout this area were approximately 1090 million years.

The age similarity in a region approximately 500 mi long led Wasserberg et al.[23] to speculate that the rocks in the belt were emplaced and metamorphosed during a single diversified orogenic period. Wasserberg et al.[23] further speculate that this zone could represent a continuation of the Grenville Orogenic Belt of eastern North America. Dates of approximately 1250 million years and 1400 million years[23] in Precambrian rocks north of this "Grenville Belt" (i.e., Eddy County and Roosevelt County, New Mexico, and the Arbuckle Mountains) suggest some type of north to south progression of Precambrian orogenic events.

Late Precambrian rifting along the margin of ancestral North America resulted in the formation of a slowly subsiding continental shelf typical of a passive tectonic margin.[24] When the sea transgressed over this continental margin in the early Ordovician, it transformed the Texas-New Mexico region into a shallow carbonate platform. Later in the Ordovician, crustal warping and subsidence transformed part of this platform into a 350-mi-wide sag (Figure 2.6-4) called the Tobosa Basin[25] (precursor of the Permian Basin). Clastics from highlands to the north and northwest were deposited in the shallow sea which occupied this area.[25] Throughout the late Ordovician, Silurian, and Devonian, the axial portion of the Tobosa experienced an increased rate of subsidence, which ultimately formed a deep central basin surrounded by shallow perimeter regions.[25] These shallow marginal areas were sites of carbonate deposition, while much of the deep central region was sediment starved. A slight uplift in the late Devonian caused the sea to withdraw for a short time. It did, however, transgress back over the region during the latest Devonian and earliest Mississippian.

Sometime during the mid-Paleozoic, the tectonic regime of this area changed. The southern margin of North America was no longer a tectonically quiet region riding passively away from a mid-oceanic ridge. It was instead part of the plate being subducted beneath South America.[24,4] These two continents would ultimately collide and become a part of the mega-continent, Pangea. The stresses generated during the early stages of this collision (early Pennsylvanian) had a profound effect on the Tobosa Basin. Movement on old Precambrian faults uplifted a large central block of the Tobosa Basin (the Central Basin Platform), thereby dividing it into the Delaware and Midland Basins (Figure 2.6-4). The Delaware Basin subsided extremely rapidly at this time and remained deep throughout the Pennsylvanian and most of the Permian. These forces also uplifted the Matador Arch in the Texas panhandle and the Ancestral Rockies in New Mexico and Colorado.[26]

The collision between North and South America began in the east and progressed to the west. By the mid-Pennsylvanian the suturing of the two continents was complete in the Ouachita region of Oklahoma; however, it was still in progress south of the Delaware Basin. Large thrust sheets of the Marathon Allochthon moved northward as the subduction complex began to run aground.[4,27] This Marathon Allochthon (part of the Ouachita Tectonic Belt) formed a southern margin to the Delaware Basin (Figure 2.6-2). Renewed thrusting in the early Permian[4,28] significantly decreased the distance between the Marathon Orogenic Belt and the Diablo Platform, creating the Hovey Channel. It was this channel that allowed fresh sea water to circulate through the Delaware Basin until late in the Permian period.

The Marathon Orogenic Belt and other uplifts surrounding the basin provided a large quantity of clastics in the early Permian. These sediments were initially deposited on the steep unstable slopes surrounding the basin. The periodic slumping and collapse of these slopes generated turbidity currents, which transported the sediments to submarine fans within the deep basin.[25] One region of low clastic input was the northern shelf. This relative lack of clastics allowed a reef (the Abo) to form in the region of the Artesia-Vacuum Trend[25] (Figure 2.6-2).

During the mid-Permian (Leonardian) low algal banks rimmed the basin, including the region of the Central Basin Uplift (which by this time had been eroded to a flat platform and submerged beneath a shallow sea). These banks were not continuous. Channels that flowed between them transported clay and fine sand to the basin. The banks did however create enough of a barrier to restrict water circulation on the broad shelves behind them. These regions became shallow hypersaline lagoons.

The beginning of the late Permian (Guadalupian) was similar in many respects to the Leonardian. At this time the basin was rimmed by large algal reefs; first the Goat Seep and then the Capitan. Clastics continued to enter the basin through channels in the reefs. It is believed that changes in sea level played an important role in determining the amount of clastics that reached the basin.[29] Drops in sea level would stop the reef growth. They would also enable streams to transport clastics across the back reef and deposit them directly into the basin. Rises in sea level would once again flood the back reef area, greatly decreasing the quantity of clastics that reached the basin.

Each of these reefs slowly built towards the basin on its thick deposits of fore reef debris (Figure 2.6-5). The progradation of the Capitan reef gradually reduced the size of the Delaware Basin. (Reef growth from both the Marathon Orogenic Belt and the Diablo Platform decreased the size of the Hovey Channel to such an extent that the Delaware Basin was essentially cut off from the fresh sea water) This lack of fresh marine water killed the reef organisms and initiated deposition of the Ochoan evaporites. The oldest of these formations was the Castile Formation, which consists of fine laminae of limestone and anhydrite alternating with thick sequences of halite. The rate of evaporite precipitation gradually exceeded the rate of subsidence, creating a significantly shallower basin (Figure 2.6-5). The anhydrite and halite of the overlying Salado Formation (Figure 2.6-5) were precipitated in very shallow saline lagoons that progressed through numerous wetting and drying cycles.[30] The Rustler Formation, which lies above the Salado (Figure 2.6-5), records an influx of clastics and a much wider range of depositional environments. The clastics, sulfates, and carbonates that comprise this formation were deposited in environments that ranged from normal marine to saline mudpans and sabkha-like areas.[31] The red silts and sands of the Dewey Lake Formation were deposited above the Rustler and closed out the Permian Period.

Uplift and erosion occurred throughout the early and mid-Triassic. Fluvial deposition began in the late Triassic. Regional uplift occurred again in the Jurassic causing erosion of Triassic, and possibly some Permian, rocks from the western Delaware Basin. During this period, and perhaps as early as the Triassic, dissolution of some of the upper Permian evaporites produced karst terrains.[11,32] Uplift and tilting in the late Jurassic and early Cretaceous resulted in widespread erosion.[14,27]

Later in the Cretaceous, the region subsided slightly, and shallow, intermittent seas, advancing from the south, deposited a thin layer of carbonates and coarse clastics. Late in the period, the seas withdrew, probably for the last time.[21,33] The close of the Mesozoic was marked by the Laramide Orogeny and the uplift of the Rocky Mountains, with tectonic and igneous activity west and north of the WIPP facility. During this time, southeastern New Mexico underwent a broad epeirogenic uplift and was tilted slightly to the northeast.

No early or middle Tertiary sedimentary rocks are present in the Permian Basin area. The Cretaceous and Triassic rocks of the area underwent intense erosion to form a surface of low relief that sloped gently to the east and southeast.[11,15] By the Miocene, the Permian rocks in the northern Delaware Basin were again exposed to dissolution.[11]

Basin and Range tectonic activity commenced to the west during the late Tertiary and produced (1) the western faulted escarpments of the Delaware, Guadalupe, and Sacramento Mountains; (2) regional uplift; and (3) east-to-southeast tilting. Streams flowing down this eastward dipping slope deposited the extensive Ogallala clastics in thick coalescing alluvial fans and produced the even surface of the Llano Estacado.[34] When Ogallala deposition ceased some three to four million years ago, the region was tectonically stable with a semiarid to arid climate. This arid environment enabled a caliche caprock to form on the Llano Estacado surface.

Renewed uplift of the Guadalupe Mountains occurred in the Late Pliocene and early Pleistocene[21] and was followed by an intensive period of erosion.[11] The sediments eroded from the Guadalupe Mountains formed large fields of longitudinal dunes on the Ogallala surface to the east. Since that time, erosion and sediment reworking has generally exceeded deposition in the Permian Basin.

The coarse fluvial clastics that comprise the Gatuna Formation are an exception. They were deposited, very locally, during one of the several moist climatic periods of the mid-Pleistocene.[11] Dissolution of Ochoan evaporites is also believed to have occurred during these periods of increased precipitation. Since the mid-Pleistocene, the climate has fluctuated with a general trend toward greater aridity. The Mescalero caliche accumulated during the more stable, semiarid periods which followed Gatuna deposition.[11] Detrital materials, reworked by winds from the west and southwest, form the deposits of dune sand, which now cover large parts of southeastern New Mexico.

Slight uplift is apparently still occurring along the western faulted escarpments of the Basin and Range structures, i.e., the Guadalupe Mountains (Section 2.8.2).[35] Periodic downcutting by streams and subsurface solution, with resultant subsidence, have continued to the present. Most of the recent erosion has been confined to the Pecos Valley, and solution and subsidence have occurred at a slower rate than during the mid-Pleistocene.[10] The only regions of recent deposition include local accumulations of terrace alluvium and playa deposits.

2.6.3 REGIONAL STRATIGRAPHY AND LITHOLOGY

The stratigraphic sequence of southeastern New Mexico and west Texas is dominated by the sediments of the late Paleozoic Permian Basin. A metasedimentary-igneous Precambrian basement is overlain by a maximum of about 20,000 ft of Paleozoic carbonates, evaporites, and clastics which are, in turn, mantled by relatively thin, primarily terrestrial Mesozoic and Cenozoic clastics, caliche, and eolian deposits.[36] Figure 2.6-6 shows a geologic map of the region. The major rock units underlying the area are discussed below, from oldest to youngest. Figures 2.6-5 and 2.6-7 are north-south and east-west cross sections demonstrating the relative thicknesses and relationships of these units.

2.6.3.1 Precambrian Rocks

Precambrian outcrops composed of siltstone, shale, quartz sandstone (intruded by diabase sills), and gneiss are present west of the Delaware Basin.[14,37,38,39] Further east in the basin, the Precambrian dips beneath the thick sedimentary section to depths of up to 20,000 ft below sea level. It then rises rapidly on the Central Basin Platform to between 4000 and 5000 ft below sea level (Figures 2.6-7 and 2.6-8).

Slightly foliated and sheared granitics underlie most of south-central New Mexico, including the vicinity of the WIPP facility and nearby parts of Texas.[22,40,41] Radiometric dates for these granites range from between 1250 and 1400 million years in the north to 1090 million years in the south[23] (Section 2.6.2). Diabase and slightly metamorphosed clastics are also present in the northwest and southwest.[42] Rhyolitic materials, predominantly undeformed, overlie much of the older Precambrian of the region. These rhyolites, which yield an average age of 1450 $\pm$ 50 million years,[20] are intruded by gabbros and basalts in Texas and in the vicinity north of the WIPP facility. (Muehlberger et al.[20] discusses the regional classification of these terrains.)

2.6.3.2 Paleozoic Rocks

Paleozoic strata overlying the Precambrian basement consist of several thousand feet of lower through middle Paleozoic carbonates and clastics overlain by up to about 18,000 ft of upper Paleozoic clastics, carbonates, and evaporites. This area contains the most massive and complete section of Permian evaporites in North America. The formation nomenclature and correlation within this section follows the 1983 AAPG correlation chart series.[43]

2.6.3.2.1 Cambrian System

The Bliss Sandstone is exposed only to the west of the Delaware Basin in the Sacramento, San Andres, and Franklin Mountains.[36] It consists mainly of fine to coarse, well-sorted quartz sandstone. Thin beds of clastic dolomite form approximately one-fourth of the beds, while siltstone and shale occur only in minor quantities. Many beds are cross-laminated, and others contain burrows approximately .1 to .2 in in diameter.[37] Some layers of the formation weather to a dark reddish-brown because they contain the mineral glauconite.

The sands of the Bliss Formation were deposited in the beach or nearshore environments of the sea, which slowly transgressed over the Precambrian continental margin. The formation is therefore time transgressive and ranges in age from late Cambrian (to the west) to early Ordovician (to the east). Under the WIPP facility area, the Bliss is probably of early Ordovician in age.[44,45,46]

2.6.3.2.2 Ordovician System

The Ordovician System is composed almost entirely of shallow water carbonates. These carbonates comprise the El Paso Group (known as the Ellenberger Group in Texas), the Simpson Group, and the Montoya Group. The El Paso Group[9] varies in thickness from 400 to 1600 ft and is composed predominantly of light olive gray, finely crystalline dolomite. Dolomitic quartz sandstone and chert nodules are present in the lower portions of the group.

A withdrawal of the sea in the mid-Ordovician ended carbonate deposition for a short time. The subsequent transgression of the sea, a little later in the Ordovician, led to the deposition of the carbonates, shales, and sands of the Simpson Group. Because there is no evidence of a nearshore facies within these sediments, Galley[48] suggests that the group once extended beyond the Permian Basin (possibly into Oklahoma and Kansas) and that subsequent erosion reduced its areal extent to the Permian Basin region.

The carbonates of the upper Ordovician Montoya Group were deposited above the Simpson. This group, which ranges in thickness from 280 to 440 ft in southwest New Mexico, is composed predominantly of dolomite and cherty dolomite, except for a thin interval of dolomitic quartz sandstone or sandy dolomite near its base. The top of the unit is marked by a distinctive zone of cherty dolomite.[49,50]

2.6.3.2.3 Silurian - Devonian Systems

The Silurian, Devonian, and Mississippian strata of the Delaware Basin were deposited in the broad subsiding region of the Tobosa Basin. The Silurian of the Delaware Basin and Central Basin Platform is represented by the Fusselman Dolomite of middle and possibly early Silurian age,[44,51] and the Wristen Formation of upper Silurian age.[43] The Silurian of the Carlsbad and Northern Shelf regions is represented by a carbonate unit known only as the "Silurian Limestone."[43]

Lower to Middle Devonian strata in the Delaware Basin and on the Central Basin Platform are referenced to as the Thirty-one Formation.[43] This unit is composed primarily of chert, siliceous micrite, and light-colored calcarenite.[52] Along the Sacramento Mountain escarpment to the west, the upper middle-Devonian unit is the Onate Formation.[39] This formation consists of dark gray, finely crystalline dolomite interbedded with silt, sand, and shale.

The sea withdrew from the region in the late Devonian. The subsequent transgression deposited a shale known in the basin and on the Central Basin Platform as the Woodford Shale and in the Sacramento and Franklin Mountains as the Percha Shale and Canutillo Formation.[52] This unit, which is less than 200 ft thick in the Delaware Basin, consists of black, fissile, bituminous, spore-bearing shale. It contains interbedded chert layers to the south and west and becomes arenaceous to the north.

2.6.3.2.4 Mississippian System

The Woodford Shale, in the Delaware Basin and on the Northern Shelf, is overlain unconformably by the argillaceous gray limestones of the Rancheria Formation,[37,50] which in turn are overlain by the fine-grained clastics of the Helms Formation.[43] The Mississippian system on the Central Basin Platform is also composed of a lower carbonate unit (the Mississippian Limestone)[43] and an upper clastic unit (the Barnett Shale)[43]. In the Western Palo Duro Basin, to the northeast, the Mississippian system is composed entirely of carbonates (Osage Limestone, Meramec Limestone, and Chester Limestone).[43]

2.6.3.2.5 Pennsylvanian System

The stresses generated by the collision of North and South America began to affect the west Texas-New Mexico region in the Pennsylvanian. The Central Basin Platform and the Matador Arch were uplifted while the Delaware and Midland Basins were depressed. This rapidly differentiating basin and shelf structural configuration makes the correlation of Pennsylvanian rock units extremely difficult.

The northern Delaware Basin was the site of clastic deposition in the early Pennsylvanian (Morrowan Epoch). These argillaceous carbonates, sands, and shales comprise the Morrow Group.[33,53] Clastic deposition continued into the beginning of the Atokoan Epoch; however, as this epoch progressed, carbonates became more abundant.[53] The mid-Pennsylvanian Des Moines Series is composed predominantly of carbonates. Deposition during this time was very much influenced by the developing basin and shelf environments. The shelves were the sites of shallow carbonate deposition, while the deeper basins received dark brown, fine-grained cherty carbonates.[54] These basinal sediments, known as the Strawn Group, are noted for containing numerous stratigraphic oil and gas traps.[51] The Missourian rocks of early late-Pennsylvanian age, generally present only in the deeper portions of the Permian Basin, consist of clastics as well as carbonates. The uppermost Pennsylvanian section, the Virgilian, differs from the earlier series in that reefs began to grow around the northern margin of the Delaware Basin. The reefs, which would continue to grow in the Wolfcampian (lowermost Permian), restricted water circulation and initiated the precipitation of the evaporites found in the Virgilian Series.[54,55]

2.6.3.2.6 Permian System

The Wolfcampian (early Permian) was the time of final thrusting in the Marathon Orogenic Belt.[4] This event sent sands and coarser clastics into the southern part of the basin, while the central and northern portions received only shale and carbonates. (Figure 2.6-9 contains an isopach map of the Wolfcampian Series.) The shelf areas of this time were sites of shallow water limestone and dolomite deposition. The Wolfcampian of the Northern Shelf is divided into two cherty limestone units separated by red, green, and gray mud- stones interbedded with limestone. Each of these units becomes thicker and sandier toward the north. The Wolfcampian of the Central Basin Platform is represented by limestones of the Hueco Formation[33] (Figure 2.6-10). This formation, although chiefly limestone, contains a thick basal unit of red and green shale and conglomerate.[33]

The circulation on the shelves was generally good during the Wolfcampian because the reefs, which later rimmed the basin, were not yet abundant. There was, however, one reef (the Abo) rimming a portion of the northern basin. This reef is outlined today by the Artesia-Vacuum Trend (Figure 2.6-2), which formed because of the uneven compaction over the Abo.

The lower Leonardian was similar in many respects to the Wolfcampian. The fine-grained, dark, arenaceous limestone of the Bone Spring Formation was deposited both in the basin and on the basin margin (Figure 2.6-10). The dolomites and red clastics of the Abo Formation and Wichita Group were deposited in the lagoons and coastal regions of the Northwestern Shelf and the Central Basin Platform, respectively (Figure 2.6-10).

Changes occurred in the late Leonardian. For the first time, the basin margin was the site of increased organic productivity. The Victoria Peak Member (massive, white to light buff dolomite) of the Bone Spring Formation was deposited on a low broad bank which rimmed the basin[9] (Figure 2.6-10). Eventually this shallow carbonate bank subsided and was covered by the black shales and dark dolomites of the Cutoff Member of the Bone Spring Formation.[9] (See Figure 2.6-9 for an isopach map of the Leonardian Series.)

The events that occurred after the deposition of the Cutoff Member are questionable. King[9] believed that a drop in sea level exposed the surrounding shelves and significiantly lowered the sea level in the Delaware Basin. Harms,[56] however, believes that the sea level remained relatively stable, and that the 1150 ft of fine-grained quartz sand and silt were transported out into the basin by density flows originating in the more saline shelf regions. These early Guadalupian sediments that contain small patch reefs,[57] channel structures, ripple marks, and cross-bedded strata[56] comprise the Brushy Canyon Formation. This formation is the first of three basinal formations known as the Delaware Mountain Group. (The other two are the Cherry Canyon and Bell Canyon, Figure 2.6-10).

The events that occurred during the remainder of the Guadalupian Epoch are less controversial. Most workers agree that water in the basin reached depths of up to 1970 ft[56], while more shallow, saline water covered large portions of the shelves. The Cherry Canyon, which consists of thin tongues of dark-colored bioclastic limestone separated by unnamed divisions of fine-grained sandstone[57] was deposited in the basin while the carbonate and clastics of the San Andres were deposited on the shelves (Figures 2.6-5 and 2.6-10). The sands constituting the clastic members of the Cherry Canyon and the later Bell Canyon are believed to have been transported across the shelves during periods of relatively low sea level.[29] Once the sand reached the basin, it was deposited on the slopes and later swept into the basin by turbidity currents. Most of these clastic members thin and pinch out near the basin margin, however, the earliest sandstone tongue of the Cherry Canyon was deposited over the basin margin and onto the shelf, interfingering with the San Andres[57] (Figure 2.6-10).

Eventually a reef (the Goat Seep) formed around the basin margin. Its fore reef debris interfingered with the Cherry Canyon sediments which were deposited in the basin (Figure 2.6-5). Sometimes landslides from the reef front transported large blocks, weighing several tons and measuring up to 14 ft across,[57] into the deep basin. These deposits appear as unstratified subangular fragments and blocks of limestone in a matrix of fine-grained gray limestone and quartz sandstone.[57] The dolomites and sandstones of the Grayburg and Queen Formation were deposited in the more restricted lagoonal areas behind the Goat Seep reef (Figure 2.6-5).

The Capitan reef grew around the basin somewhat later in the Guadalupian. The depositional environments did not change appreciably. The reef talus once again interfingered with the basinal deposits (the Bell Canyon Formation), and the Seven Rivers, Yates, and Tansill Formations were deposited in the restricted lagoonal and shoreline environments of the back reef (Figures 2.6-5 and 2.6-10). (See Figure 2.6-9 for an isopach map of the Guadalupian Series.)

The Capitan reef virtually encircled the Delaware Basin. It is exposed in the bold escarpment along the Guadalupe Mountains in the vicinity of White's City and in the Glass Mountains to the south. It is composed of two members[21]: a massive cliff, forming fine-textured, fossiliferous limestone with virtually no bedding planes (the actual reef) and a limestone composed of microbreccia and angular cobbles and boulders of limestone and dolomite (the fore reef talus). This fore reef talus constitutes approximately two-thirds of the entire Capitan Limestone.[21]

The Capitan reef grew towards the basin, on top of this huge pile of fore reef debris. This growth greatly reduced the size of both the Delaware Basin and the Hovey Channel. This channel, located to the southwest, supplied fresh sea water to the Delaware Basin. When its size decreased, the quantity of sea water entering the basin also decreased. Gradually the water in the basin became more saline, killing the reef and initiating the precipitation of the gypsum, calcite and gypsum laminae, and halite of the Castile Formation (Figures 2.6-5 and 2.6-10). The precipitation of these evaporites gradually filled the deep Delaware Basin and transformed the environment into one of shallow saline lagoons, which progressed through numerous wetting and drying cycles.[30]

Approximately 2000 ft of halite, argillaceous halite, anhydrite, red mudstone, sandstone, and siltstone were deposited in the lagoons.[30] The evaporites and clastics of the Salado Formation are not limited to the Delaware Basin but were deposited throughout the entire Permian Basin (Figures 2.6-5 and 2.6-10). The wetting and drying cycles that affected these shallow lagoons are reflected in the 2 to 30-ft-thick cyclic sequences present in the formation.[30] Each cycle begins with a detrital layer consisting predominantly of claystone. This lowermost zone is followed by a layer of anhydrite, which in turn, is followed by a layer of halite. The entire sequence is capped by a bed of argillaceous halite.[15,28,58]

The cyclic deposits of the Salado are overlain by the sulfates, carbonates, and clastics of the Rustler Formation (Figure 2.6-10). At the WIPP facility, this formation has been divided into five members.[59] The lowest unnamed member consists of 100 ft of siltstone and sandstone interbedded with gypsum and anhydrite. This is overlain by the 30 ft of gray, microcrystalline, cavity-rich dolomite of the Culebra Dolomite Member. The Tamarisk Member, located above the Culebra, is composed of 115 ft of anhydrite with a single siltstone bed. This in turn is overlain by 20 ft of wavy dolomite, anhydrite, and gypsum laminae (the Magenta Dolomite Member). The fifth and uppermost member of the Rustler is the Forty-Niner, that is approximately 65 ft thick and composed of anhydrite and siltstone. The sulfates, carbonates, and clastics which comprise these five members were deposited in a wide variety of environments ranging from normal marine to saline mudpans and sabkha-like areas.[31]

The Rustler Formation is conformably overlain by the red siltstones and sandstones of the Dewey Lake Formation (Figure 2.6-10). This unit, which varies in thickness from 250 ft[59] to 493 ft[60,61] due to post-depositional erosion, is traditionally placed within the late Permian; however, a lack of fossil evidence leaves its age open to some question. The precise depositional environments of the Dewey Lake are also questionable. Theories range from a large saline lake[59] to shallow hypersaline water bodies, tidal flats, and sabkhas.[62] (See Figure 2.6-9 for an isopach map of the Ochoan Series.)

2.6.3.3 Mesozoic Rocks

2.6.3.3.1 Triassic System

The only rocks of Triassic age in the area are the upper Triassic Dockum Group redbeds, sandstones, and conglomerates. Away from the WIPP facility, the Dockum Group has been subdivided into three formations. In descending order, they are the Chinle Formation equivalent, the Santa Rosa Sandstone and the Tecovas Formation. McGowan et al.[62] indicate that it is preferable to refer to the Triassic deposites in the vicinity of the WIPP facility as Dockum undivided, not as the Santa Rose Sandstone. The Dockum Group reaches a maximum thickness of 1500 ft near the Texas-New Mexico border and thins westward, due to partial removal by post-Mesozoic erosion.[23]

2.6.3.3.2 Jurassic System

No record of Jurassic deposition is known to exist in southeastern New Mexico.

2.6.3.3.3 Cretaceous System

Only scattered patches of probable early and mid-Cretaceous limestone and sandstone remain in the area as remnants of deposition in shallow transgressing seas.[13,21,33] A conglomeratic sandstone, approximately 150 ft thick and overlain by shale, is present along the crest of the Sacramento Mountains.[63] Further south, on the

Northwestern Shelf and along the Capitan reef escarpment, solution cavities in the Castile Formation contain fragments of fossiliferous, sandy limestone of Lower Cretaceous age. Several exposures of Cretaceous rocks have been identified in Lea County; these consist of slump blocks of massive, fossiliferous, light-colored shaly sandstone near Eunice and a dark gray siltstone with interbedded brown and gray crystalline limestone near North Lake.[33,64] (Cretaceous rocks are generally continuous in the subsurface of northeastern Lea County; however, farther west and south only discontinuous occurrences have been encountered).

2.6.3.4 Cenozoic Rocks

2.6.3.4.1 Tertiary System

Widespread uplift and erosion occurred following the Cretaceous, and as a result, no lower or mid-Tertiary clastics are known in the region. However, early to mid-Tertiary intrusive bodies and Tertiary to Quaternary volcanic terrains have been identified within 200 mi of the WIPP facility. They are probably the result of Laramide and Basin and Range activity centered to the west. Figure 2.6-11 shows the distribution of the major igneous outcrop areas in the region.

The igneous rocks of the northern Delaware Basin have been observed in two potash mines and several drill holes (Table 1, Reference 65) and appear to exist as a dike or a series of en echelon dikes that rise vertically from basement rocks and pinch out in an upward direction.[66] These dikes trend N50E for a distance of perhaps 80 mi from the Yeso Hills in the southwest to the Vacuum oil field south of Buckeye in central Lea County.[10] They pass 10 mi northeast of the WIPP facility (Figures 2.6-11 and 2.6-12) and intrude units as young as the Salado.

The width of the dikes is uncertain. Drill hole intercepts and exposures in potash mines reveal nearly vertical intrusives, which vary in thickness from a few inches to 12 ft.[65] Interpretations made from aeromagnetic data suggest that the width of the dike or dike zone increases with depth. Elliot[66] suggests a width of tens of miles near the basement while Calzia and Hiss[65] depict the width of the dike zone as between 1 and 1.5 mi at basement level.

The rock composing the dike is a medium gray-to-black, fine-grained, slightly porphyritic material identified by Jones[67] as a lamprophyre and by Calzia and Hiss[65] as a basaltic andesite. It contains numerous vertical to subhorizontal fissures and amygdules (up to .08 in across) filled with a variety of secondary minerals. The dike has a chilled border and a flow structure expressed by lath-shaped plagioclase crystals. The halite of the intruded beds has been recrystallized as far as 3/4 in from the contact and contains gases such as methane. A vein of polyhalite, with minor accessory minerals, extends from the intrusive contact through the adjacent salt, indicating that some fluid migration, recrystallization, and plastic flowage (with healing of any fissures) occurred after the intrusion.[73] The emplacement of this dike system occurred during the early Oligocene (about 32.2 $\pm$ 1.0 million years) according to K/Ar whole-rock dating by Calzia and Hiss.[65] The structural relationships of this dike system are discussed below in subsection 2.6.4.1.1.

The remainder of the igneous materials in the region occurs well to the west, north, and south of the WIPP facility (Figure 2.6-11). Tertiary alkalic intrusives have been identified in the area of the Guadalupe and Delaware Mountains.[9,69] To the south, the Trans-Pecos "magmatic province," (extending from the Cornudas Mountains down through the Davis Mountain volcanic area) is composed of more than 200 intrusive bodies, each of which is over 1/2 mi in exposed surface area. The northernmost section of this igneous province (centered about 105 mi west-southwest of the WIPP facility) contains the Cornudas Group, which is composed of a number of syenite plugs surrounded by sills and laccoliths. Further south is the Davis Mountain volcanic area.[70] The volcanics within this 6000 mi^2 region range in age from 16 to 43 million years.[71,72]

About 67 mi north of the site, on the Northwestern Shelf are two east-west trending Tertiary dikes[70,73] (Figure 2.6-11). The southernmost, named El Camino del Diablo, is composed of altered, fine-grained, slightly porphyritic andesite. It is exposed for approximately 25 mi and ranges in width from 32 to 47 ft.[14,70] Thirteen miles north of the El Camino del Diablo is the Railroad Mountain dike, exposed for a distance of 30 mi. This dike, which is approximately 100 ft wide at the surface, forms a ridge some 60 to 80 ft high composed of massive, dark blue, medium-grained granite.

Other major igneous features in the area are the mid-Tertiary intrusions composed of leucocratic quartz syenite[14,73] which form the Capitan Mountains laccolith or stock, and the early to mid-Tertiary volcanics, dikes, and stocks of Sierra Blanca[14,74] (Figure 2.6-11). According to Eardley,[2] these intrusions are part of a belt of Laramide stocks, laccoliths, dikes, and sills that extend from Colorado to Mexico.

The oldest Cenozoic sedimentary unit in the region is the Miocene to Pliocene Ogallala Formation, which was deposited in coalescing alluvial fans built out from the Rocky Mountains.[13] The Ogallala, which is not present in the immediate vicinity of the WIPP facility, consists of yellowish gray, semi-consolidated, fine-to-medium grained calcareous sand, and smaller amounts of silt, clay, and gravel. The Ogallala, which in places is cemented by silica, ranges in thickness from a few inches to over 400 ft. It contains no consistent Marker Beds due to the complex intertonguing of the sediments.[10,13,33] Ogallala deposition ended three to four million years ago.[11]

The Ogallala is capped by a dense layer of brecciated and pisolitic caliche ranging in thickness from a few feet to as much as 60 ft. At the surface the caliche is well indurated calcium carbonate; however, it becomes softer and more porous in the lower portions and eventually grades into the underlying sands. This soil probably developed atop the Ogallala sands during the late Pliocene, before the extensive Pleistocene erosion in the area.[13,33]

2.6.3.4.2 Quaternary System

Although erosion was dominant during the Quaternary, there were periods of sedimentation that formed the Gatuna Formation and terrace, channel, playa, and windblown sand deposits. The Gatuna, of probable early to middle Pleistocene (Kansan) age,[9] unconformably overlies rocks as old as Permian and Triassic. It consists of up to several hundred feet of reddish brown, friable sand, silt and cherty conglomerate with local gypsum, gray shale, and claystone. The Gatuna appears to have been deposited in local depressions such as stream channels and in solution-subsidence areas.[10,59]

The Mescalero caliche was formed on the Gatuna and older units during the Yarmouthian interglacial period,[11] approximately 510,000 to 410,000 years ago. The caliche consists of from three to less than 10 ft of sandy, buff to white, calcareous material with a lower nodular zone overlain by a dense laminar caprock.[11]

Late Pleistocene to Holocene channel, terrace, and playa materials have been deposited primarily along the Pecos River and Guadalupe Mountains. Three terraces, the Pleistocene Blackdom and Orchard Peak, and the Holocene Lakewood, are recognized in the region. They consist of limestone conglomerates, capped by caliche and younger river conglomerates, as well as lacustrine deposits.[10,75] Playa and shallow lake deposits consist of alluvium, reworked eolian sand, silt, and clay. Gypsum, carbonates and halite have also been deposited around some of the standing lakes.[58,75]

Windblown quartz sands, in the form of dune ridges and hummocky sheets as deep as 100 ft, mantle much of the land surface east of the Pecos River. The light brown to pale reddish brown sand is fine-grained and fairly uniform in size. Most of it has been stabilized by vegetation. The long dimensions of these dunes appear to be aligned parallel to the wind direction, which prevailed at the time of their formation.

2.6.4 REGIONAL STRUCTURE AND TECTONICS

The major tectonic structures of the region are shown in Figure 2.6-2. Most of the large-scale structures were completely formed before the late Paleozoic. The remainder of the major tectonic features, as well as the gentle east-southeast regional tilt, were formed as a result of the mid to late Tertiary and Quaternary Basin and Range-related doming and faulting.

The WIPP facility lies near the western margin of the Permian Basin, which extends from the Amarillo uplift in the north to the Marathon uplift in the south (approximately 520 mi) and from west central Texas to the Diablo Platform and Guadalupe Mountains (approximately 300 mi)[27] (Figure 2.6-2). The Permian Basin is a Paleozoic feature composed of a series of sedimentary basins in which halite and associated salts accumulated during the late Permian and where Permian rocks reach their maximum thickness.

The structural development of the Permian Basin began in the late Ordovician when a broad sag, the precursor of the Permian Basin, was formed. This sag, named the Tobosa Basin by Galley,[48] occupied a slightly more restricted area than the Permian Basin (Figure 2.6-4).

Before the late Mississippian, several periods of minor folding, faulting, uplift, and subsequent erosion occurred, however, a general structural stability prevailed. Tectonic activity eventually accelerated in the area, climaxing in the late Pennsylvanian and earliest Permian, coincident with the Marathon Orogeny to the south. This tectonic activity split the basin into two rapidly subsiding basins: the Midland to the east and the Delaware to the west[45] (Figure 2.6-4). Structural development of the Delaware Basin continued until the late Permian. At that time, the basin stabilized and subsequently lost its topographic expression due to filling by evaporites. Since then, the Permian Basin as a whole has remained internally stable. Late Cenozoic Basin and Range mountain building occurred along the western margin of the Permian Basin and produced a series of fault-bounded mountains and grabens (Figure 2.6-2).

The structure and development of each of the major tectonic units in the southeastern New Mexico-west Texas region is described below. The features are discussed according to structural type; those features that underwent major development in Paleozoic time are discussed before those which are primarily Basin and Range in origin. The major folds, flexures, and faults of the WIPP facility region are discussed separately in the following section.

2.6.4.1 Basins

2.6.4.1.1 Delaware Basin

The Delaware Basin is a broad, asymmetrical trough that extends roughly 75 to 100 mi in the east-west direction and 135 to 160 mi in the north-south direction (Figure 2.6-2). The northern boundary of the basin, which encloses an area of approximately 12,000 mi^2, is usually taken at the shelf edge as delineated by the Capitan reef but for older Permian levels it is commonly taken at the Abo reef front, 25 mi to the north (Artesia-Vacuum Trend - Figure 2.6-2). Structurally, the basin has a north-south trend and a southward plunge with more than 15,000 ft of relief on the Precambrian (Figure 2.6-8). The eastern slope of the Delaware Basin rises rapidly to the Central Basin Platform, while the western slope is much gentler.

The Delaware Basin was structurally defined by the early Pennsylvanian. Major structural adjustments occurred during the late Pennsylvanian and early Permian. Regional subsidence in conjunction with broad arching, folding, and faulting took place until the late Permian, when the structural development of the basin ended.[15] Regional uplift followed in the Triassic, and emergent conditions continued through the Cenozoic.

During the Cenozoic, Basin and Range faulting tilted the basin to the east, shifting its axis close to the Central Basin Platform.[76,77] Late Cenozoic structural developments in the basin seem to be related to the dissolution and associated collapse of late Paleozoic sediments.[11]

Minor flexures, particularly within the lower and mid-Permian strata, minor folding of younger beds, and possible anticlinal features within the Ochoan evaporites, all occur in the Delaware Basin (Section 2.6.4.3). Faults are also present in the basin and include deep-seated Paleozoic basement faults, minor Permian gravity faults, and Paleozoic basin-margin faults (Section 2.6.4.4.1).

Collapse structures dot the surface of the basin. They are formed by the dissolution of evaporites, the hydration of anhydrite within the Rustler and Salado Formations, and the collapse of overlying strata into cavities formed in the Capitan reef by phreatic dissolution (Section 2.6.1).

Two sets of joints, striking northwest and northeast, are recognized in the basin rocks. The northeast trending set is generally better developed and appears to have formed some time before the Cenozoic. This age is indicated by the fact that exposures of the Capitan and Tansill Formations (near Carlsbad Caverns) have joints containing Cretaceous sandstone and conglomerate.[78] It is believed that this pre-Cenozoic structural weakness had some effect on the emplacement of the northeast trending mid-Tertiary dikes (Figure 2.6-11).

The precise origin of these dikes is uncertain. Eardley[2] suggests that they may be related to late Laramide activity, while Hills[77] believes that they are related to early Tertiary movement, which tilted the Delaware Basin. Similarly, Hayes[21] states that the three small alkali-trachyte dikes found in the Guadalupe Mountains area may have been intruded during or following the Cretaceous to very early Tertiary uplift tilting, and mild tectonism, which affected the area. A third possible explanation for these dikes (dated at 32.2 to 33.9 million years by Calzia and Hiss[65]) is that they are the result of very early Basin and Range extension (30 or 31 million years)[79] in the Trans-Pecos region.

2.6.4.1.2 Val Verde Basin

The Val Verde Basin is a deep, early Permian depositional structure at the southeastern extent of the Permian Basin (Figure 2.6-2). It is south of the Delaware Basin and adjacent to the northern rim of the Ouachita Tectonic Belt. The synclinal axis of the Val Verde Basin trends west-northwest toward the Delaware Basin.

The southeastern portion of the Val Verde Basin may have been established in the early Pennsylvanian. In the early Permian, the entire basin was abruptly deepened and its northern side steepened as a result of large-scale thrust faulting associated with the Marathon Orogeny. This major downwarping enabled early Permian strata to accumulate to a thickness of over 17,000 ft, the maximum for the entire Permian Basin region. By the mid-Permian, the deformation had decreased markedly, and a shelf formed across part of the area. Early Triassic warping and erosion of the Permian rocks probably ended the structural activity of the Val Verde Basin.[28,80,81]

2.6.4.1.3 Midland Basin

The Midland Basin, to the east of the Central Basin Platform, extends some 200 mi along a north-northwest trend (Figure 2.6-2). The Midland Basin is more symmetric than the Delaware Basin, with a relief on the Precambrian of only 4000 to 5000 ft, compared with the 15,000 ft of the Delaware Basin. Major faulting occurred in the southern and western parts of the basin prior to the late Permian[82]; however, general tectonic stability has prevailed since that time.

2.6.4.1.4 Salt Basin

The Salt Basin (or Salt Flat Graben) is a large late Cenozoic bolson located west of the Guadalupe and Delaware Mountains and east of the Diablo Platform (Figure 2.6-2). This bolson, which rises on both its north and south ends to merge into rocky plateaus,[7] is approximately 150 mi long and 8 to 20 mi wide. The floor of the basin is covered by evaporites and sandy unconsolidated Cenozoic sediments. The evaporites in the basin precipitate from groundwater[83] and out of shallow saline lakes, which form in parts of the basin after particularly wet seasons.

Structurally, the Salt Basin is a large down-faulted block with an average floor elevation of about 3600 ft and relief of approximately 800 ft.[12] It was formed by high-angle Basin and Range faulting, which was most pronounced from the late Pliocene to the early Pleistocene.[9] This faulting (which is probably continuing to the present) and recent studies of the Salt Basin are discussed in Sections 2.6.4.4.6 and 2.6.4.5.3.

2.6.4.2 Platforms, Shelves, and Mountain Systems

2.6.4.2.1 Northwestern Shelf

North and northwest of the Delaware Basin is an area underlain by shelf limestone and Virgilian-age reefs and evaporites. This "northwestern shelf" (Figure 2.6-2) may have originated in the early Paleozoic when it formed the margin of the early Tobosa Basin[28,48] (Figure 2.6-4). The abundance of pre-Permian shelf limestone and reefs indicates that it was definitely well developed before the Permian. During the late Permian, the Northwestern Shelf was a low-lying, lagoonal tidal flat area. Decreased circulation in this back reef area frequently led to the precipitation of gypsum and other evaporites.

Except for the Guadalupe Mountains, which are located in the south-western portion of the shelf, deformation has been minor. Structural features consist primarily of early Tertiary and older folds, arches, flexures, and several linear shears or monoclinal features. Many of the fold systems lie parallel to or near the reef front escarpment. Some of these folds reflect deep basement faulting while others are superimposed over older flexures or are thought to result from sedimentary compaction.[45] Many of the folds, particularly those in the southwestern part of the shelf, were formed in the early to mid-Permian, possibly as a result of the Marathon Orogeny. Rejuvenation of some of these features, such as the Bone Spring Flexure, occurred prior to the late Permian and influenced the growth of the Guadalupian reefs. Some minor folding and shearing to the north may have continued during the Laramide Orogeny and into the Tertiary. The major types of folds and flexures on the shelf are discussed in Section 2.6.4.3.

An area of prominent fault-like structures (on the shelf) lies north of the Delaware Basin and consists of a zone of straight northeast trending shears: the Border Hills, Six-Mile Hill, and Y-0 buckles shown in Figure 2.6-2. Movement along these shears, which are considered in more detail in Section 2.6.4.4.4, may have been initiated in the Carboniferous or earlier geologic time period.[14,15] Another area of faulting, which may have been active throughout the Mississippian to early Permian, underlies the northern Guadalupe Mountains.[21] The most recent faulting of the Northwestern Shelf was the late Tertiary to Quaternary faulting associated with Basin and Range activities (Section 2.6.4.2.5). Since that time the shelf has represented a broad area of tectonic stability.

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North and northwest of the Delaware Basin is an area underlain by shelf limestone and Virgilian-age reefs and evaporites. This "northwestern shelf" (Figure 2.6-2) may have originated in the early Paleozoic when it formed the margin of the early Tobosa Basin[28,48] (Figure 2.6-4). The abundance of pre-Permian shelf limestone and reefs indicates that it was definitely well developed before the Permian. During the late Permian, the Northwestern Shelf was a low-lying, lagoonal tidal flat area. Decreased circulation in this back reef area frequently led to the precipitation of gypsum and other evaporites.

Except for the Guadalupe Mountains, which are located in the south-western portion of the shelf, deformation has been minor. Structural features consist primarily of early Tertiary and older folds, arches, flexures, and several linear shears or monoclinal features. Many of the fold systems lie parallel to or near the reef front escarpment. Some of these folds reflect deep basement faulting while others are superimposed over older flexures or are thought to result from sedimentary compaction.[45] Many of the folds, particularly those in the southwestern part of the shelf, were formed in the early to mid-Permian, possibly as a result of the Marathon Orogeny. Rejuvenation of some of these features, such as the Bone Spring Flexure, occurred prior to the late Permian and influenced the growth of the Guadalupian reefs. Some minor folding and shearing to the north may have continued during the Laramide Orogeny and into the Tertiary. The major types of folds and flexures on the shelf are discussed in Section 2.6.4.3.

An area of prominent fault-like structures (on the shelf) lies north of the Delaware Basin and consists of a zone of straight northeast trending shears: the Border Hills, Six-Mile Hill, and Y-0 buckles shown in Figure 2.6-2. Movement along these shears, which are considered in more detail in Section 2.6.4.4.4, may have been initiated in the Carboniferous or earlier geologic time period.[14,15] Another area of faulting, which may have been active throughout the Mississippian to early Permian, underlies the northern Guadalupe Mountains.[21] The most recent faulting of the Northwestern Shelf was the late Tertiary to Quaternary faulting associated with Basin and Range activities (Section 2.6.4.2.5). Since that time the shelf has represented a broad area of tectonic stability.

2.6.4.2.2 Pedernal Uplift and Matador Arch

Two ancient structures to the north, the Matador Arch and the Pedernal Uplift (Figure 2.6-2), influenced the depositional and structural history of the northern Delaware Basin. The Matador Arch (uplifted in the early Pennsylvanian) was a narrow east-west trending Paleozoic highland, which separated the Delaware and Midland Basins from the basins in the Texas Panhandle (Figureably a broad uplift in some places and a fault-bounded block in others.[14] From the early Pennsylvanian until the Permian,[39,84] it was connected to the Diablo Platform. Clastics from the uplift were deposited on the shelf and in the basin. The structural development of the Pedernal ended with the slight uplift and northward tilting that occurred during the late Jurassic and early Cretaceous.[14]

2.6.4.2.3 Central Basin Platform

The Central Basin Platform is a broad feature that at one time formed a topographic high, separating the Delaware and Midland Basins. It is approximately 200 mi long and extends in a north-northwest trend from southwest Texas into southeast New Mexico.[10] The platform has a complex horst configuration formed by a number of fault blocks with vertical separations of up to several thousand ft.[45] In the structurally high parts of the platform, centering around Hobbs and Eunice,[45] the Precambrian surface is from 4000 to 7000 ft below sea level,[22,45] while the adjacent low, extending from Monument through Jal, stands at 6500 to 11,500 ft below sea level. The Central Basin Platform is separated from the Delaware Basin on the west by a complex fault system across which the maximum structural relief is remarkably uniform at about 9000 ft.[45] The faults of the Central Basin Platform are discussed in more detail in Section 2.6.4.4.3. The major structural features of the platform are illustrated by: the structure contours in Figure 2.6-8, the aeromagnetic map of the Carlsbad area (Figure 2.6-13), Foster and Stipp's map of the Precambrian,[22] and Figures 10 and 15 of Hills.[77]

The Central Basin Platform had a more intense deformational history than the adjacent basins or shelves.[13] The Central Basin Platform's tectonic development may have begun in the Precambrian, and it appears to have been a structural high during the early Ordovician and the late Devonian. It was generally stable until the latest Mississippian or early Pennsylvanian. At that time the area was deformed into an emergent north-northwest trending fold belt, with faults trending toward the northeast and northwest.[77] Submergence and deposition followed, however, during the late Pennsylvanian and early Permian, renewed uplift produced large north-northwest trending faults. By the late Permian, erosion had significantly reduced the elevation of the platform, and it was once again submerged beneath a shallow sea.

The Central Basin Platform appears to have been structurally stable since the Permian. Hills[77] suggests that some minor early Tertiary activity along the western margin of the platform may have helped to tilt the Delaware Basin eastward; however, no tectonic displacement has been found in rocks younger than the late Permian, and no surficial fault scarps have been observed.[85] Recent low-magnitude seismic activity has been recorded within the Central Basin Platform, but it is postulated to have nontectonic origins (Section 2.8).

2.6.4.2.4 Diablo Platform

The Diablo Platform is a northwest trending horst, located to the southwest of the Delaware Basin (Figure 2.6-2). It extends from the Cornudas Mountains southeastward to the Ouachita Tectonic Belt. The platform has an average elevation of 3660 ft and is bounded on the east, west, and south by grabens. At its northeastern extent (its closest approach to the WIPP facility), the platform is bordered by the Salt Basin and the Guadalupe Mountains.[15]

The Diablo Platform underwent its primary deformation, consisting of uplift, folding, and faulting, in the early Permian.[28] Post-Permian faulting however, has occurred along the northeastern margin of the platform, and late Cenozoic Basin and Range activity has produced regional uplift as well as buckling and block faulting, primarily along northwest trending faults.[28] Contemporary arching of the Diablo Platform - Salt Basin area has been suggested by leveling surveys (Section 2.6.4.5.3) and may represent some form of preseismic deformation or intracrustal magmatic activity,[86] possibly indicative of continuing Basin and Range tectonism in this area.[87]

2.6.4.2.5 Guadalupe Mountains

The Guadalupe Mountains (and their southern extension--the Delaware Mountains) trend northwestward from the Diablo Platform, along the western portion of the Delaware Basin and onto the Northwestern Shelf (approximately 110 mi). The southern margin of the Guadalupe Mountains is coincident with the Reef Escarpment while the northeastern margin is coincident with the Huapache Monocline (Flexure). The uplift therefore is triangular in shape and thins from 11 mi in the south to about 3 mi in the north (Figure 2.6-2).

Both the Guadalupe and Delaware Mountains were formed in the late Pliocene and early Pleistocene when a large fault block was uplifted and tilted toward the east. The late Cenozoic fault scarp, composed of en echelon normal faults with displacements ranging from 2000 to 4000 ft, forms the steep western slope of the range. The broad eastern flank dips gently toward the east. Offset alluvial fans and scarps along the western escarpment suggest that the structural uplift of the Guadalupe Mountains may be continuing today. (See Section 2.6.4.4.6 for a discussion of recent faulting.) All of the principal structural elements within the mountains are described in detail by Hayes[21], Boyd[88], and King.[9]

Although the Basin and Range forces of the late Pliocene and Pleistocene were primarily responsible for the formation of the Guadalupe Mountains, there were earlier uplifts in the region. In the Pennsylvanian and early Permian, movement occurred on a northwest trending fault zone which existed along the east side of the Guadalupe Mountains (Sections 2.6.4.3 and 2.6.4.4.2). This fault zone may have defined the eastern boundary of a southeastern extension of the Pedernal landmass, or one of a chain of smaller positive elements.[21] The broad southeast dipping Bone Spring Flexure was formed in the late Leonardian and early Guadalupian (late early to early middle Permian) and later rejuvenated in the mid-Guadalupian (Section 2.6.4.3). Minor Guadalupian flexing may also have taken place along the older northwest trending Huapache faults (Section 2.6.4.3), producing the Huapache Monocline.

2.6.4.2.6 Sacramento Mountains

The Sacramento Mountains, which are located west of the Northwestern Shelf (Figure 2.6-2), constitute a north-south trending uplift approximately 45 mi long. Their overall structure, like that of the Guadalupe Mountains, is that of a gently tilted fault block. Most of the structures within the range exhibit a northerly trend, and greater uplift along a central crest has produced a slight doming effect.

The eastern flank consists of relatively undeformed strata with easterly dips of 100 to 140 ft/mi, while the western side is bounded by normal faults with several thousand feet of displacement.[26]

The range developed through at least three periods of tectonic activity, beginning probably in the late Pennsylvanian or earliest Permian. During this period, the strata were folded and faulted, creating many of the internal structures of the range. During the Mesozoic or early Cenozoic, strong folding, faulting, and intrusive igneous activity occurred. The final development of the range began with late Cenozoic Basin and Range faulting, uplift and tilting. This uplift appears to be continuing.[89]

2.6.4.3 Folds and Flexures

The northern Delaware Basin contains open, undulatory, flexure-like structures in the Paleozoic section. Many of these structures formed during the rapid basinal downwarping that occurred in the early to mid-Permian. Other structures formed in the early late Permian (Guadalupian) during the deposition of the Bone Spring Formation and the Delaware Mountain Group.

The movement or dissolution of halite is also thought to be responsible for many of the anticlinal structures within the basin.[67,90,91,92] Borns et al.[92] attributed anticlinal and domal features to the flowage of salt within the lower units of the Castile. This salt flowage produces large variations in the thickness of the lower halite beds and creates a series of anticlinal and synclinal structures in the overlying strata. Three possible mechanisms for salt flowage, outlined by Borns et al.,[92] are: (1) syndepositional or closely post-depositional deformation that is gravity-driven and in part initiated by irregular basement topography or by minor basement faulting, (2) gravity foundering, and (3) gravity sliding. The age of salt flowage is obviously dependent on which of the three mechanisms is being considered. Syndepositional or closely post-depositional deformation occurred in the Permian. Borns et al.[92] stressed, however, that if syndepositional deformation did occur it was only one component of the entire spectrum of stresses, which resulted in salt flowage. Gravity foundering and sliding mechanisms require a much longer time period. Borns et al.[92] indicated that the force for gravity foundering has been present since deposition in the Permian and is still a force today. They also suggested that gravity sliding could be associated with basin tilting events that occurred in the Mesozoic and Cenozoic and is also possibly ongoing. Anderson and Powers[90] suggested that salt anticlines, found both within and rimming the basin, formed when salt dissolution and the resultant unloading led to the creation of a differential stress regime. These anticlinal structures are dated as mid-Cenozoic or later. Jones[67] described folds believed to be the result of the overlying strata's attempt to conform to the salt surface in areas of dissolution. Jones[67] believed these "subsidence folds" to be post-Cretaceous but pre-late Tertiary in age.

The movement of halite is also responsible for an unusual type of fracturing and microfolding within the Castile anhydrite. Jones[72] described these features as sharp intraformational folds that crumple the salt and anhydrite in the middle member of the Castile and appear to die out toward the northwest (updip). They seem to coincide with a prominent southeasterly plunging trough at the base of the Castile.

This folding within the Castile has produced some buckling and downwarping of the overlying Salado, as well as broad arching of all the overlying strata. Jones[67] brackets the time of deformation as being between the late Triassic and the Pliocene.

North of the Capitan reef front, in the basinal regions that existed prior to reef progradation and subsequent conversion to back reef, are the Carlsbad Folds (Figure 2.6-2). They are a 6 to 9-mi-wide belt of sharply flexured, symmetrical folds, with an average wave-length of 1.5 mi and an average amplitude of approximately 100 ft.[93] This fold belt extends in a 65-mi-long arc bringing it within approximately 15 mi of Carlsbad and 10 mi of the WIPP facility. These folds, which are partially expressed in the present topography, contain biohermal shelf domes, suggesting that this region may have been topographically positive during Capitan deposition. The major fold development occurred during the Laramide Orogeny (late Cretaceous).[15,21] Other folds in this same region include the Waterhole Anticlinorium and numerous Cenozoic folds, which parallel the reef.

The largest folds in the Northwestern Shelf region are the Artesia-Vacuum Trend and the Huapache Flexure (Figure 2.6-2), both of which reflect older structures. The Artesia-Vacuum Trend, an eastward plunging anticline of early Permian age,[26] is 75 mi long and located approximately 35 mi north of the Capitan reef front.[26] It was formed as a result of the differential compaction over the Abo reef (early Permian).[15] The Huapache Flexure is a long, northwest trending monocline, generally less than 2 mi wide, involving rocks as young as late Guadalupian.[21] The flexure extends from the western Delaware Basin, across the reef escarpment, and onto the Northwestern Shelf (Figure 2.6-2), terminating at the northern extent of the Guadalupe Mountains. It dips between 5 and 15 to the east[14] and has a structural relief on the Precambrian of between 300 ft (in the north) and 1000 ft (in the south).[14] The flexure may overlie a series of thrust faults which offset rocks from the Wolfcampian (lower Permian) down through the Precambrian basement.[21,26,58]

Drill data from the Huapache Flexure suggest that it might be a drape feature which formed when deposition occurred across the thrust fault, burying it by the Leonardian time.[13] Hayes[21], however, believes that the Huapache Monocline resulted from late Permian to post-Permian flexing along the older thrust zone. The precise time of this renewed flexing is difficult to pinpoint, however, it may be concluded[21] that if minor flexing had occurred it could have taken place up until the Guadalupian (late Permian). Other folds in this vicinity of the Delaware Basin -Northwestern Shelf are described as early Tertiary to Guadalupian or older; therefore, it is reasonable to place the age of the Huapache Flexure somewhere in this time frame.

2.6.4.4 Faults

General topics to be considered in this section include (1) the nature and history of faulting activity (major faults of the region are shown in Figure 2.6-2), and (2) the occurrence of and potential for surface faulting (also discussed in Section 2.6.3). The capacity of these faults for generating ground motion at the WIPP facility is discussed in Section 2.8.

2.6.4.4.1 Delaware Basin Faults

Deep seated, high-angle normal or reverse faults are present throughout the Delaware Basin. They offset strata from the Precambrian through the Pennsylvanian and also portions of lower Wolfcampian. Some of these faults originated during the widespread block faulting[25] which occurred as a result of the rapid Pennsylvanian to early Permian subsidence of the basin. The presence of continuous post-Wolfcampian strata (across these faults) indicates that movement ceased before the mid-Permian.

The closest fault structure to the WIPP facility is the Bell Lake Fault, located in Lea County, 15 to 20 mi east of the WIPP facility (Figure 2.6-13).[94] Haigler and Cunningham[94] and Haigler[58] describe the Bell Lake Fault as being about 15 mi long and displacing strata from the Precambrian up through the Pennsylvanian (Figures 20 through 22 of Reference 45). This displacement, approximately 500 ft in the Precambrian, is also reflected in the Wolfcampian (lower Permian) as a north-south trending high with closure to the south. Closure is also indicated on the Bone Springs Formation; however, it is not known whether this represents Leonardian movement on the Bell Lake Fault or the effects of compaction.[45]

The Barrera and Carlsbad Faults[14] are located along the reef escarpment 20 mi and 10 mi southwest of Carlsbad, respectively. Kelley[14] suggests that these faults have "late Tertiary with possible Quaternary movement," however, many geologists who have investigated the area are not convinced that the features exist.[18,68,95] In a recent study specifically addressed to the investigation of these two faults, Hayes and Bachman[96] conclude "that the faults are nonexistent and that Kelley's conclusions were based on misinterpretation of exposures of fan gravel, jointing and shrub alignment."

There are no known Quaternary faults of tectonic origin in the WIPP facility area (Section 2.9).[59,95] Bachman[10,4] conducted a detailed investigation of the surface features within the WIPP facility area and concluded that no recent faulting had taken place.[95] The only differential movements subsequent to late Permian evaporite deposition were produced by the local settling that resulted from the dissolution of these evaporites.

2.6.4.4.2 Faults Bounding the Delaware Basin

The only large-scale fault structure near the western perimeter of the Delaware Basin is a probable thrust fault system that underlies the Permian to Cenozoic Huapache Flexure (Section 2.6.4.3). This flexure, shown on Figure 2.6-2, extends from the northern Guadalupe Mountains southeastward just beyond the Texas-New Mexico border.

The fault system thought to underlie this feature dips steeply and offsets strata from the Precambrian through the early Permian. Displacement in this fault system appears to be between 4000 and 6000 ft.[21,58]

Northwest-trending high-angle normal or reverse faults form the boundary between the Delaware Basin and the Central Basin Platform. Hills[77] described one of the faults along the southern boundary of these two features and named it the West Platform Fault. Foster[45] cites a displacement of about 2000 ft for this fault system, while Haigler[58] believes that the displacement is nearly equivalent to that in the Huapache structure (5400 ft) on the west side of the Delaware Basin.

In addition to vertical movement, the Platform-Delaware Basin bounding faults may also have undergone considerable right lateral movement.[77] The amount, however, is difficult to determine. The stress that gave rise to this movement may have resulted from the early mid-Wolfcampian thrusting of the Ouachita Belt to the south.[77]

Later in the Permian normal movement,[77] which contributed to the deepening of the basins, may have occurred on the old fault planes as a result of the relaxation of stress. Hills[77] cites as evidence for this theory, the increased thickness and small lateral extent of the Permian carbonate beds in the vicinity of the West Platform Fault. These data suggest that the Guadalupian reefs may have had to grow upward rather than toward the basin in order to stay in the shallow water of a rapidly subsiding sea floor.

Hills[77] has also speculated that movement on the West Platform Fault has continued through the Cenozoic and into the Holocene. His evidence for fault movement however, is very indirect, and he also reports, (p. 1825) "... nowhere in the Permian Basin do the faults and sharp folds at the lower Paleozoic rocks continue into the Permian rocks above the middle Wolfcamp." This geologic evidence suggests that fault movement has not occurred since the early Permian and therefore does not support his hypothesis of Cenozoic movement.

2.6.4.4.3 Central Basin Platform Faults

Faults within the Central Basin Platform are similar in type to those bordering the platform. High-angle faults, with vertical displacements over 1000 ft, border each of the horst-like blocks that together compose the platform. Foster[45] indicates that "The fault system separating the highs of Hobbs and Eunice from the Monument-Jal low has a displacement of about 1000 feet in the north to possibly 4000 feet west of Eunice"; and "the fault bounding the west side of the Monument-Jal low extends about 50 miles southward into Texas, with an inferred displacement of 1500 feet at the north to over 6000 feet west of Jal." Horizontal movement is also evident on some of these faults.[77]

Two groups of faults are present on the platform: an early late-Mississippian to late middle-Pennsylvanian system, and an early Permian system.[77] The older group of faults consists of two sets: one strikes N55-80 degrees east and has indications of right lateral movement, while the other strikes N50-65 degrees west and has indications of left lateral movement. The early Permian fault system strikes just slightly west of north and includes the West Platform Fault described by Hills.[77] These platform faults, like the basin bounding faults, exhibit no post-early Permian displacement, and seismic activity recently recorded on the Central Basin Platform does not correlate with the subsurface traces of the faults (Section 2.8).

2.6.4.4.4 Northwestern Shelf Faults

The most prominent region of faulting on the Northwestern Shelf is the zone of straight, northeast-trending features that extend from the area north of the Guadalupe Mountains to approximately 25 mi northeast of Roswell (Figure 2.6-2). The major structures of this group, such as the Y-O, Six-Mile Hill, and Border Hills Buckles, are exposed for 35 to 80 mi along strike and are spaced 8 to 20 mi apart. The nature of deformation may change markedly over a short distance along strike and includes such features as folding, faulting along strike, and overthrusting. Evidence suggests that movement along these zones was initiated in the Carboniferous or earlier and may have been primarily right lateral.[14,15] These features, like many other structures on the Northwestern Shelf, have been inactive since at least the Tertiary.

2.6.4.4.5 Faulting in the Midland Basin - Diablo Platform Area

Extensive faulting occurred in the southern and western part of the Midland Basin before the deposition of the Ochoan evaporite sequence.[82] Movement ceased before the end of the Permian and, as in the Delaware Basin, general tectonic stability has prevailed since that time.

Major faulting took place in the Diablo Platform throughout the late Pennsylvanian and early Permian and the resulting uplift being the greatest in the Van Horn area to the south (Figure 2.6-2). Late Cenozoic Basin and Range activity also affected the Diablo Platform through block faulting and buckling. The major movement occurred on northwest-trending faults along the northeastern margin of the Diablo Platform[28] (discussed in more detail in the following section). Contemporary arching of this area has also been observed and is discussed in Section 2.6.4.5.3.

2.6.4.4.6 Faulting West of the Delaware Basin

The Sacramento Mountain area was the site of faulting throughout the Pennsylvanian and early Wolfcampian (early Permian). Other faulting, accompanied by igneous activity,[93] occurred during the Mesozoic or early Cenozoic. Late Cenozoic Basin and Range faulting produced the uplift and tilting, which gave the range its present configuration. The dominant late Cenozoic movement occurred on the large, steeply dipping normal fault zone along the western margin of the Sacramento Range.

Recent fault scarps, which offset a Quaternary geomorphic surface, suggest that the uplift along this zone is still in progress.[89] Displacements on this Quaternary surface[97] of as much as 100 ft[98] indicate that major seismic events have occurred within the past 500,000 years. Offset has also been observed in the San Andres Range, which borders the Tularosa Basin to the west.[98]

The Guadalupe Mountains region also underwent late Paleozoic faulting. The largest of these faults is thought to lie beneath the Huapache Monocline (Section 2.6.4.3). The major faulting in the Guadalupe-Delaware Mountain uplift however consists of a complex system of nearly en echelon north-to-northwest trending normal faults of late Cenozoic age which form the west-bounding fault scarp.[14,30] King[9] dates most of the major faults of the Guadalupe Mountains as late Pliocene or early Pleistocene. He points out, however, that the dissection of early Pleistocene deposits (indicative of a lowered base level) might be indirect evidence for a renewed period of faulting in the late Pleistocene. King found no evidence of movement later than late Pleistocene in either the Delaware or Guadalupe Mountains.[9]

There is, however, evidence that suggests that the uplift of the Guadalupe and Delaware Mountains may be continuing at a reduced rate. Leveling surveys from the Diablo Plateau to Carlsbad have revealed uplift within the Diablo Plateau relative to Carlsbad (Section 2.6.4.5.3). Kelley[14] reports a small scarp in the alluvial fans along the northern end of the Guadalupe fault scarp (T20S, R17E), and recent field investigations in the Salt Basin[35,98,99] have identified over 100 Quaternary-age, normal, down-to-basin faults, with displacements of as much as 20 ft. The scarps, which have a predominant north-to-northwest orientation due to pre-existing zones of weakness,[35,99] are short and widely scattered along the eastern side of the graben but are more continuous along the western side. This suggests that the western border of the graben, is actively subsiding.[99] The orientation of the scarps, the proximity of recurring seismic activity (Section 2.8), and the youthfulness of offset surfaces all suggest that these scarps have a tectonic origin and are maintained by intermittent activity. In some places movement has occurred within the past 1000 years and is probably continuing.[35] Releveling measurements of the Diablo Plateau - Salt Basin region indicate relative uplift of 8 $\pm$ 1 in between 1934 and

1977.[86] The maximum uplift occurred approximately 8 mi west of the boundary between the Diablo Plateau and Salt Basin.[86] These data indicate that the Basin and Range system within southeastern New Mexico and west Texas is a region of ongoing structural development.

2.6.4.5 Actual and Potential Subsidence, Uplift, or Collapse

2.6.4.5.1 Natural Subsidence, Uplift, or Collapse Features

The karst topography, which is extensive in southeastern New Mexico, contains subsidence and collapse features (discussed in Section 2.6.1). Cavernous features, such as Carlsbad Caverns, are present in the exposed portions of the Capitan reef, the carbonates of the Artesia Group, and the San Andres Limestone.[21] The lithologic and structural conditions conducive to carbonate cave formation do not exist in the Delaware Basin; however, numerous caves have been formed in the gypsum of the Castile Formation.[100]

Major landslides and mudflows have had little effect on the landscape of the Delaware Basin because of its relatively low ground relief, however, minor landslides into solution cavities are common. Small slides have also occurred along the margins of the Clayton Basin, the Pecos River, and Nash Draw[11] (Figure 2.7-2). The slides along the Pecos River are particularly abundant on the steep eastern bank south of Carlsbad.

Within southeastern New Mexico and west Texas, there is evidence of contemporary uplift of the Diablo Plateau region relative to El Paso on the west and Carlsbad on the east.[87,101] This is discussed in Section 2.6.4.5.3.

2.6.4.5.2 Subsidence, Uplift, or Collapse Due to Human Activities

Human activities in the region of the WIPP facility include underground potash mining, hydrocarbon production, and groundwater extraction. Underground potash mining north and west of the facility (Figure 2.6-14) has caused subsidence over an area of 14 mi^2. The maximum known subsidence ranges between 2 ft 8 in and 5 ft 4 in or about two-thirds the height of the ore zone being mined. Future subsidence is expected to involve an area of 40 mi^2. The subsidence zones are located from 3.5 to 26 mi north, northwest, and west of the WIPP facility (Section 2.7.10).[102]

The hydrocarbon-producing areas around the WIPP facility are shown in Figure 2.6-14. The northern Delaware Basin is the site of several gas producing wells; however, they are not, at the present time, large-scale producers. Little well flooding is anticipated in the region; therefore, no subsidence or uplift, due to well operations, is forecast.[103]

The mining at the WIPP may result in surface subsidence above the workings. Estimates of the maximum value of subsidence at the surface once all the panels are mined range from 0.8 feet to 1.25 feet. Surface subsidence is estimated to be an order of magnitude less in the area around the shafts protected by the shaft pillar.

The groundwater extracted from the southeastern New Mexico region is used primarily for watering livestock,[33,104] field flooding on the Central Basin Platform, potash mining and refining, and minor domestic purposes. Extraction of groundwater is believed to be the primary cause of subsidence along the El Paso to Pecos and Roswell to Pecos routes, surveyed in 1916 and again in 1956.[105] Because there is little potential for large-scale groundwater usage near the WIPP facility, the problem of subsidence due to water table lowering is not expected to arise.

2.6.4.5.3 Regional Warping

The northern Delaware Basin has been tectonically stable since the Permian (Section 2.6.2).[82] The latest regional warping to affect the WIPP facility region is related to Basin and Range activity to the west. This activity produced a gentle east-to-southeast tilting that averages approximately one degree and affects the entire western Permian Basin.

Regional tilting began in the late Tertiary and probably accelerated, in conjunction with the major uplift of the Guadalupe and Delaware Mountains, during the late Pliocene to early Pleistocene. The presence of scarps cutting Quaternary material indicates that this movement has continued throughout the past 500,000 years (Section 2.6.4.4.6).

In addition to the evidence of Quaternary uplift to the west, leveling studies have detected minor uplift in the southern part of the region over a period of 20 years. Releveling surveys,[87,101] conducted in 1934 and 1958 from the Diablo Plateau across the Salt Basin to Carlsbad, have revealed uplift within the Diablo Plateau and western Salt Basin relative to Carlsbad. The maximum uplift occurs near the eastern edge of the Diablo Plateau, about 7.5 mi west of the Salt Basin and correlates with a positive Bouguer gravity anomaly.[87] The amount of uplift decreases northeastward toward the Guadalupe Mountains and the Delaware Basin.[87] A 1977 survey over the same region showed a similar trend, with the greatest amount of uplift (8 ± 1 in) occurring 8 mi west of the boundary between the Salt Basin and Diablo Plateau.[86] These leveling studies suggest that Basin and Range related uplift and perhaps eastward tilting may be continuing west of the WIPP facility.

The leveling survey from El Paso to Carlsbad[87] also indicates that Carlsbad, located on the northern edge of the Delaware Basin, is relatively stable with respect to Roswell, which is located well outside regions of known neotectonic activity.[87] This is consistent with the long-term tectonic stability[10,39] of the northern Delaware Basin and suggests that the WIPP facility area, 30 mi east of Carlsbad, is not significantly affected by the uplift occurring in the Basin and Range province to the west.

In 1977 the DOE commissioned the National Geodetic Survey to put in a first order line across the WIPP facility area. This line extends from Carlsbad to San Simon Sink. It runs through both Nash Draw and the WIPP facility. In 1981, this line was resurveyed and showed subsidence in the WIPP facility at less than 0.04 in.[106]

2.6.5 REGIONAL GROUNDWATER

Regional groundwater conditions are discussed in Section 2.5.2 above.

2.6.6 PLEISTOCENE CLIMATE OF THE WIPP FACILITY

The Pleistocene climatic conditions of the WIPP facility area led to the development of the glacial and periglacial features, which are discussed below.

2.6.6.1 Quaternary Climatic Conditions

Desert conditions are believed to have prevailed over the southern Great Plains during the late Pliocene and early Pleistocene. A trend towards greater precipitation and lower average annual temperatures began in the Nebraskan glacial stage and climaxed in the Kansan (less than 700,000 years ago) when the annual rainfall in the region may have exceeded 25 in.[11,107] It was during this time that the Gatuna Formation was deposited, and the Rustler and Salado Formations were exposed to the increased rates of subsurface dissolution, which produced much of the karst topography in the area. After this relatively wet period, the southern Great Plains region became semiarid. Only short humid periods corresponding to glacial episodes occurred through the late Wisconsin. The preservation, over much of the area, of the caliche that formed shortly after deposition of the Gatuna Formation attests to the existence of a relatively stable, arid climate since the Kansan.[11]

2.6.6.2 Glacial or Periglacial Features

The continental ice sheets of the Pleistocene came no closer than about 650 mi of the WIPP facility. The closest alpine glaciation occurred in Sierra Blanca, approximately 140 mi northwest of the WIPP facility.[108,109,110] The nearest alpine glaciation of major extent was in the southern Rocky Mountains.

Periglacial features in southeastern New Mexico consist of moraines, intermontane lake deposits, strand lines, and stream terraces. The moraine deposits closest to the WIPP facility are those on the northeast side of Sierra Blanca Peak.[109] A lateral moraine and a broad terminal moraine are believed to have formed on this peak during the early and late stages of the Bull Lake glaciation (early Wisconsin). Most of the intermontane basins west of the WIPP facility, including the Salt Basin and Tularosa Basin, contained lakes during the Pleistocene pluvial periods. Well-defined beach and lacustrine deposits mark the various stages of these lakes. The Tularosa Basin, west of Sierra Blanca and the Sacramento Mountains, contained Lake Otero, which was 115 ft deep and had an area of about 700 mi^2. The lake in the Salt Basin had two distinct phases of existence, reached a maximum depth of 43 ft, and occupied approximately 328 mi^2.[108]

The precise time of lake formation during the Pleistocene of southeastern New Mexico is uncertain. The high stage of many of the lakes is believed to be early Wisconsin,[110] and evidence has been found in Lake San Agustin (west of the Rio Grande) to suggest that lacustrine sedimentation ended there approximately 20,000 years ago.[108]

Large lakes did not develop in the Delaware Basin area, although many of the larger sinkholes, particularly east of the Pecos River, contained water during pluvial times. Some depressions still retain generally perennial lakes, such as the Laguna Grande del Sal in Nash Draw. The resulting playa and shallow lake deposits, which date from the late Pleistocene to Holocene[59,75] consist of alluvium, reworked eolian sands, silts, and clay. Gypsum, carbonates, and halite are also found around the margins of standing lakes.

Other periglacial features found in southeastern New Mexico are two late Quaternary terraces along the Pecos River and its tributaries, which drain Sierra Blanca. These terraces, which are possibly early and late Wisconsin in age, may have developed during the recession of the glaciers on Sierra Blanca. Further south along the Pecos River, terraces are recognized at levels of 55 to 82 ft, 16 to 39 ft, and 10 to 33 ft above the stream channel. The older two, the Blackdom and Orchard Peak, may correlate with those found to the north, and the lowermost, the Lakewood, is of possible Holocene age.[111] The oldest terrace (the Blackdom) contains coarser deposits than the others, however, in general, all of the terraces are similar and consist of 16 to 49 ft of sand, clay, and limestone conglomerates capped by caliche. The Lakewood Terrace, which is the youngest, also contains river conglomerates, as well as pond, marsh, and lake silts.[10,75] Sares and Wells[100] have also delineated two terraces in the upper portion of Chosa Draw, a tributary to the Black River.

Based on the type and location of the glacial and periglacial features of the region, the probability of future glacial disturbance in the WIPP facility area is minimal. If glacial conditions were to return to southeastern New Mexico, an increase of playa and small lake deposits and the development of new terraces along the Pecos River would be expected. It is also believed that most erosional activity will, as in the past, be placed on large pre-existent drainage features, including Nash Draw and San Simon Swale. If this is the case, it will leave the divide areas, such as that on which the WIPP facility is located, relatively undisturbed by the processes of erosion and dissolution.[11]

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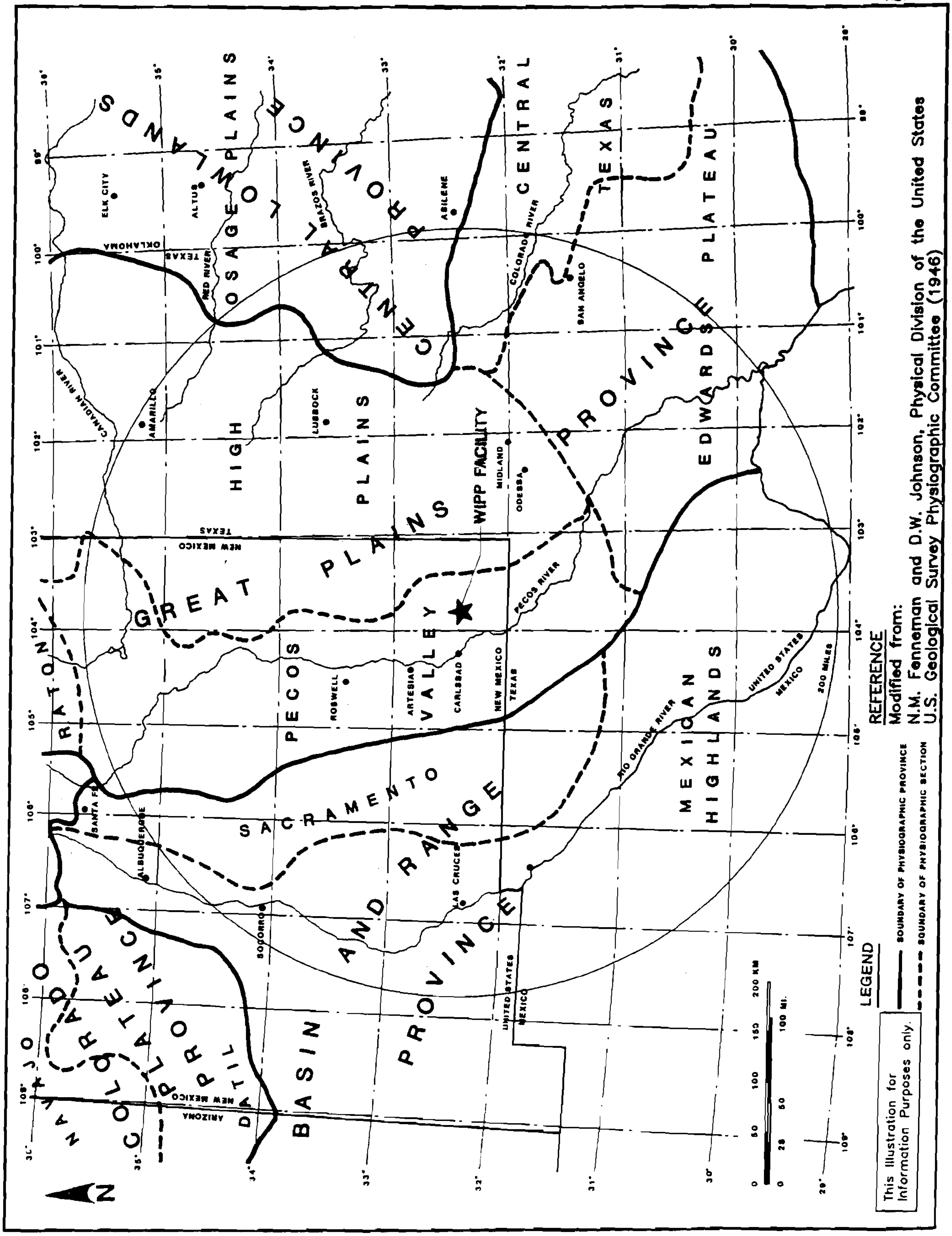
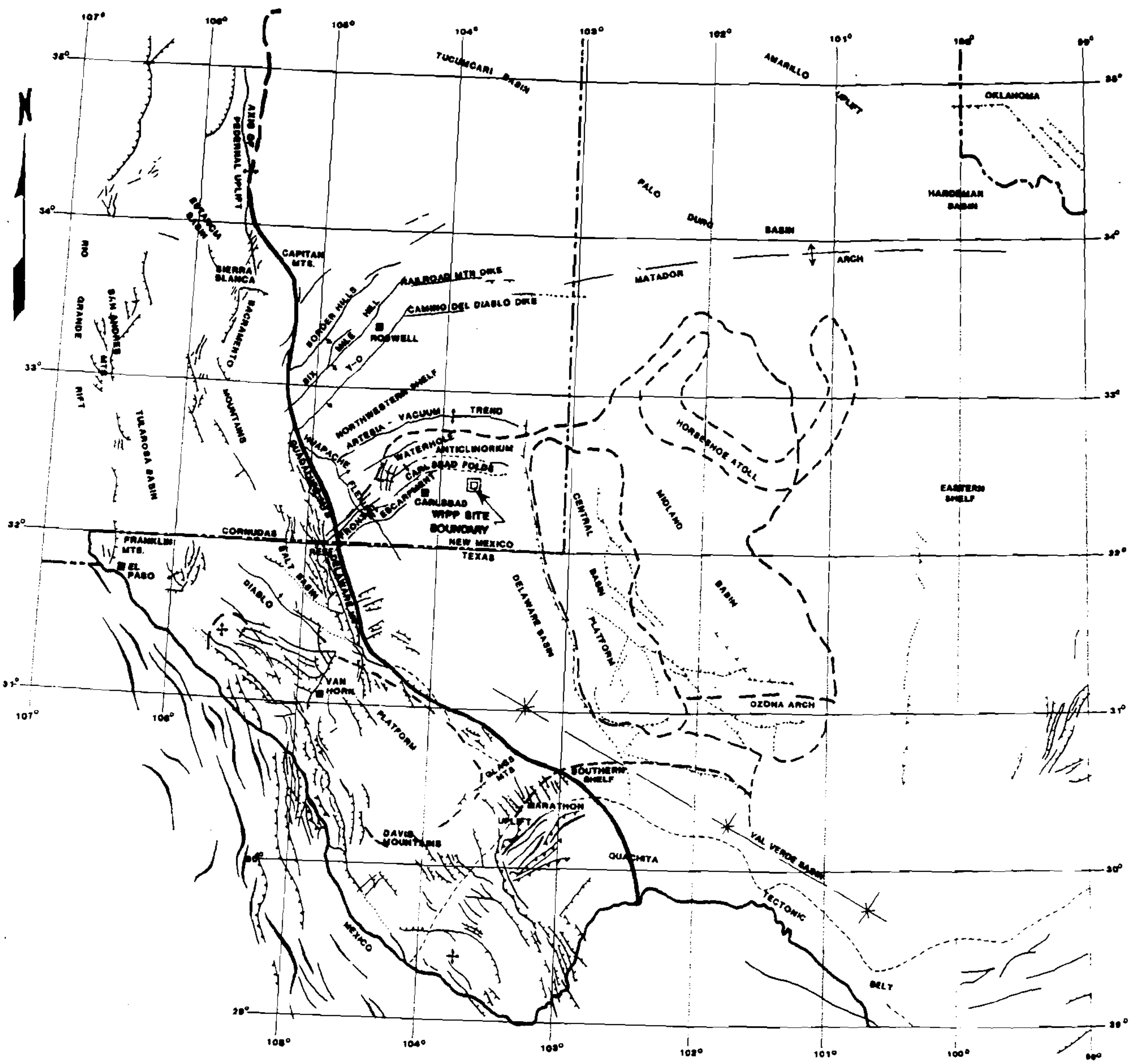


FIGURE 2.6-1
Regional Physiographic Setting of the WIPP Facility



REFERENCE

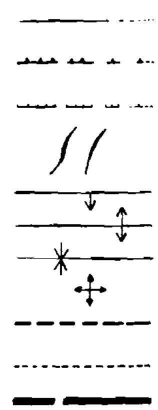
Modified from:
Oriel, S.S., et al., Paleotectonic Investigations of the Permian System in the United States, West Texas Permian Basin Region, Geologic Survey Professional Paper No. 515-C, Fig 7 (1967)

This illustration for Information Purposes only.

FIGURE 2.6-2
Major Structural Features of the Texas-New Mexico Region

LEGEND

Fault, type unspecified: dashed where inferred, dotted where concealed	
Thrust fault, saw teeth on upthrown side, dashed where inferred, dotted where concealed.	
Normal fault: hachured on downthrown side, dashed where inferred, dotted where concealed.	
Elongate, closely compressed anticline: width suggests height, steepness or size of fold	
Axis of monocline	
Axis of major anticline	
Axis of major syncline	
Dome	
Boundaries of major Paleozoic structural elements. (From Oriel, S.S., et al, 1967) (Ref. 29)	
Front of Ouachita Tectonic Belt	
Approximate boundary between Great Plains and Basin and Range Physiographic Provinces.	



This illustration for Information Purposes only.

Explanation to Figure 2.6-2

ERAS	PERIODS	EPOCHS	MILLIONS OF YEARS: DURATION	MILLIONS OF YEARS: BEFORE THE PRESENT	
CENOZOIC	Quaternary	Holocene	10,000		– Eolian and erosional/dissolution activity. Development of present landscape.
		Pleistocene	1,990,000		– Deposition of Ogallala fan sediments. Formation of caliche caprock.
	Tertiary	Pliocene	3,100,000		– Regional uplift and east–southeast tilting; Basin and Range uplift of the Sacramento and Guadalupe – Delaware Mountains.
		Miocene	19,500,000	20,000,000	– Erosion dominant. No early to Mid–Tertiary sediments present.
		Oligocene	13,400,000		
		Eocene	16,900,000		
		Paleocene	10,100,000	65,000,000	– Laramide Orogeny causes the uplift of the Rocky Mountains. Tectonism and igneous activity to the west and north.
MESOZOIC	Cretaceous		79,000,000		– Submergence. Intermittent shallow seas.
	Jurassic		69,000,000	144,000,000	
	Triassic		35,000,000	213,000,000	– Emergent conditions. Erosions. – Deposition of fluvial clastics. – Uplift and erosion.
PALEOZOIC	Permian		38,000,000	248,000,000	– Evaporites fill the Delaware Basin. – Reef growth decreases the size of the Hovey Channel, resulting in evaporite precipitation in the Delaware Basin. – Extensive reef growth around the Delaware Basin.
	Pennsylvanian		34,000,000	286,000,000	– Rapid subsidence of the Delaware Basin. Basin, Basin margin and shelf configuration develops.
	Mississippian		40,000,000	320,000,000	– Collision of North and South America causes thrusting in the Marathon Orogenic Belt and Uplifting of the Central Basin Platform, Matador Arch and Ancestral Rockies.
	Devonian		48,000,000	360,000,000	– Renewed Submergence. – Shallow sea retreats from region.
	Silurian		30,000,000	408,000,000	
	Ordovician		67,000,000	438,000,000	– Initial subsidence of the Toboso Basin. – Formation of a carbonate shelf.
	Cambrian		85,000,000	505,000,000	– Initial Transgression of the sea. – Subsidence of continental shelf.
PRECAMBRIAN				590,000,000	– Rifting of Ancestral North America from a larger landmass.

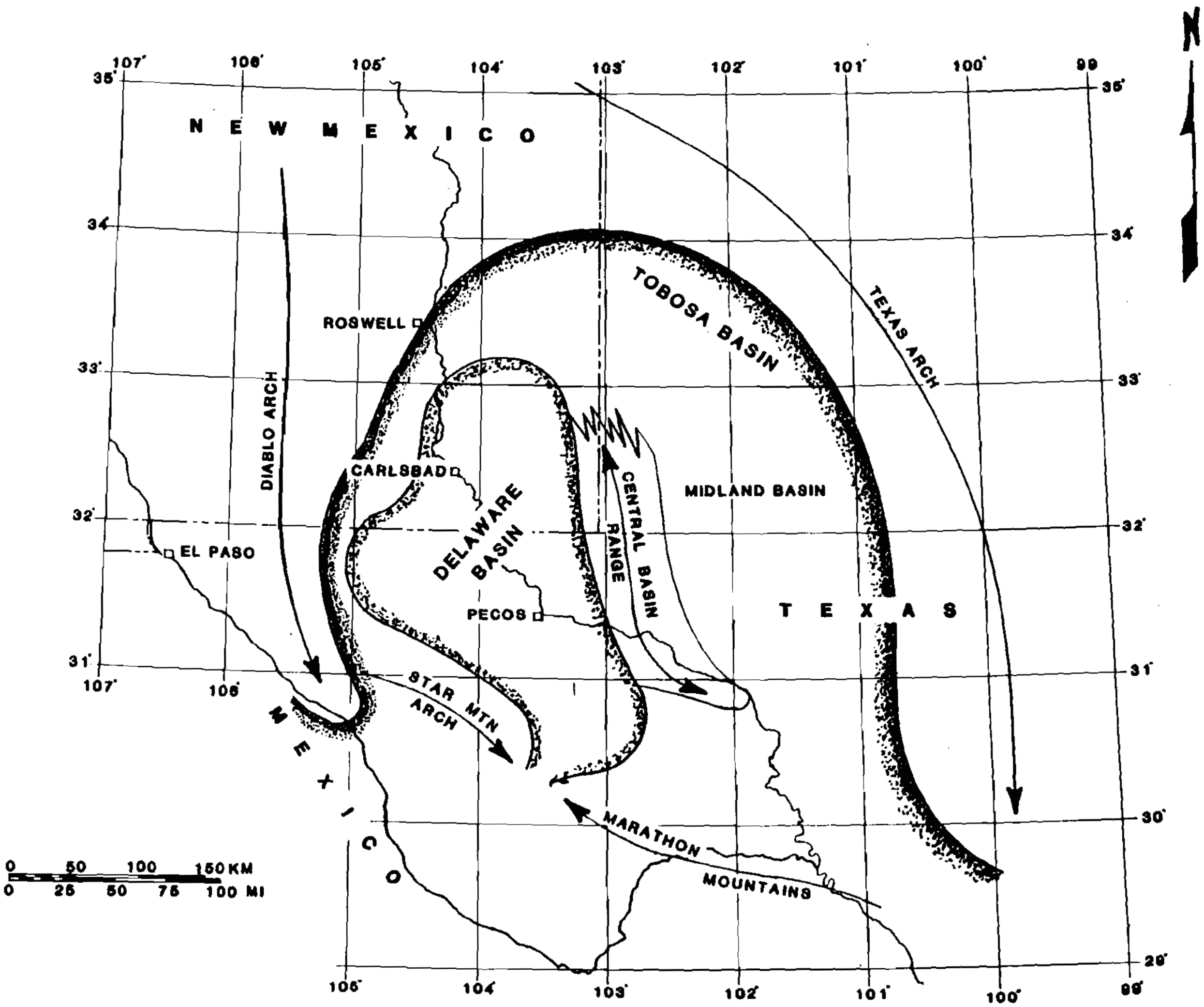
REFERENCE

TIME SCALE: W. B. Harland et al, 1982

This Illustration for Information Purposes only.

FIGURE 2.6-3

Major Geologic Events of Southeastern New Mexico



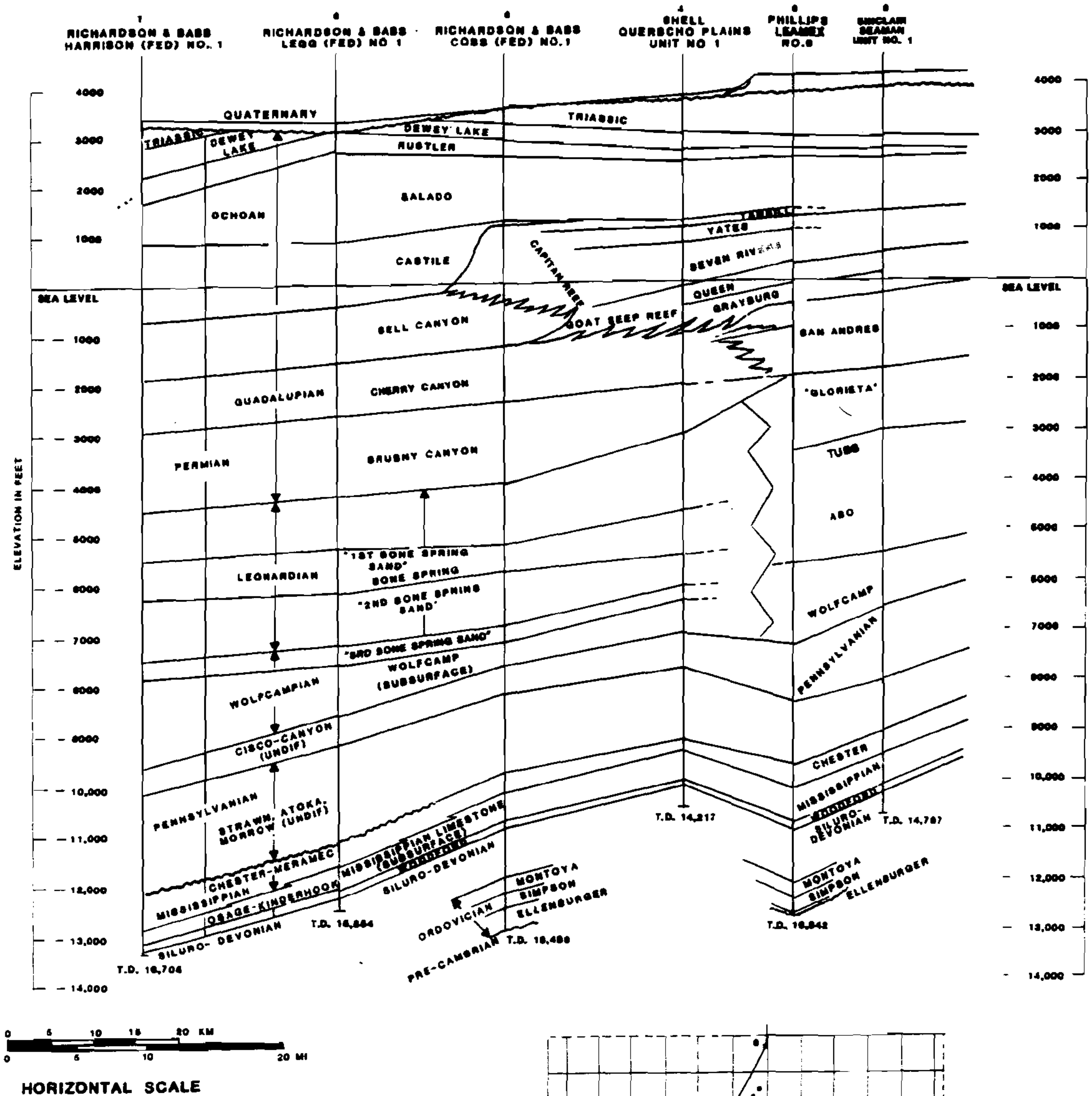
REFERENCE

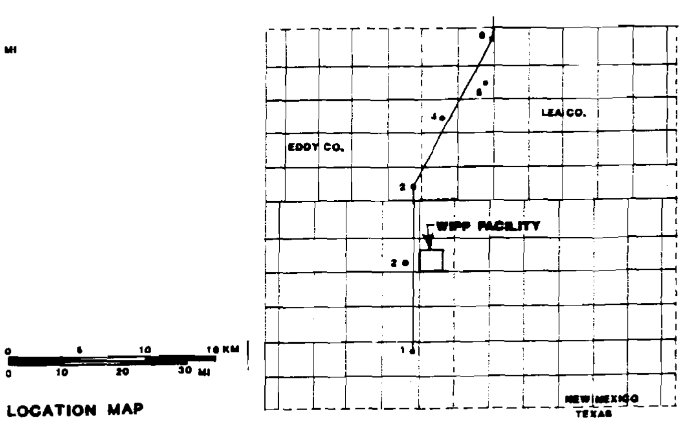
Modified from:

Adams, J.E., "Stratigraphic – Tectonic Development of Delaware Basin", Am. Assoc. Pet. Geol. 49, (11) pg 2140–2148 (1965)

This illustration for Information Purposes only.

FIGURE 2.6-4
Delaware, Midland, and Tobosa Basins



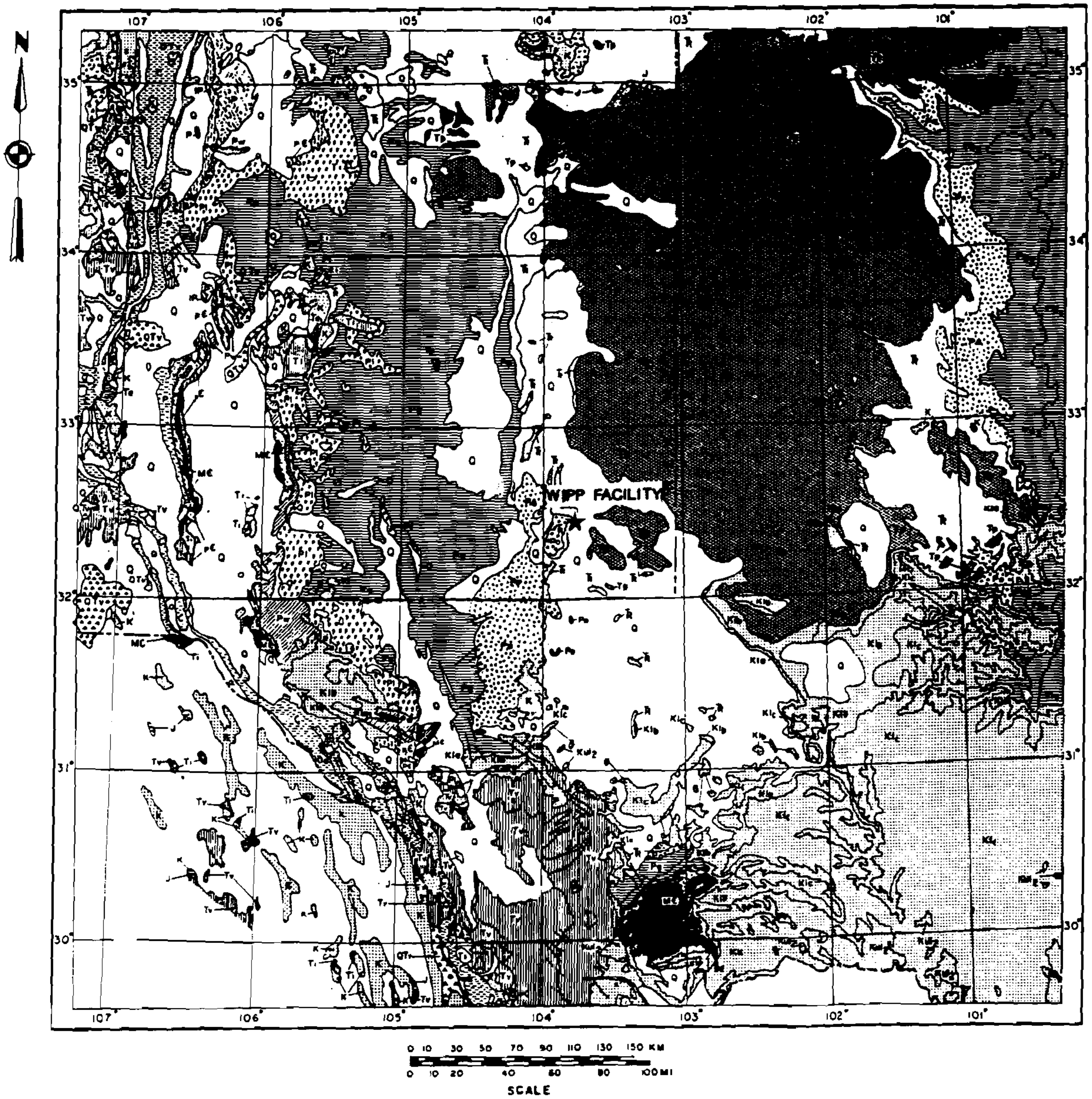


REFERENCE

Modified from:
Roswell Geological Society (1958) Field Trip Guidebook

This illustration for Information Purposes only.

FIGURE 2.6-5
North - South Cross Section
Delaware Basin Northwest Platform



This Illustration for Information Purposes only.

FIGURE 2.6-6
Regional Geologic Map

LEGEND

Q	Quaternary
QTv	Quaternary-Tertiary Volcanics
Tv, Ti	Tertiary Volcanics
Tp	Pliocene
Te	Eocene
C	Cenozoic (undifferentiated)
K	Cretaceous
J	Jurassic
Ŧ	Triassic
P	Permian (undifferentiated)
Po	Permian (Ochoan)
Pg	Permian (Guadalupian)
Pl	Permian (Leonardian)
Pw	Permian (Wolfcampian)
IP	Pennsylvanian
M€	Cambrian-Mississippian
p€	Precambrian

REFERENCES

Geological Highway Map of the Southern Rocky Mountain Region (AAPG, 1967)

Geological Highway Map of Texas (AAPG, 1973)

Geologic Map of the United States (USGS, 1974)

Geologic Map of North America (1969)

Explanation to Figure 2.6-6

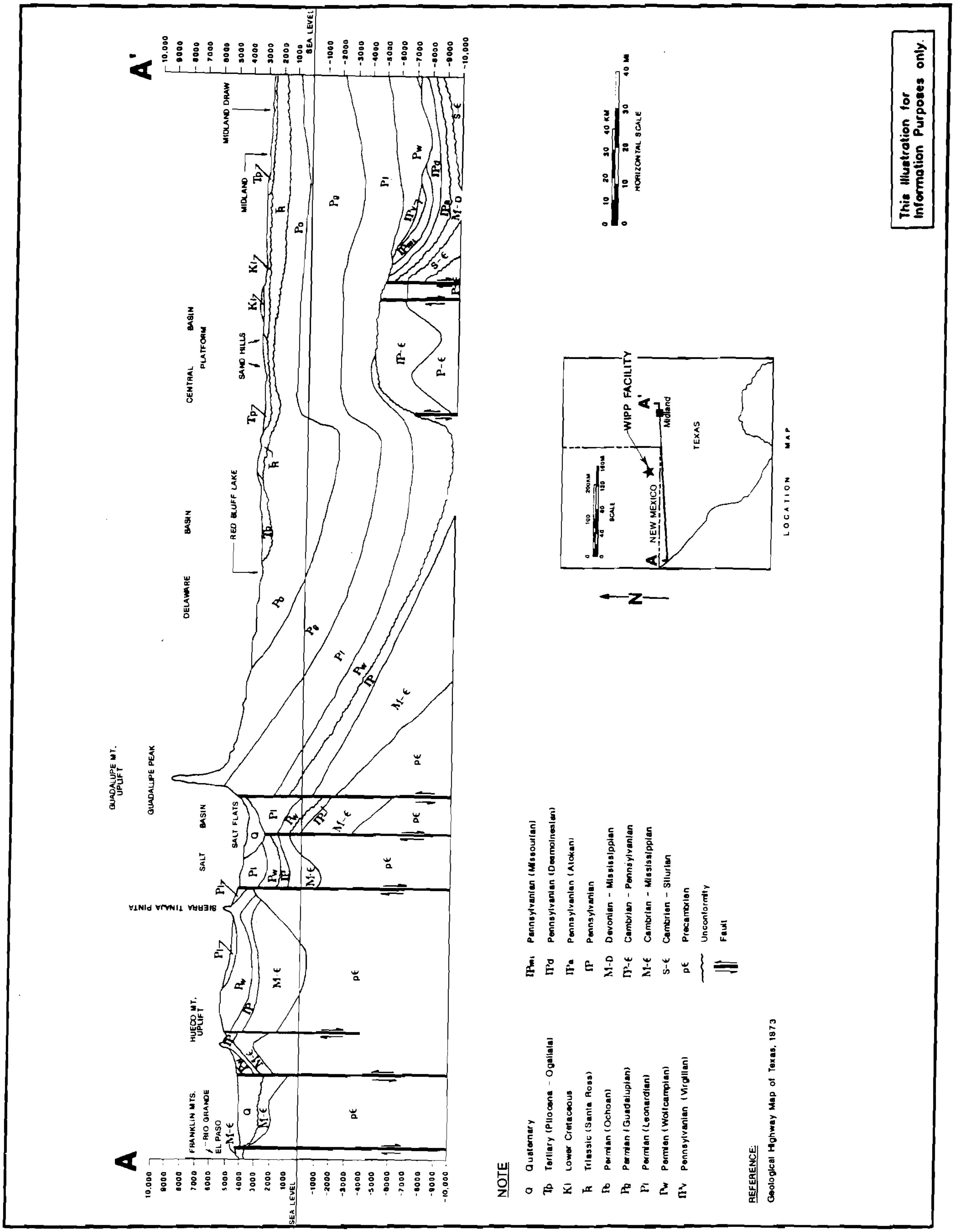
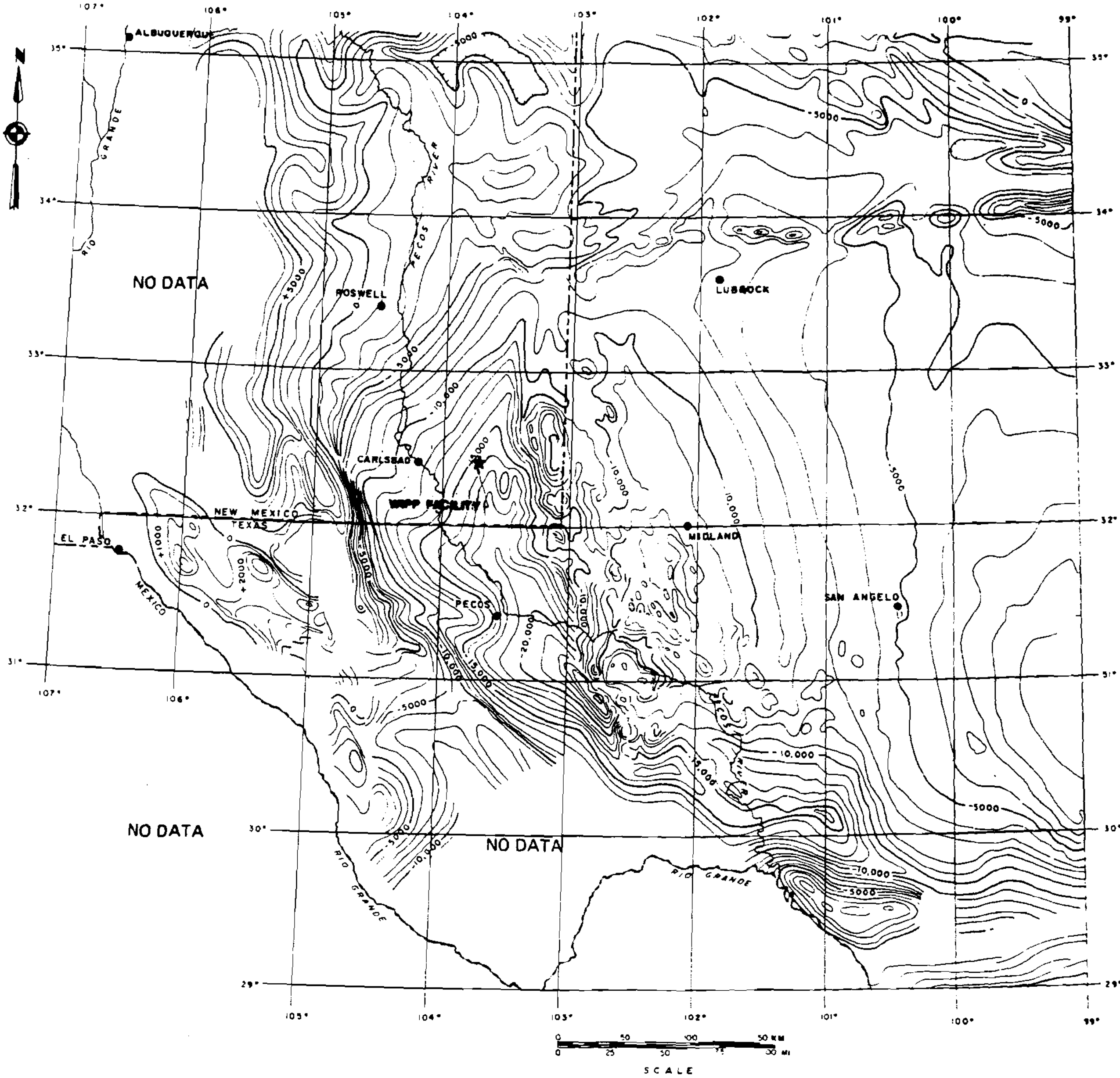


FIGURE 2.6-7
East West Cross Section
Along Southern New Mexico-
Texas Border



LEGEND

The contours show the elevation of the top of the Pre Cambrian. The contour interval is 1000 feet, and the datum is sea level

NOTE

Where structure contours are not shown, information is not available.

REFERENCE

Modified from:

G.V. Cohee, Tectonic Map of the United States, US Geol. Survey and Am. Assoc. Pet Geol. (1962)

This illustration for information Purposes only.

FIGURE 2.6-8
Structure Contour Map of the Precambian Surface

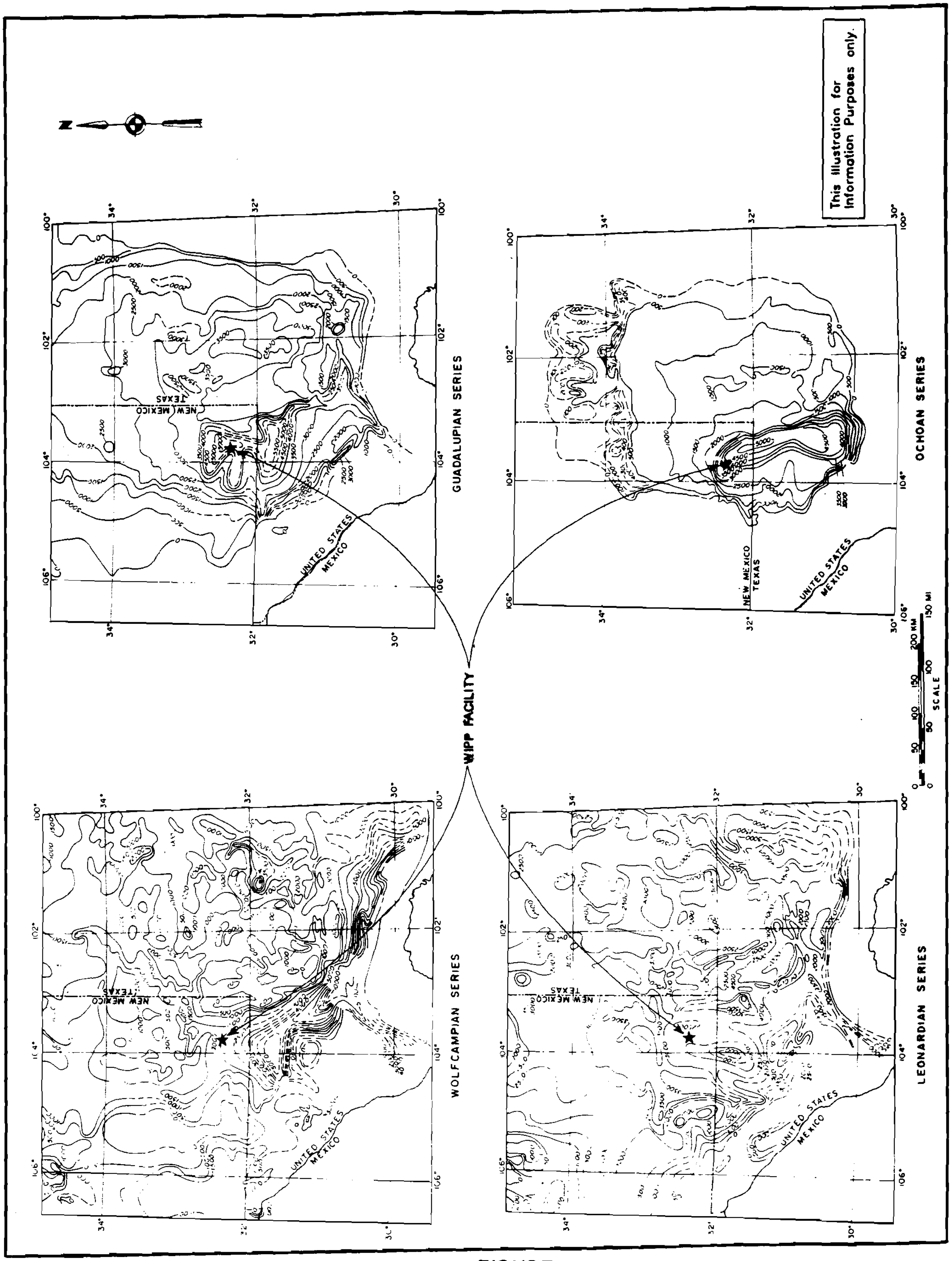


FIGURE 2.6-9
Isopach Maps of Permian System

EXPLANATION

Thicknesses of the rocks comprising the Permian System, southeast New Mexico-west Texas region

ISOPACH INTERVALS:

Ochoan - 100' and 500'

Guadalupian - 500'

Leonardian }
Wolfcampian } 500' and 1000'

Isopachs dashed where control is poor, dotted where Permian rocks have not been penetrated by drill.

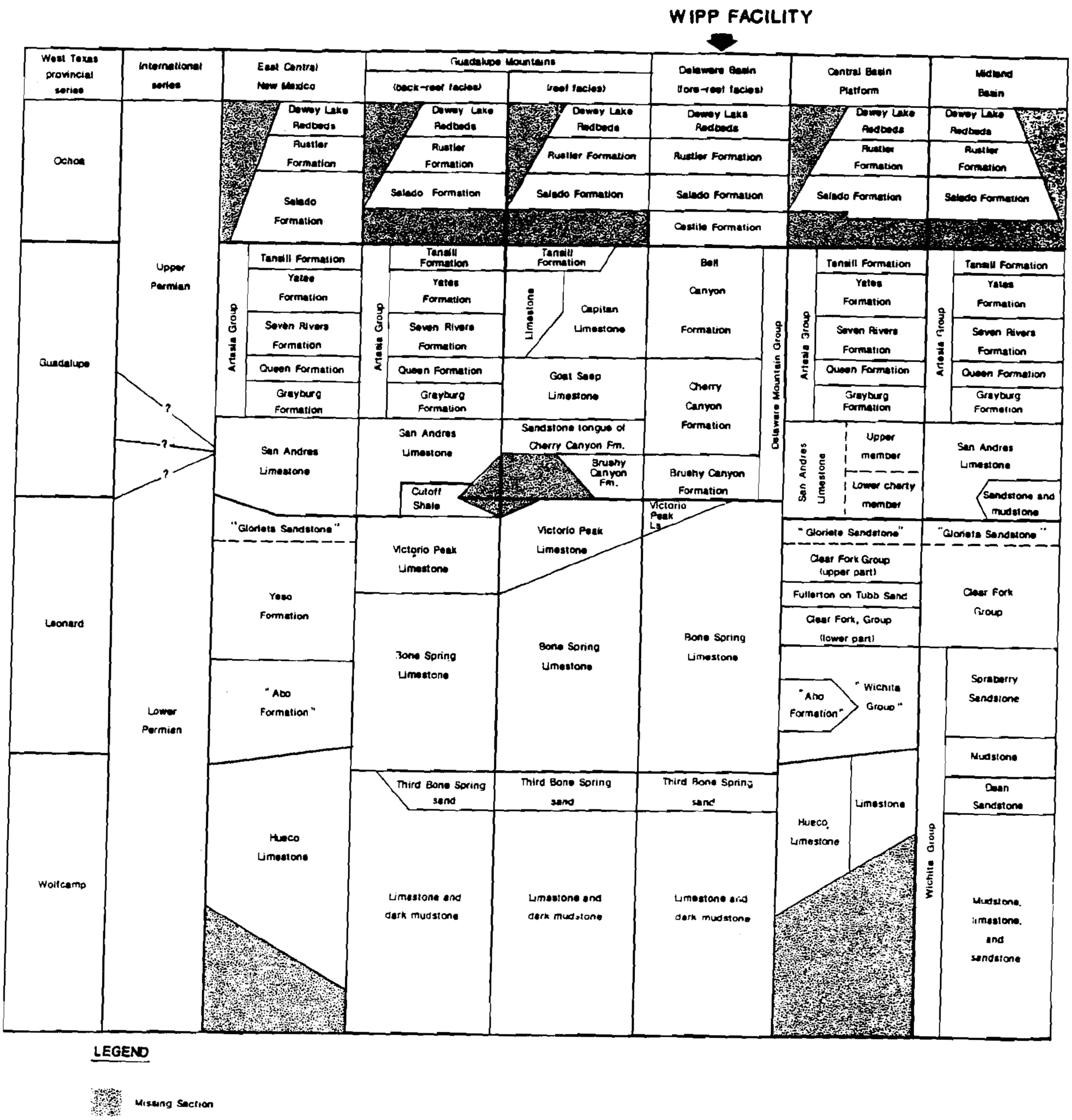
REFERENCE

Modified from:

Oriel, S.S., et al., Paleotectonic Investigations of the Permian System in the United States, West Texas Permian Basin Region, Geologic Survey Professional Paper No. 515, Fig 12, 13, 15, 16 (1967)

This Illustration for Information Purposes only.

Explanation to Figure 2.6-9

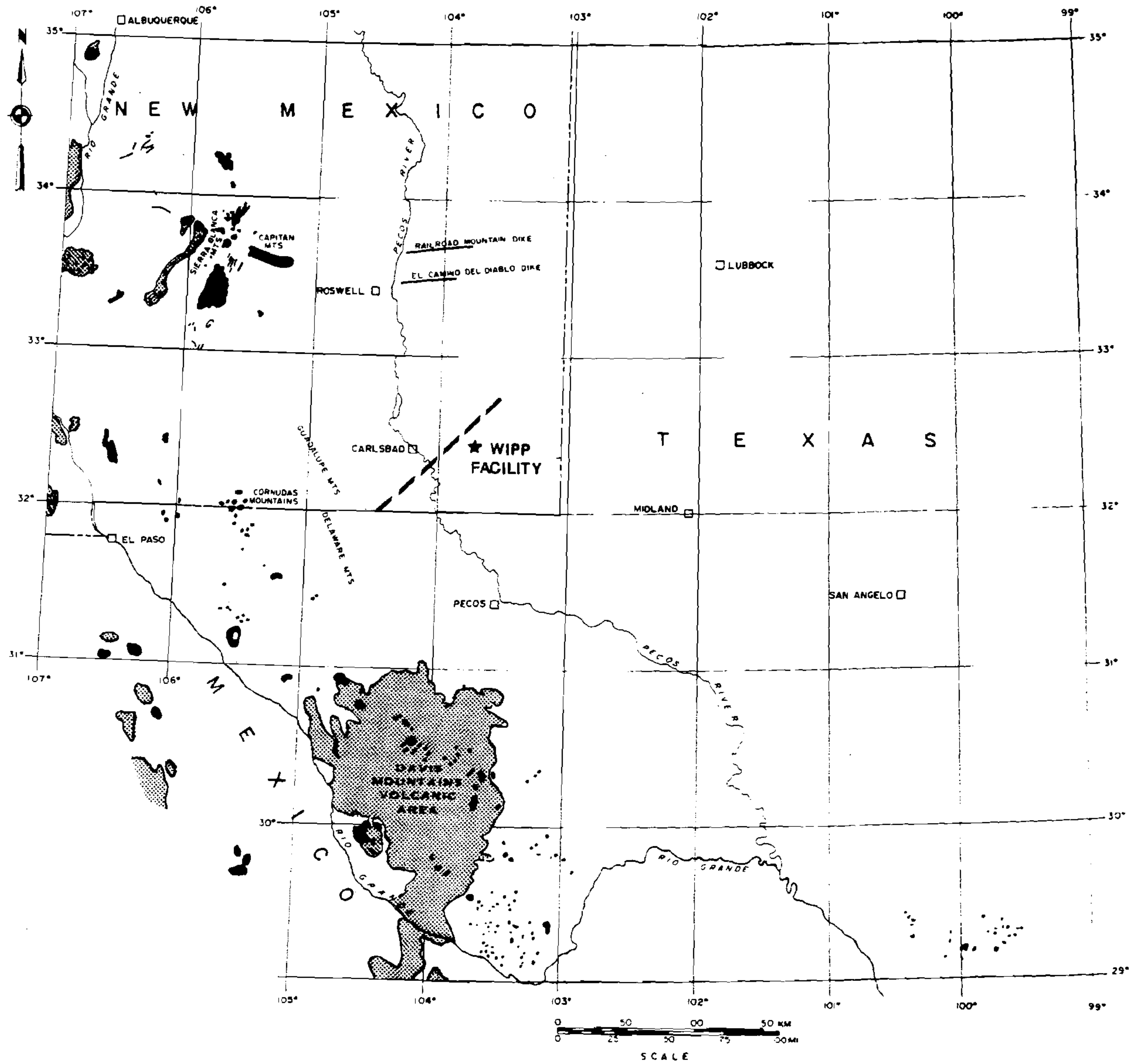


REFERENCE

Modified from:
Oriel, S.S., et al., Paleotectonic Investigations of the Permian System in the United States, Geologic Survey Professional Paper No. 515, Table 1, (1967)

This illustration for Information Purposes only.

FIGURE 2.6-10
Stratigraphic Correlation of the Permian System in Southeastern New Mexico



This Illustration for Information Purposes only.

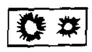
FIGURE 2.6-11
Regional Distribution of Igneous Features

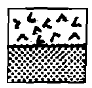
LEGEND

INTRUSIVE IGNEOUS ROCKS

Tertiary intrusive bodies; dikes, plugs, stocks, laccoliths 

VOLCANIC ROCKS AND FEATURES

Volcanoes and volcanic cones of Quaternary and Late Tertiary age. 

Tertiary and Quaternary volcanic rocks. Only larger areas or areas of tectonic significance are shown. Mainly of various Tertiary ages. Quaternary volcanic rocks distinguished by V pattern. 

Probable trend of Mid-Tertiary lamprophyre dike (see Figure 2.6-12)

REFERENCE

Modified from:
G.V. Cohee, et al., Tectonic Map of the United States US Geol. Society and Am. Assoc. Pet. Geol. (1962)
D.S. Barker, "Northern Trans–Pecos Magmatic Province, Introduction and comparison with KEYA Rift," Geol. Soc. Am. Bull. 88, (10), Pg 1421–1427 (1977)
D.S. Barker et al., "Petrology and Rb–Sr Isotope Geochemistry of Intrusions in the Diablo Plateau, Northern Trans–Pecos Magmatic Province, Texas and New Mexico. Geol. Soc. Am Bull. 88, (10), pg 1437–1446 (1977)

This illustration for information Purposes only.

Explanation to Figure 2.6-11

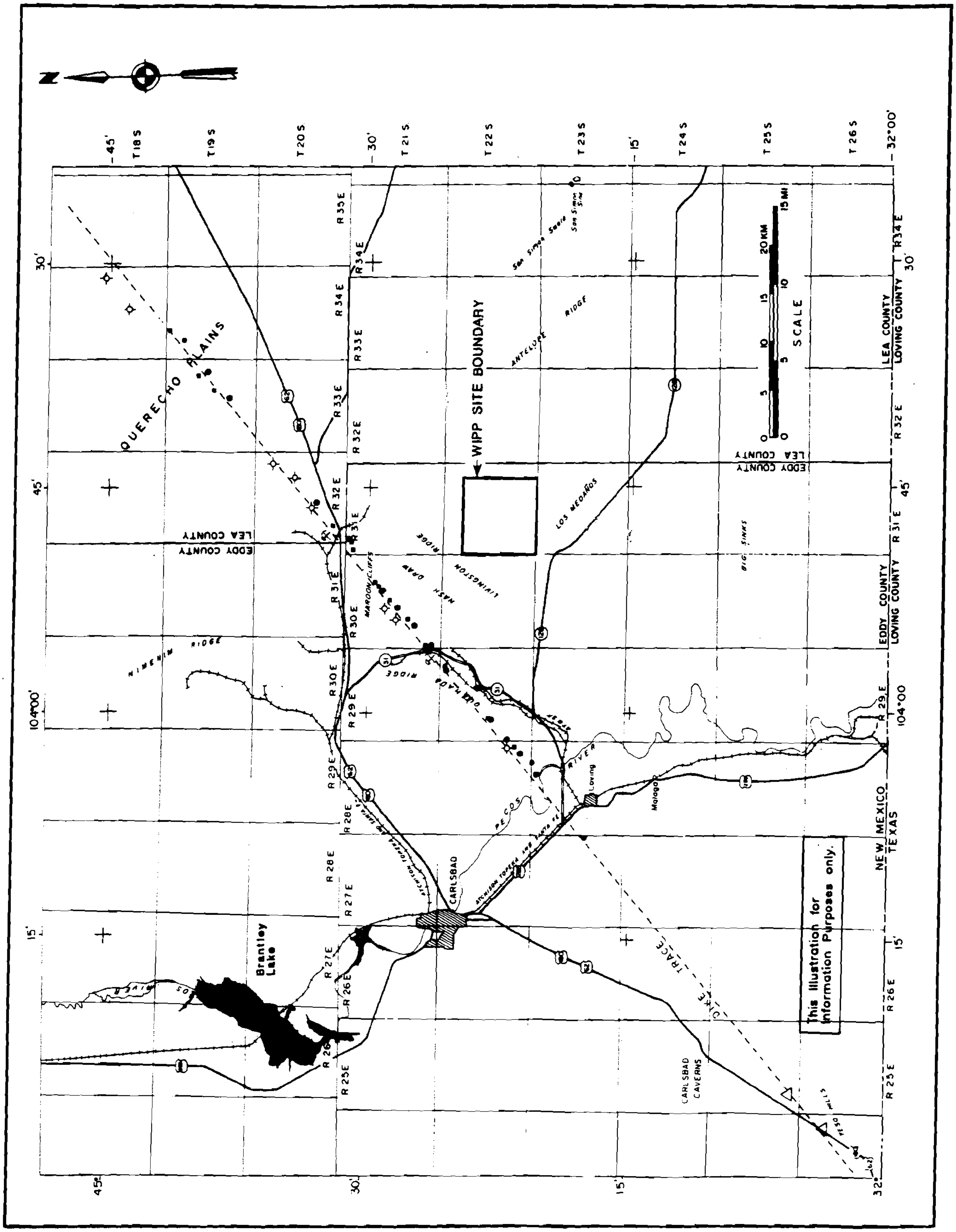


FIGURE 2.6-12

Evidence of Near-Site Dike

LEGEND

Outcrop of dike	△
Well intercept of dike	⌖
Airborne Magnetic Response - 1960	●
Airborne Magnetic Response - 1963-64	•
Dike exposed in mine	⚒

REFERENCE

Modified from:

Griswold, G.B., Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, N.M., SAND 77-0946 Fig 1

This Illustration for Information Purposes only.

Explanation to Figure 2.6-12

This illustration for Information Purposes only.

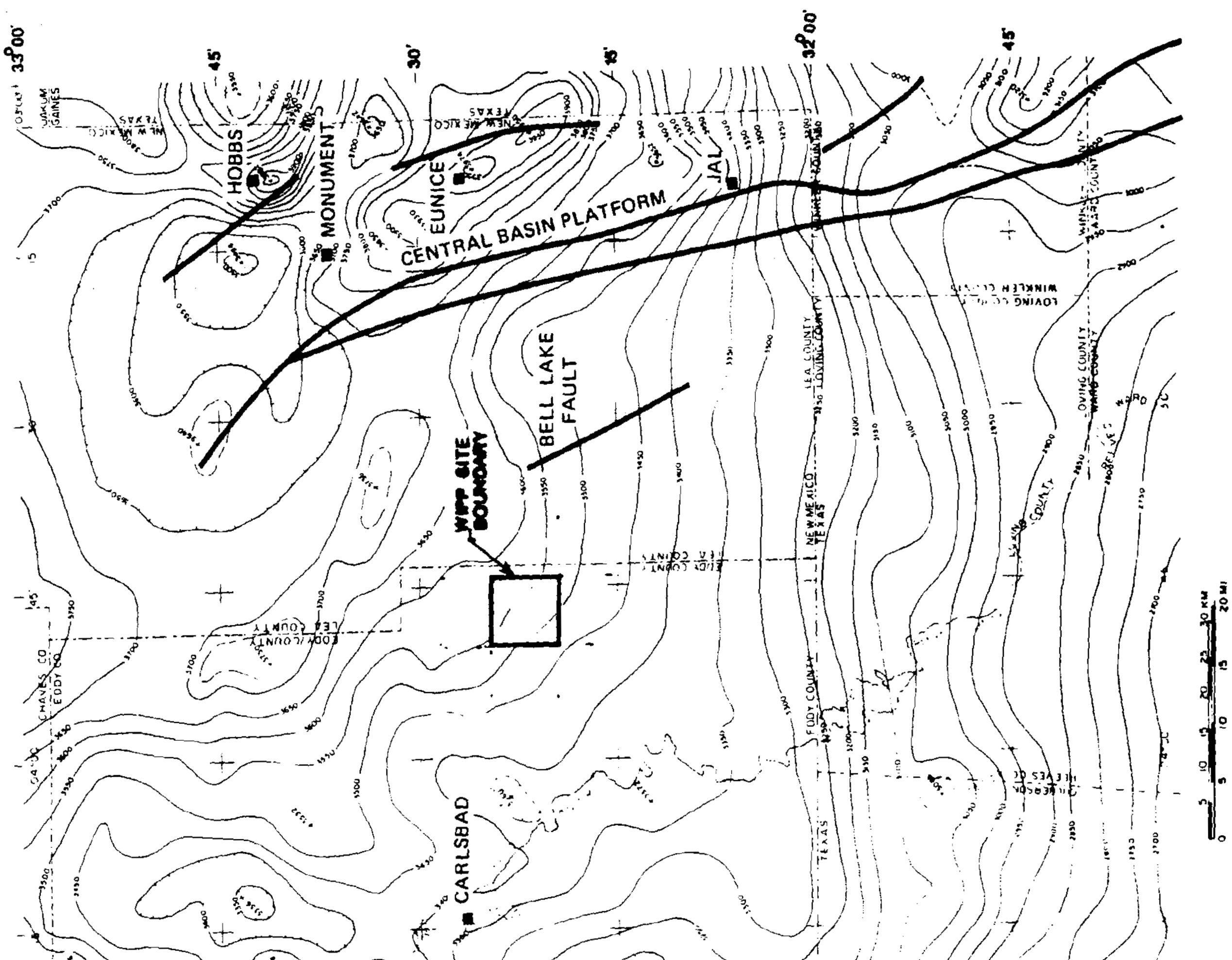


FIGURE 2.6-13

Aeromagnetic Map of the Carlsbad Area, New Mexico

LEGEND

MAGNETIC CONTOURS

Map shows the intensity of the magnetic field in the Carlsbad region. Gamma values given are relative to an arbitrary datum.

Magnetic contours, 50 gamma interval.
Dashed where data are incomplete.

Interpolated intermediate contours,
25 gamma interval.

Hachured contours indicate closed
areas of lower magnetic intensity.

Measured maximum or minimum intensity
within closed high or closed low.

Paleozoic Fault.

NOTE

Bell Lake and Central Basin Platform Faults were obtained from Hills, 1976 and superimposed on the magnetic contours.

REFERENCE

Modified from:

Aeromagnetic map of the Carlsbad area, New Mexico and Texas, 1973 (U.S. Geological Survey)
R.W. Foster, Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste, New Mexico Bureau of Mines and Min. Res. Open File Report (1974)
J.M. Hills, "Late Paleozoic Structural Directions in Southern Permian Basin, West Texas Southeastern New Mexico," Am. Assoc. Pet. Geol. Bull. 54, (10) pg 1809-1827 (1976)

This Illustration for Information Purposes only.

Explanation to Figure 2.6-13

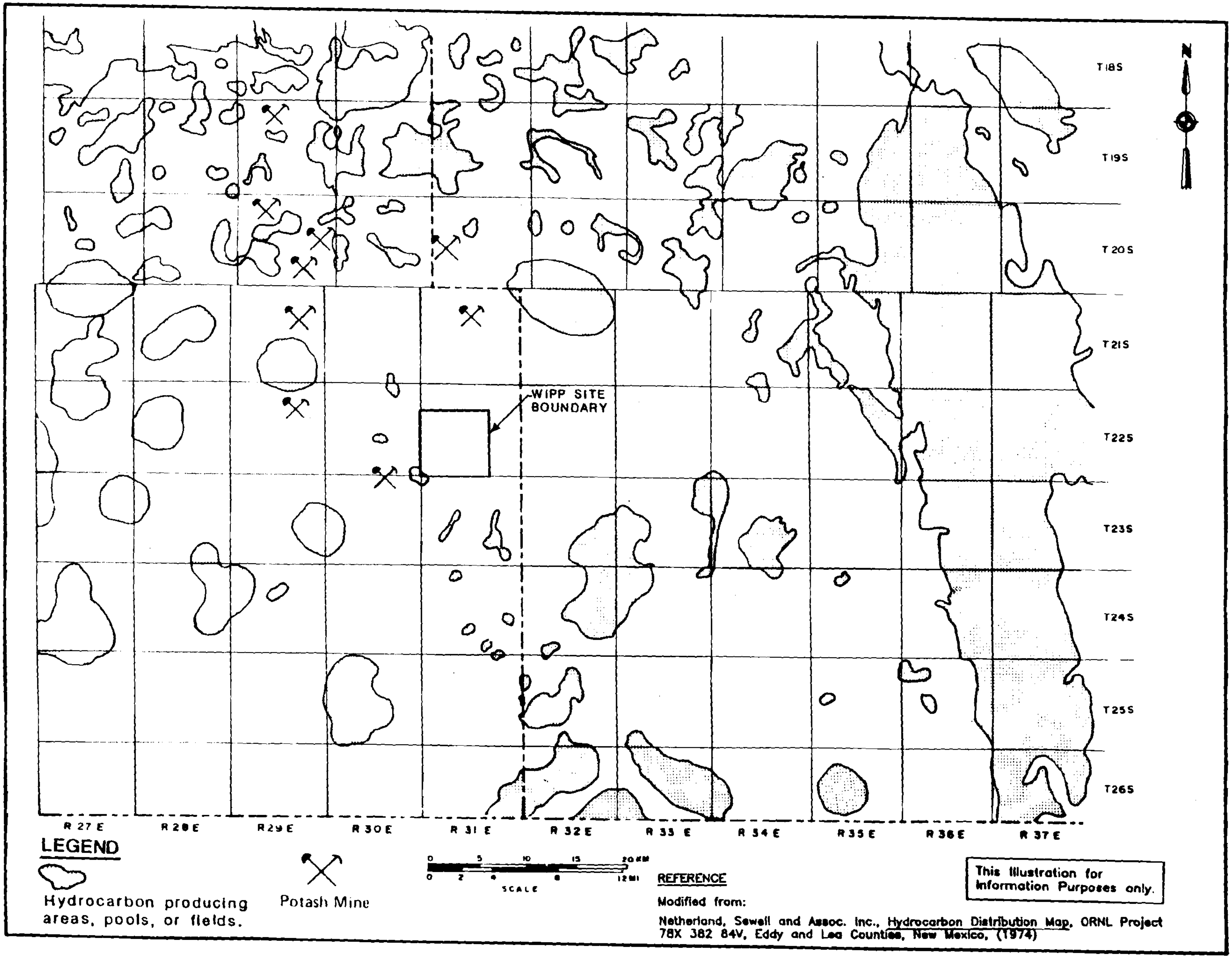


FIGURE 2.6-14
Resource Extraction Location Map

2.7 GEOLOGY IN THE VICINITY OF THE WIPP FACILITY

2.7.1 PHYSIOGRAPHY AND GEOMORPHOLOGY

The WIPP facility is located near the eastern edge of the Pecos Valley section of the southern Great Plains physiographic province. The physiographic provinces and sections within 200 miles of the facility are described in Section 2.6.1.

The land surface at the facility slopes gently to the west and southwest at approximately 45 ft/mi. Elevations in the vicinity of the WIPP facility range from 3550 feet in the east 3300 feet in the west (Figure 2.7-1).

Much of the area around the WIPP facility is covered with eolian sand, which is either partially stabilized or occurs as active sand dunes (Figure 2.7-1). The sand, of Holocene age, is very erratic in distribution and thickness. On the broad flats, the sand is partially stabilized by mesquite and bunchgrass and forms small hummocky dune ridges. Active sand dunes are located immediately south of the WIPP facility. In general, the active dune areas are underlain by as much as 100 feet of sand, whereas the more stabilized areas are usually underlain by five to 15 feet of sand. The long dimension of the dune ridges appears to parallel the prevailing direction of the strongest winds when the dunes were formed.[1]

Livingston Ridge, located about four miles northwest of the WIPP facility is the most prominent physiographic feature in the area. This northeast-trending escarpment is about 12 miles long and 75 feet high, and it marks the eastern edge of Nash Draw. Late Permian Dewey Lake Redbeds and the Pleistocene age Gatuna Formation and Mescalero caliche crop out along the ridge (Figure 2.7-1).

Nash Draw is northwest of Livingston Ridge and is a shallow northeast-trending depression three to nine mi wide. It is the nearest drainage course to the west of the WIPP facility. Elevations within Nash Draw range from 3,300 feet at its head in the northeast to 2,945 feet at Salt Lake near the Pecos River and are generally 200 to 300 feet lower than the surrounding terrain. Nash Draw is believed to have developed as a result of the subsurface dissolution of salt from the Rustler and upper Salado Formations and gypsum and anhydrite from the Rustler, followed by subsidence of overlying materials.

East of the WIPP facility, the nearest major drainage course is the San Simon Swale (Figure 2.7-2). The swale is a southeast-trending depression about 25 miles long and from two to six miles wide that overlies the southern extent of the Capitan reef. Elevations within the depression range from 3,650 feet in the northwest to 3,270 feet in the collapse feature called San Simon Sink at the southeastern end of the swale, about 18 miles east of the WIPP facility. The sink is filled with fine sand and calcareous silt, and the surface of the swale is covered by eolian sand, which masks the relief.

San Simon Swale probably originated from a combination of surface stream erosion and solution subsidence because the area of collapse seems to be confined to the sink areas and is not pervasive over the entire swale. Rather, collapse in the sink areas steepened the local drainage gradient, resulting in headward cutting and widening of the swale.[2] Further discussion of San Simon Swale dissolution is found in Section 2.5.9.1.1.

Between San Simon Swale and the WIPP facility is a broad, low mesa named "the Divide." About seven miles east of the WIPP facility, the Divide rises about 100 feet above the surrounding terrain and has an elevation of about 3,800 feet. It marks the local boundary between the southwest drainage toward Nash Draw and the southeast drainage toward San Simon Swale. The Divide is capped by the Ogallala Formation of late Tertiary age and an overlying caliche. In the future, if the climate of the area becomes more humid, perennial streams would probably follow the present drainages, and Nash Draw and San Simon Swale would likely undergo the greatest amount of erosion. As a result, the Divide area is expected to remain relatively intact.[3] Located on the flank of this natural divide between drainage basins, the WIPP facility is protected from serious flooding and erosion.

2.7.2 STRATIGRAPHY AND LITHOLOGY

The WIPP facility underground storage area is being constructed near the middle of a sequence of evaporite beds 3,600 feet thick and consisting primarily of halite and anhydrite. These rocks are found at depths between 500 and 4,100 feet at the WIPP facility location.

About 18,000 feet of Ordovician to Holocene sedimentary strata overlie the Precambrian basement rocks at the WIPP facility. A generalized stratigraphic section is shown in Figure 2.7-3. The stratigraphy, from the oldest to the youngest formations, is summarized below.

2.7.2.1 Precambrian Rocks

The Precambrian crystalline basement is believed to have been formed about 1,300 million years ago and is composed of either granitic igneous rock or metamorphosed granite and rhyolite. The basement surface near the WIPP facility is at a depth of about 17,900 feet, according to Foster and Stipp,[4] while a depth of about 18,200 feet has been inferred by independent consultants.[5] The basement rocks occur within what has been considered by Flawn[6,7] to be a part of a regional Precambrian granitic terrane. A later investigation that reclassified the Precambrian section assigns the basement rocks of the WIPP facility area to the Chaves Granitic Terrane.[8] The terrane is composed of granite, granodiorite and gneiss, with some metasedimentary rocks. Measured radiometric dates for basement rocks in the area range from 1,050 to 1,350 million years[8,9]

2.7.2.2 Paleozoic Rocks

2.7.2.2.1 Cambrian System

Cambrian age strata are not recognized in the subsurface in the vicinity of the WIPP facility.

2.7.2.2.2 Ordovician System

In the WIPP facility area, the lowermost Paleozoic section consists of an estimated 1,300 feet of Ordovician rock. In ascending order, the sequence includes the Ellenburger, Simpson and Montoya Groups, representing Early, Middle, and Late Ordovician strata, respectively.

About 12-1/2 miles north-northeast of the WIPP facility in the Texas 1 Richards well, the Ordovician rocks are 975 feet thick. The section thickens to the south-southeast at about 25 to 40 ft/mi, mostly due to the thickening of the Ellenburger and Simpson Groups.[9] The Ellenburger Group generally consists of at least 300 feet of dolomite with some chert and includes a 75-feet thick basal member of sandstone and conglomerate. The top of the Ellenburger may be at a depth of 17,800 feet beneath the center of the WIPP facility.[10] Overlying the Ellenburger dolomite is the Simpson Group, a sequence of alternating limestone and green or gray shale members, with several sandstone units occurring near the top. The Late Ordovician Montoya Group is almost entirely carbonate rock. The lower half of the Montoya, in the Texas 1 Richards well, is limestone, and the upper half, dolomite. Chert is fairly common, particularly in the middle of the section.

2.7.2.2.3 Silurian System

Carbonate rocks of Silurian or perhaps Siluro-Devonian age lie above the dolomite of the Ordovician Montoya Group. Near the WIPP facility carbonate rocks consist of a light colored dolomite with chert, and two prominent intervals of limestone, one about 100 feet thick near the middle of the section and another about 200 feet thick near the top.[9] The basal contact is apparently disconformable in this area. Isopach maps indicate that the total thickness of the Silurian or "Siluro-Devonian" carbonate at the WIPP facility is about 1,140 ft.[9] The sequence thins westward at about 25-50 ft/mi.

The lithologic contact between the Silurian carbonate and the overlying Devonian shale generally provides a good seismic reflecting horizon. Structure contour maps indicate that the top of the Silurian lies at a depth of about 15,850 feet beneath the center of the WIPP facility.[10]

2.7.2.2.4 Devonian System

The Devonian System is represented by a distinctive unit of organic, pyritic, black shale unconformably overlying the Silurian carbonate sequence. McGlasson correlates it with the upper Devonian Woodford Shale of Oklahoma and describes it as a "dark brown to black, fissile, bituminous, spore-bearing shale."[11] McGlasson shows that it is a transgressive unit that overlaps successively older units to the northwest. Beneath the WIPP facility, it is about 175 feet thick and thickens gradually southeastward.[9] Haigler and Cunningham show the top of undifferentiated Silurian and Devonian rocks at a depth of approximately 15,700 feet below the WIPP facility.[12] The uppermost portion of the Woodford Shale in the Delaware Basin may be of earliest Mississippian age.[11]

2.7.2.2.5 Mississippian System

Rocks of the Mississippian System at the WIPP facility include a series of limestones referred to as "Mississippian limestone" and an overlying shale interval called the Barnett Shale. At the Texas 1 Richards locale, the limestone is generally light yellowish-brown and locally cherty, with some minor gray shale. The gray shales of the Mississippian limestone are easily distinguished from the brown, locally silty shale of the Barnett. Like the top of the Silurian carbonate, the top of the Mississippian carbonate affords a good reflecting horizon. Structure contour maps indicate that it is about 15,150 feet below the WIPP facility.[10] The thickness of the limestone is about 480 feet below the WIPP facility, gradually thickening northward. The overlying black shale is about 175 feet thick.

2.7.2.2.6 Pennsylvanian System

About 2,200 feet of Pennsylvanian strata occur in the subsurface at the WIPP facility.[9] The section consists of alternating members of sandstone, shale and limestone and rests unconformably on the underlying Barnett Shale.

Unlike most of the earlier Paleozoic strata, the Pennsylvanian strata in the Delaware Basin are characterized by numerous lithologic and lateral facies changes. Thus, lithologic units traceable over broad areas in the subsurface cannot be assumed to be contemporaneous.[13]

According to Meyer,[14] the Lower Pennsylvanian Series includes rocks assigned to the Morrowan Stage, the Middle Pennsylvanian Series rocks assigned to the Atokan (or Derryan) and Des Moinesian (Strawn) Stages and the Upper Pennsylvanian Series rocks assigned to the Missourian and Virgilian Stages.

Morrowan rocks near the WIPP facility consist mostly of fine- to coarse-grained sandstone with varying amounts of dark gray shale. Some limestone, generally as a series of relatively thin beds with some shale and sandstone, typically occurs in the upper part of the sequence. The Morrow sand is a known producer of gas in the Delaware Basin.

The Atokan rocks are principally limestones that become cherty toward the middle of the section and alternate with varying amounts of medium to dark gray shale. The Atoka has locally significant hydrocarbon potential in the Delaware Basin, as in the Los Medanos field southwest of the WIPP facility.

The lower part of the Strawn is dominated by light gray to white, medium to coarse-grained sandstone, locally conglomeratic in the area of the WIPP facility. In its upper part, the group is dominantly limestone with a minor amount of chert, which becomes more abundant northeastward in the site vicinity.[9] Thin beds of dark gray and brown shale are present throughout the section.

Records of the apparent thickness of the Morrowan, Atokan and Strawn units vary considerably because there is no standard method of selecting "picks" on downhole logs and seismic reflection data. Sipes et al.[5] show the top of the Des Moinesian (Strawn) at an elevation of 9,400 feet below mean sea level (MSL) at the center of the WIPP facility. The picks shown in the C. W. Williams, Jr., Badger Unit Federal well two miles northeast of ERDA-9 yield thicknesses of 1224, 607 and 257 feet for the Morrow, Atoka and Strawn rocks, respectively, for a total Pennsylvanian thickness of 2,088 ft[5].

It is presumed that one or more units thicken slightly southwestward to attain the 2,200 feet that Foster[9] shows beneath the WIPP facility, which excludes at least some Missourian - Virgilian strata. A thickness of 2,500 feet (shown by Meyer's Figure 48)[14] is probably more representative of the total accumulation of strata beneath the WIPP facility during Pennsylvanian time.

2.7.2.2.7 Permian System

The nearly 13,000 feet of Permian strata that were deposited within the Delaware Basin area constitute the most complete Permian sequence in North America.[15] The Permian section beneath the WIPP site averages about 12,800 feet. About 3,600 to 3,800 feet of thick evaporite beds (primarily halite and anhydrite with only minor amounts of clastic material) occur in the upper part of the sequence in which the WIPP facility underground storage and experimental areas are being constructed.

Permian rocks are divided into four series, two of which (Wolfcampian and Leonardian) are equated with Early Permian time and two (Guadalupian and Ochoan) with Middle and Late Permian.[16] Massive reef deposits bordering the Delaware Basin were built up mainly during Guadalupian time. Evaporite deposition occurred during Ochoan time, between 225 and 250 million years before present (m.y.b.p). The regional correlations of the Permian are shown in Figure 2.6-10.

<u>Wolfcampian Series</u>-In the area of the WIPP facility, the upper Pennsylvanian is overlain by a thick sequence of interbedded dark limestones, shales and dolomites. Formational status has not yet been designated for this interval. Informally, the sequence is sometimes called the "Wolfcamp Formation." It thickens southward with increasing shale and sand content toward the Val Verde trough (Figure 2.6-2), while toward the north, it thins and increases in limestone content, suggesting a shelf margin facies. At the WIPP site the shale content is believed to approximately equal the carbonate.[9] Isopachs presented by Foster indicate slightly less than 1,400 feet of Wolfcampian strata beneath the WIPP facility.[9] The nearest pick, in the Badger Unit Federal well two mi northeast of the site, shows 1,493 feet of Wolfcampian strata.[5] These differing values reflect the uncertainties in identifying lower and upper limits of subsurface Wolfcampian strata in the Delaware Basin.

Leonardian Series-The Early Permian Leonardian Series is represented by basinal sandy equivalents of the Bone Spring Limestone. The Leonardian Series was originally defined for a shelf and bank facies at the margin of the Delaware Basin. Conditions favoring a significant buildup of reef and bank limestone at the edge of the Delaware Basin existed in Leonardian time as evidenced by the Victorio Peak Limestone, but the most extensive of these limestones developed later, in Guadalupian time. In the vicinity of the WIPP facility, the Bone Spring interval consists of alternating units of sandstone and dark colored limestone with a thick, slightly cherty limestone at the top. Three laterally persistent, very fine to fine-grained sandstone units are named the first, second and third Bone Spring sands. Shale is a minor constituent of the Bone Spring strata, but the limestone beds are commonly argillaceous.

Foster shows the WIPP facility to be near a localized center of thickening of Bone Spring strata, to about 3,500 feet.[9] The unit becomes thinner to the east and northeast. The Badger Unit Federal well penetrates 3,427 feet of Bone Spring rocks.

Guadalupian Series-At the WIPP facility, the Guadalupian Series consists of basin facies rocks composed predominantly of sandstones interbedded with some dark shale and a few thin bedded limestones. A marked facies change takes place about 10 miles north of the site, where all but the lowermost basin facies rocks truncate abruptly against massive reef limestones, of which the Capitan Limestone is the principal unit.

A total thickness of 3,944 feet for the Delaware Mountain Group is recorded two miles northeast of the WIPP facility. Surface mapping at the margins of the basin has led to the recognition of three formations: in ascending order, Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. In the Shell No. 1 James Ranch well about three miles southwest of the WIPP facility, Foster shows 3,970 feet[9] Delaware Mountain Group Strata. Sipes et al., give a similar correlation in the Clayton W. Williams, Jr. well to the northeast of the WIPP facility.[5]

In the Shell No. 1 James Ranch well, the Brushy Canyon Formation is 1,540 feet thick and consists of mostly fine-grained, gray to brown sandstone with minor amounts of brown shale and dolomite. The Cherry Canyon Formation consists of 1,070 feet of sandstone, interbedded with shale, dolomite, and some limestone. The Bell Canyon Formation, 1,180 feet thick, also consists predominantly of fine-grained sandstone, but as a result of being closer to the shelf margin, has a greater percentage of limestone. A limestone member at the top of the Bell Canyon Formation, known as the Lamar limestone, is recognizable over a considerable part of the Delaware Basin. Basin wide, the sands of all three formations are targets for hydrocarbon exploration. The top of the Delaware beneath the WIPP facility has been contoured by Sipes et al. at a depth of 4,065 feet.[5] It is overlain by the evaporites of the Castile Formation.

Ochoan Series-The Ochoan rocks are of marine origin and have two distinct parts: a thick lower section of evaporites and a thin upper section of redbeds.[17] The lower section includes, in ascending order, the Castile, Salado and Rustler Formations. The upper section consists of the Dewey Lake Redbeds. An excellent summary of our knowledge about the Ochoan evaporites in the northern Delaware Basin is provided by Bachman.[18]

According to Oriel et al.,[19] the Ochoan Series in the area of the WIPP facility "includes perhaps the thickest and most extensive evaporite rock sequence in North America." It also contains, within the Salado Formation east of Carlsbad, extensive potash deposits, which constitute 65 percent of the presently exploitable potash resources available within the United States.[20] Lithologic percentages of the Ochoan evaporite sequence obtained from exploratory potashdrilling in the area of the WIPP facility are as follows: 59 percent halite and associated potash deposits; 33 percent anhydrite and gypsum, with glauberite and polyhalite; six percent carbonate rock (limestone, dolomite, magnesite) and two percent clastics (clays and silts).[21]

At the WIPP facility, the Ochoan rocks are about 4,000 feet thick, of which 3,600 feet are the evaporite sequence. This represents about the maximum thickness for the region. The Salado Formation constitutes nearly one half the total thickness. Both the underlying Castile and overlying Rustler are richer in anhydrite and poorer in halite (rock salt) than the Salado, and they provide the halite-rich Salado Formation with protection from fluids present in adjacent units.[17]

The Castile Formation, which gradationally overlies the Bell Canyon Formation,[15] is almost completely confined within the limits of the Delaware Basin.[18,19]

Lithologically, it is the least complex of the evaporite formations, being composed chiefly of anhydrite with a few interbeds of halite and some limestone. A lithologic summary of the Castile by Jones[21] lists 59 percent anhydrite and other sulfates; 30 percent halite and other chlorides; 11 percent limestone, dolomite and magnesite; and no clastics. The rock is sparingly bituminous and has a fetid odor. It has a faint to conspicuous lamination involving a color change, a difference in texture, or a rhythmic alternation of bituminous calcite and anhydrite, bitumen and anhydrite, or anhydrite and halite in layers a fraction of a millimeter to a few centimeters thick. The color of the rock ranges from white to dark gray, becoming darker with increasing depth below the top of the formation.[20]

A detailed classification of the Castile Formation has been proposed by Anderson et al.,[22] dividing the Castile into three halite members and four anhydrite members across the width of the Delaware Basin. Bachman,[18] has refined our knowledge of the details present within the Castile and has prepared some detailed cross sections just south of the WIPP site. In this scheme, Anderson et al.[22] described eight informal members of the Castile in ascending order and designated them with roman numerals: Basal Limestone, Anhydrite I, Halite I, Anhydrite II, Halite II, Anhydrite III, Halite III, and Anhydrite IV. Bachman recognized an additional halite bed within Anhydrite IV, which he designated Halite V.

There is disagreement as to the nature of the Castile-Salado contact. Anderson[22] and Borns and Shaffer,[72] assert that the contact is unconformable, while Jones[17] states that it is conformable, with Bachman generally confirming the latter's conclusions.

The exact nature of the contact is important in determining whether the variations in thicknesses of individual evaporite beds in the lower Salado and Castile Formations are the result of depositional facies changes or interstratal dissolution. If the Salado-Castile contact is conformable and intertonguing, variations in individual bed thicknesses are best explained as depositional facies changes. If the contact is indeed unconformable and represents an erosional surface of the Castile prior to deposition of the Salado, then the contact can legitimately be used as a datum for determining thicknesses of individual evaporite beds. It has been argued that such a datum permits an interpretation of evaporite bed thickness data that assumes interstratal dissolution rather then depositional facies changes as the cause of variations in bed thickness. Bachman[18] concluded that the contact was conformable and that the apparent discontinuity between the two formations was caused by dissolution which occurred long after both were deposited. A discussion of evaporite dissolution is given in Section 2.5.9.1.

According to Jones,[21] the base of the Castile is at an elevation of 680 feet below sea level near the WIPP facility. Sipes et al.[5] show it at 650 feet below sea level. Since ERDA-9 (KB3420.41')intersected the top of the Castile at a depth of 2836 feet the Castile is about 1,234 to 1,264 feet thick at the WIPP facility. Drill hole AEC-8 encountered 1,333 feet of Castile in Section 11, about four miles northeast of ERDA-9.[24]

The <u>Salado Formation</u> contains the thick halite beds in which the WIPP facility underground storage and experimental areas are being constructed. Core hole ERDA-9, near the center of the WIPP facility, core hole WIPP-12, one mile north, and core hole DOE-1, about one and a quarter mile southeast of the WIPP facility, have been drilled through the Salado and into the Castile Formation. Core hole B-25, located near ERDA-9, was drilled into the top of the Salado Formation. Schematic sections of these holes, with general lithology, location of Marker Beds, halite zones, and underground horizons are shown in Figures 2.7-4, 2.7-5, and 2.7-6. Detailed lithologic logs of ERDA-9, WIPP-12, DOE-1, B-25, and the exploratory and vent shafts are presented in Appendix 2C. At ERDA-9, the top of the Salado is 848 feet below the ground surface and the base is at 2,824 feet for a total thickness of 1,976 feet. The waste storage horizon, consisting of argillaceous halite, is between 2,150 and 2,162 feet below the ground surface. At WIPP-12, the Salado is 1,774 feet thick, between elevations 2,518 and 744 feet. At DOE-1, the Salado is about 1,960 feet thick, between the elevations 2,497 and 537 feet. Based on data from the AEC and ERDA test holes, the thickness of the Salado varies between 1,700 and 2,000 feet (Griswold's Table III).[21] In areas affected by halite flow deformation, the thickness of the Salado may exceed 2,000 feet.

The Salado Formation is composed of halite, anhydrite and potassium rich rocks with varying amounts of other evaporites and fine-grained clastics. Halite constitutes about 85 to 90 percent of the formation except in the western part of the area, where groundwater has dissolved and removed much of the salt near the top of the formation. The next most abundant rock in the formation is anhydrite. The remainder of the formation is chiefly polyhalite and other potassium-rich rocks with subordinate amounts of glauberite, magnesite, sandstone, siltstone and claystone.[17]

The halitic zones consist of relatively clean halite, with argillaceous halite occurring in alternating layers which range in thickness from an inch to several feet. Impurities in the argillaceous layers consist chiefly of quartz and clay, including illite, chlorite and a corrensite type of swelling, regular mixed-layered clay mineral.[25]

The Salado halite also contains traces of polyhalite and anhydrite. Locally, glauberite is present in small amounts, and there are several potassium and magnesium minerals, including sylvite, carnallite, kieserite and several other evaporite minerals that occur in seams in the halite. These minerals generally occur in the middle and upper part of the formation. Other constituents of the halite and argillaceous halite include fluid inclusions, which are minor amounts of brine and gas that fill very small cubic and rectangular cavities in crystals of halite and other evaporite minerals. Less common are fractures containing halite-saturated brine and/or gas consisting chiefly of Nitrogen, confined under pressure sufficient to produce "blow-outs" when encountered during drilling operations.[17]

Interspersed in the dominantly halite section are beds or seams of polyhalite and anhydrite, which are continuous through the region. The thickness of these beds ranges from several inches to almost 30 feet but averages somewhat less than one feet. In the upper half of the Salado, these beds are predominantly polyhalite, and in the lower half generally anhydrite. At the base of many of these beds occurs a 0.05 to 0.3 feet thick, medium gray clay seam.

The Salado Formation is divided informally into three members, an unnamed lower member, a middle member known as the McNutt potash zone, and an unnamed upper member. Furthermore, since beds are very persistent, individual seams of anhydrite and polyhalite are numbered in descending order.

The lower member of the Salado Formation is located between Marker Bed 136 and the top of the Castile Formation and is made up of alternating thick layers of halite and thinner seams of anhydrite and polyhalite. Thin bands of magnesite form a carbonate-rich zone in the lower part of most of the anhydrite and polyhalite seams. Seams of claystone underlie the anhydrite and polyhalite beds.[17] The clay seams are underlain in turn by dark to medium gray argillaceous halite, which grades into polyhalitic or clear halite. In places, the argillaceous, polyhalitic and purer halite zones alternate several times between two adjacent anhydrite zones or, in the upper portion of the member, between polyhalite beds. Some clay seams and thinner partings not associated with the markerbeds also occur, becoming more numerous north of the site, where the halite section thins. A few beds of very fine-grained halitic sandstone, a few inches to a foot thick, are found near the base and top of the member. The member is relatively free of carnallite and other hydrous potassium and magnesium evaporite minerals in all parts of the site area, but the upper part contains small amounts of these minerals several miles to the north.[17] The Cowden anhydrite forms a distinctive, 20 feet thick, areally extensive bed of anhydrite, below which is a very pure halite bed. The thick salt section (274 feet thick at ERDA-9) lying below the Cowden and above the Castile-Salado contact is sometimes referred to as the Infra-Cowden.

The lower member of the Salado is the rock unit in which the waste storage area horizons are being placed. As shown in Figure 2.7-4, the storage horizon is located above Marker Bed 139 near the middle of the lower member.

The lower member of the Salado is 1,094 feet thick in ERDA-9, 941 feet thick at WIPP-12 and 1,056 feet thick at DOE-1. An isopach map of the lower member of the Salado is shown in Figure 2.7-7. Southward, according to Jones,[17] the lower 240 to 300 feet of the member grades by intertonguing into the upper part of the Castile Formation, and the thickness of the member decreases to between 785 and 950 feet. Anderson,[26] however, asserts that the Infra-Cowden wedges out southward and that the top of the Castile is unconformable with the Salado because of dissolution at or near the top of the Castile Formation.

The McNutt potash zone, located between the six to ten foot thick Vaca Triste halitic sandstone and Marker Bed 126, differs from the other members of the Salado in that it contains potassic rocks rich in sylvite, langbeinite and hydrous evaporite minerals.[17] These potassic rocks occur at varying intervals in seams of rock salt scattered through the McNutt zone and provide much of the potential reserves of potash minerals mined commercially in the Carlsbad district west of the WIPP facility. In addition to the potassic rocks, the McNutt is composed of thin seams of anhydrite and polyhalite within the dominant halite. Partings of claystone occur beneath most anhydrite and polyhalite seams and above layers of argillaceous halite.

Figure 2.7-8 shows the thickness of the McNutt potash member. The member is thickest in the southern area of the WIPP facility and thins northward. The member is 394 feet thick about one and a quarter mile southeast of the site center, 380 feet thick at the center of the WIPP facility and thins to 355 feet one mile north. The thinnest section of the McNutt member in the area of the WIPP facility is located to the northwest of the WIPP facility, where it is about 340 feet thick. This decrease in thickness is accounted for by northward thinning of the salt between each Marker Bed.

The upper member of the Salado consists of halite, minor amounts of anhydrite and polyhalite and two persistent beds of very fine-grained halitic sandstone, which are, respectively, 30 to 40 feet and 112 to 120 feet below the top of the unit. Claystone underlies seams of anhydrite and polyhalite and coats the upper surfaces of argillaceous layers in the halite. The upper member is generally free of hydrous evaporite minerals, but some intervals contain small amounts of carnallite and kieserite.[17]

At the WIPP facility, the upper member of the Salado Formation is 502 feet thick at ERDA-9, 510 feet thick at DOE-1 to the southeast and thins to 478 feet farther north at WIPP-12 (Figures 2.7-9 and 2.7-10). This northward thinning seems to be partly depositional and partly erosional, because the member is more thinly bedded in the north and contains fewer beds.

Toward Nash Draw, the upper member of the Salado thins considerably, losing as much as 300 feet. This pronounced thinning appears to be the result of dissolution of the soluble Salado salts by lateral influx of unsaturated fluids along interstratal discontinuities.[2] The residual debris is composed of clay with crudely interlayered seams of broken and shattered gypsum and fine-grained sandstone. The clay was apparently concentrated through dissolution of argillaceous halite and other clay-bearing evaporites. The gypsum represents the hydrated remnant of anhydrite and polyhalite seams. The residual debris also commonly contains ragged and embayed masses of anhydrite and polyhalite and grades laterally into anhydrite and polyhalite.

In the vicinity of the WIPP facility, the Salado Formation is overlain conformably by the Rustler Formation. The contact between the two formations is the horizon at which dominant halite is overlain by a thin anhydrite bed which gives way to a 35 to 55 feet thick unit of fine-grained sandstone that is dolomitic in the basal few feet.[17]

The Rustler Formation, the uppermost of the three Ochoan evaporite formations, contains proportionately the least amount of halite and the largest amount of clastic material. Jones[21] lists lithologic percentages in the Rustler as follows: 43 percent halite and other halides; 30 percent anhydrite, polyhalite, gypsum and other sulfates; 17 percent clastic rock and 10 percent dolomite, limestone and magnesite. Two areally persistent dolomite beds in the Rustler serve as important marker units. The lowermost of the two dolomite beds, known as the Culebra Dolomite Member, is about 23 feet thick at ERDA-9 and its base is found about 120 feet above the base of the Rustler. The upper dolomite unit, the Magenta Dolomite Member, is about 24 feet thick and its top is about 58 feet below the top of the Rustler.

The Rustler Formation crops out beyond Livingston Ridge, about five mile west of the WIPP facility (Figure 2.7-1). In the outcrops in Nash Draw, the Rustler is a jumbled mass of gypsum, with minor amounts of dolomite and a few seams of unconsolidated sands and clays. Exposed rocks are porous, friable, strongly jointed, cavernous and locally brecciated; stratification is obscured and bedding attitude can rarely be determined.[17]

At the WIPP facility, the Rustler is lithologically divided into a sandy lower part and an anhydritic upper part.[20] The sandy, lower, 100 feet thick part is a very fine-grained, silty sandstone containing lesser amounts of abundant anhydrite and rock salt. The sandstone is halitic and light to dark gray in its lower section and reddish-brown and salt free in its upper section. The 210 feet thick anhydritic upper part of the formation contains gray anhydrite with a few interbeds of reddish brown clay and gray dolomite. The Culebra and Magenta Dolomite Members are found within this upper section.

Proceeding eastward across the WIPP facility and into Lea County, the gypsum in the Rustler gives way to anhydrite with minor amounts of polyhalite and the sands and clays grade into sandy and argillaceous halite.

With the eastward, down-dip change in composition from gypsum to anhydrite and halite, the thickness of the Rustler also changes significantly. An isopach map of the Rustler Formation is shown in Figure 2.7-11. The isopachs suggest a consistent thickness of about 300 to 350 feet throughout most of the area around the WIPP facility. The closely spaced isopachs at the east edge of the WIPP facility show the increasing amount of salt remaining in the Rustler toward the east. The formation increases in thickness eastward and southeastward by about 180 feet over a distance of about 2.5 miles, or about 70 ft/mi. As with the Salado Formation, these contours appear to indicate a dissolution front in the Rustler. Near the center of the WIPP facility, ERDA-9 encountered 310 feet of Rustler, and at WIPP-12 and DOE-1, 326 feet and 309 feet of Rustler were encountered, respectively. The thickness of the formation indicates that much of the original halite has been leached away, particularly in the upper part of the formation. The difference in formation thickness between the southeast and northeast corners of the area is at least partly depositional in origin, since the formation is more thickly bedded in the southeast where it is generally thickest.[17]

The contact between the Rustler Formation and the overlying Dewey Lake Redbeds is marked by a change from gray anhydrite to reddish brown. The anhydrite below the contact is free of sand and clay and ranges in thickness from 18 to 32 feet. The Dewey Lake Redbeds rest conformably on the Rustler Formation.[18]

The Dewey Lake Redbeds are the uppermost of the Late Permian Ochoan Series and represent the top of the Paleozoic in the Delaware Basin. The term "Dewey Lake" replaced the term "Pierce Canyon" originally proposed by Lang[23] and applied to the redbeds in the Nash Draw area by Vine.[1]

The Dewey Lake crops out along the east edge of Nash Draw (Figure 2.7-1), but generally the formation is mantled by dune sand and caliche. Beneath the surficial cover, the Dewey Lake occupies a broad band between the WIPP facility and Nash Draw. It is bounded on the west by the erosional scarp of Livingston Ridge, and to the east it is overlain by Triassic and younger sediments. The latter contact occurs across the center of the WIPP facility.[17]

The Dewey Lake is distinguished by its lithology, distinctive reddish orange to reddish-brown color, and sedimentary structures. The formation consists of mudstone, claystone, siltstone, and interbedded sandstone with locally abundant greenish-gray reduction spots. Gypsum-filled fractures occur throughout the lower portion. The Dewey Lake is thinly bedded, with horizontal laminations, fine cross-laminations, ripple marks, and soft sediment deformation features.[18,27,28]

The gypsum-filled fractures are mostly horizontal to subhorizontal and parallel to the bedding planes.[29] Vertical to subvertical fractures are common, but less frequent than horizontal and subhorizontal fractures. The gypsum filling in the fractures is fibrous and varies in thickness from less than 1/32 inches up to three inches.[29] Zonation of the fracture fillings is common and probably indicates more than one episode of fracture movement and filling.

Although stratification is generally parallel, small-scale cross-laminations do exist. Many bedding surfaces contain oscillating ripple marks, and silt-filled mud cracks occur at the top of many mudstone layers. The small grain size and the minute scale of primary sedimentary structures suggest that the silt was deposited in extremely shallow water extending over a broad flat. Lenses of medium scale, cross-laminated, fine-grained sandstone or siltstone in the upper part of the Dewey Lake probably indicate a gradual change toward fluvial deposition toward the end of Dewey Lake time.

According to Vine,[1] the Dewey Lake Redbeds represent the beginning of continuous deposition of detrital sediment following the long period of predominantly evaporitic deposition in the Delaware Basin and the adjacent shelf areas of southeastern New Mexico. However, the abrupt change in lithology does not necessarily signify a sudden tectonic or eustatic movement, but only a gradual decrease in the salinity or depth of the water plus a new source for the detrital sediment. Jones[20] suggests that the contact between the Rustler and Dewey Lake may be a short hiatus unconformity, whereas Bachman[18] states that the contact is conformable.

Isopachs of the Dewey Lake Redbeds (Figure 2.7-12) indicate gradual westward thinning of the formation. At ERDA-9, the Dewey Lake has a thickness of 487 feet, at WIPP-12 the formation is 474 feet thick, and at DOE-1, the Dewey Lake has a thickness of 535 feet. Its thickness varies greatly across the area, from about 550 feet southeast of the site to only 100 feet to the southwest. In the WIPP facility area, thinning of the Dewey Lake to the northwest is attributed to pre-Late Triassic erosion after the redbeds had been tilted southeastward.[17] Locally, however, where the Dewey Lake forms the surface of either the pre-Late Tertiary or Quaternary terrane, post-Triassic erosion has cut through the Dewey Lake, producing steepened isopach gradients. In Figure 2.7-12, gradients of 20 to 40 ft/mi are observable in the eastern half of the map, reflecting pre-Late Triassic erosional thinning. More abrupt thinning of up to 150 ft/mi to the southwest represents later dissection, apparently related to the post-Late Triassic erosion that has affected the Dewey Lake surface.

2.7.2.3 Mesozoic Rocks

2.7.2.3.1 Triassic System

Late Triassic rocks in the northern part of the Delaware Basin belong to the Dockum Group, which unconformably overlies the older rocks. The Dockum is of continental origin and consists of fine-grained flood plain sediments and coarse alluvial debris deposited beyond the borders of the Delaware Basin. Away from the

WIPP facility, the Dockum Group has been subdivided into three formations. In descending order, they are the Chinle Formation equivalent, the Santa Rosa Sandstone and the Tecovas Formation. McGowan et al.[30] indicate that it is preferable to refer to the Triassic deposits in the vicinity of the WIPP facility as Dockum undivided, not as the Santa Rosa Sandstone.

The Dockum Group rests unconformably on the underlying Dewey Lake Redbeds. Vine[1] calls this contact a disconformity, but Jones considers it "an angular unconformity of low angle."[17] This unconformity represents a depositional hiatus between the end of Permian time and Late Triassic time.

Bachman[31] describes the basal beds of the Dockum Group in southeastern New Mexico as consisting usually of course, angular, conglomeritic sandstone locally interfingering with shale. Where the basal beds are shaley, they are difficult to distinguish from the underlying Dewey Lake Redbeds. The Dockum Group is exposed on the east side of Nash Draw where it is no more than 75 feet thick but eastward in the subsurface in western lea County it may be as much as 1,500 feet thick.[31]

The Dockum Group represents a change in the environment of deposition from that of the Dewey Lake Redbeds. The large-scale trough-type crossbedding of the Dockum probably indicates a fluvial environment, while the lack of sorting, the arkosic composition and the angularity of the grains suggest rapid deposition by streams descending from a predominantly crystalline rock terrane.[1]

At the WIPP facility, the Dockum occurs as an erosional wedge pinching out near the center of the site. A thickness of only nine feet of sandstone was recorded at ERDA-9. Eastward, the Dockum forms the pre-Gatuna surface and is blanketed by an extensive veneer of upper Tertiary alluvial deposits and caliche and recent dune sand.

Figure 2.7-13 is an isopach map of the sandstones in the Dockum Group. The wedge of sandstone thickens rapidly eastward at the rate of up to 150 ft/mi. The formation reaches a maximum thickness of 250 feet east of the WIPP facility. One mile north of ERDA-9, in WIPP-12, the formation is 142 feet thick and it is about 87 feet thick at DOE-1, about one and a quarter mile southeast of ERDA-9. Sections compiled by Jones[17] indicate a relatively uniform thickness of 250 feet for the sandstone unit several miles east of the Lea County boundary. The steepened wedge effect of the sandstone across the WIPP facility area is probably due to the post-late Triassic, pre-Gatuna erosion that cut downward into the Dewey Lake surface.

2.7.2.3.2 Post-Triassic Mesozoic Rocks

No Mesozoic rocks younger than the Dockum Group are known to exist in the area of the WIPP facility. According to Jones,[17] the Jurassic period was a time of erosion and removal of portions of the Dockum Group. Some rocks of Early Cretaceous age, though absent at the WIPP facility, probably were deposited by seas that advanced northward across southeastern New Mexico. Small outliers and crevasse deposits of Lower Cretaceous rocks are found lying unconformably on the Capitan, Tansill and Castile Formations near Carlsbad Caverns,[23,32] on the Salado Formation near Black River Village, on the Rustler Formation a few miles northeast of Carlsbad, New Mexico, and on the Dockum Group at many places to the north and east of the WIPP facility.[33]

2.7.2.4 Cenozoic Rocks

2.7.2.4.1 Tertiary System

No Early or Middle Tertiary sedimentary rocks are known to be present in the region. A lamprophyre dike, the only igneous rock in the area younger than Precambrian age, intrudes the Salado Formation at the New Mexico Potash Corporation potash mine about nine miles northeast of the WIPP facility (Figure 2.6-12) and represents part of a northeast-trending dike or series of dikes.[13] This lamprophyre dike, which is not exposed at the surface east of the Pecos River, has been radiometrically dated at about 30 $\pm$1.5 m.y., indicating a mid-Tertiary age of emplacement.[17] This dike trend and more recent investigations that have been conducted relative to it, are further discussed in subsections 2.6.3.4.1 and 2.6.4.1.1.

In late Tertiary time, extensive alluvial fans carried sand and gravel eastward over a broad erosional plain that had developed in the region by late Miocene time. Sediments that accumulated during this alluviation formed the Ogallala Formation, which, based on the youngest fauna present, indicate that it is probably no younger than 4.6 m.y.[3]

The Ogallala Formation is found about seven miles from the center of the WIPP facility as a thin erosional remnant capping the Divide. A geologic map by Bachman[17] indicates that the Ogallala at the Divide occurs only at elevations above 3,750 feet. It is about 25 feet thick, including about 10 feet of conglomeratic sandstone at the base. The Ogallala also contains, in lenticular beds, pebbles of rounded quartzite and chert up to one and a half inches in diameter.[3]

The Ogallala is overlain by a dense, light gray to white, sandy caliche that probably formed during or shortly after Ogallala deposition.[17]

2.7.2.4.2 Quaternary System

Pleistocene Series-Pleistocene age materials in the vicinity of the WIPP facility are the Gatuna Formation, Mescalero Caliche Spring Deposits and Holocene Deposits.

The Gatuna Formation is a reddish-brown, poorly consolidated sand, gravel, and silty clay[34] that forms a thin layer throughout the area. Within the vicinity of the WIPP facility it ranges in thickness from zero to more than 75 feet (Figure 2.7-14). At ERDA-9, 27 feet of Gatuna were encountered. In Nash Draw, the Gatuna is more than 100 feet thick and fills sinkholes previously formed by dissolution of halite and other evaporites.[1]

The Gatuna outcrops out; it is usually covered by a thin veneer of caliche and surficial sand. The nearest the Gatuna crops out is along the west facing slope of Livingston Ridge at the edge of Nash Draw (Figure 2.7-1).

The Gatuna was laid down by streams under pluvial conditions.[3] Bachman[34] has identified an east-west trending channel that existed just north of the WIPP facility in Gatuna time, where more than 75 feet of fluvial sediments were deposited. In Pierce Canyon the Gatuna includes stream gravels that have collapsed into ancient sinks.[34] Bachman concludes that the Gatuna was deposited in a much wetter climate than that of the present, and that Gatuna time probably represented the most humid Pleistocene stage in southeastern New Mexico.[3]

The presence of Ogallala pisolitic debris in the Gatuna indicates that the Gatuna is Pleistocene rather than Pliocene in age. Bachman has tentatively assigned a Kansan age to the unit, which has been radiometrically dated at more than 600,000 years.[3]

The Mescalero Caliche is a hard, resistant petrocalcic soil horizon that lies beneath a cover of wind-blown sand. It averages about 4.3 feet thick in the vicinity of the WIPP facility. It is resistant to weathering and underlies extensive stable land surfaces. It forms a soil-stratigraphic unit that can be mapped in definite stratigraphic sequence with other deposits.

The Mescalero caliche consists of a dense petrocalcic horizon, usually one to two feet thick, which grades downward into a more friable calcic horizon that in turn grades into the underlying bedrock. The bedrock is generally fractured and recemented with calcareous material. In many places the caliche is brecciated and recemented,[3] and in most places where it can be observed near the WIPP facility, is cut by near-vertical pipes.[35]

The upper dense caprock of the caliche is prominently laminated parallel to the upper, undulating surface,[35] indicating that the Mescalero caliche has experienced successive cycles of dissolution and reprecipitation of the matrix. This occurred during the interval of climatic stability that followed deposition of the Gatuna Formation. Based on regional geomorphology, Bachman[3] correlated the formation of the Mescalero caliche with the early Yarmouthian interglacial stage (mid-Pleistocene time) about 600,000 years ago. Uranium disequilibrium data support this correlation, indicating that various zones within the caliche began to form between about 410,000 and 510,000 years ago.[33]

Petrocalcic horizons such as this form slowly beneath a stable landscape at the maximum depth of infiltration of soil moisture.[18,33] Its presence indicates that no significant recharge could have taken place from general infiltration during the time it was forming.[18] Once formed, the upper laminated zone is very dense and impervious and even if the climate becomes more humid than the one under which the caliche formed, the petrocalcic horizon provides an additional (although not totally unbroken[34]) obstruction to infiltration.[33]

Spring Deposits are soft, earthy, white deposits of gypsite that occur in a zone along the east side of Nash Draw. Bachman[30,33] reports that fossil snails and bones of extinct camels and horses have been found in these deposits, indicating active springs during late Pleistocene time, after deposition of the Mescalaro caliche.

Holocene Deposits in the vicinity of the WIPP facility include windblown sand, alluvium, and playa deposits.[33] The most prevalent deposit is the windblown sand that covers most of the area. The sand, known locally as Mescalero sand,[1,33] occurs either as a sheet deposit resting on caliche or as active dune fields. The average thickness of the sand in the former case is about five to 15 feet, while the active sand dunes may reach thicknesses of 100 feet. Generally, the sand consists of two parts: a slightly clayey, medium brown, eolian sand up to one and a half feet thick, and above it a loose, windblown, light brown to light yellowish-gray sand. The sand sheets are partly stabilized by sparse plant cover. The widespread deposits of windblown sand are indicative of a large source of fine sand, as well as the extreme climatic fluctuations that occurred during the Pleistocene.

Deposits of alluvium, mapped by Vine,[1] generally occur in belts 1/4 to 3/4 of a mile wide along the base of Livingston Ridge and locally in smaller depressions (Figure 2.7-1). These deposits are similar to sheet wash or small alluvial fans, and Vine considers them analogous to pediment or bolson deposits.[1] The alluvial material consists of red sand, silt, and rock fragments derived from the underlying Dewey Lake Redbeds and the Dockum. Locally, the alluvium includes gypsum and dolomite from the Rustler Formation mixed with windblown sand and silt.

Playa deposits occur in mudflats and consist of eolian sand and alluvium reworked by shallow lake waters.[33] Vine shows these areas clustered primarily within Nash Draw, where occasional stormwater runoff accumulates.[1] Many playa deposits consist of gray mud with carbonate and saline minerals derived from the evaporation of brine.

2.7.3 STRUCTURE AND TECTONICS

2.7.3.1 Tectonic and Structural Setting

2.7.3.1.1 Relation of Local Structure to Regional Tectonics

The major tectonic feature in the vicinity of the WIPP facility is the Delaware Basin. The basin evolved in late Paleozoic time through the downwarping of the Precambrian basement terrane.

Thick and rapid sedimentation occurred in the Delaware Basin from latest Pennsylvanian through Permian time. Beneath the WIPP facility about 15,000 feet of Pennsylvanian and Permian age clastics, calcareous clastics, and evaporites are present. During the late Pennsylvanian and early Permian, the central and southern portions of the Delaware Basin received much of their sediments from the mobile Ouachita tectonic belt to the south (Figure 2.6-2). The northern part of the Delaware Basin, in New Mexico, received sediments from intracratonic highs located to the west and to the east. The Delaware Basin is bordered on the southwest by the Diablo Platform, which was tectonically active in late Pennsylvanian and Permian time. The Central Basin Platform, located east of the WIPP facility along the New Mexico-Texas border, separated the Delaware Basin from its eastern counterpart, the Midland Basin, from Mississippian (or earlier) time until the Permian, when these structural elements became deeply buried by sediments.[36]

In Late Permian time, nearly 4,000 feet of evaporites, predominantly halite accumulated. Differential subsidence ceased, producing stable cratonic conditions. Later, Triassic redbeds mantled the region. Between late Triassic and Pliocene time, the basin tilted gently, producing an eastward dip of about one degree across the area around the WIPP facility. Late Permian and Triassic rocks exposed in the basin today do not reflect basin-wide warping. The major structural feature of these deposits is the regional eastward slope produced in late Cenozoic time during uplift of the Guadalupe Mountains.[37]

2.7.3.1.2 Tectonic and Nontectonic Mechanisms

At the WIPP facility, stresses associated with the origin and development of the Delaware Basin have deformed the pre-existing rocks in different ways. The structural features that occur in the area are related to the position of the rocks relative to the bedded salt. The geologic structure at the WIPP facility is described under three headings; deep structures, salt deformation and shallow structures.

This distinction is made because salt deforms more plastically or behaves as a less viscous fluid than other rock types at the same temperature, pressure, and stress. Slight tilting of the beds or lateral differences in lithostatic pressure are sufficient to initiate viscous salt flow. Since salt deformation is quite different from the deformation that would occur in the adjacent sedimentary rock, deformational features exhibited by the rocks lying above a thick salt bed may have little or no mechanical relationship to structures in the rocks beneath the salt. Rocks overlying salt may display local structures that are generated by the mass migration of salt. Also, collapse features and other irregularities brought about by uneven subsidence or upward by stopping may result from subsurface dissolution of salt.

2.7.3.2 Deep Structures

Structure contour maps show a regional homoclinal dip to the east-southeast on all pre-Ochoan Paleozoic strata. Gradients on all pre-Permian horizons are similar in magnitude and direction. They decrease from about 150 ft/mi in the lower Paleozoic to about 100 ft/mi at the top of the Pennsylvanian. Permian strata beneath the Ochoan Series slope east-southeast at about 75 ft/mi,[9] markedly less dip than pre-Permian strata. For an explanation of geologic structures within the Delaware Basin, see subsection 2.6.4.1.1.

In the WIPP facility area, seismic reflection data and drillhole information have been used in preparing detailed structure contour and seismic isochron maps. Structure contour maps cannot be accurately developed because lateral variations in seismic velocities from seismic reflection data collected in the vicinity of the WIPP facility preclude conversion of the seismic time structure and isochron maps into geologic depth structure maps.[36] Broad open folds indicated on the seismic time structure maps could represent either geologic depth structures or lateral velocity variations. Fault indentations, however, cannot be attributed to lateral velocity variations due to the manner in which the seismic reflection data were collected.[38] Thus, drillhole information was used to prepare most of the geologic depth structure (structure contour) maps. Time structure maps for many of the same horizons have also been prepared. These maps are useful for delineating geologic structures not mappable solely by drillhole data.

Figures 2.7-15 and 2.7-16 are seismic time structure maps of surfaces at the top of the Bone Spring Formation and near the top of Cherry Canyon. Figure 2.7-17 is a structure contour map of the top of the Bell Canyon Formation based on drillhole data. The structure contours indicate minor faulting and secondary warping in Paleozoic strata below the evaporite beds. All strata of Guadalupian age and older have been deformed (e.g., Figure 2.7-18, which is a structure contour map of a Devonian horizon); the intensity of deformation produced by the major tectonic activity that occurred in Late Pennsylvanian or Early Permian time increases with depth.

Figures 2.7-19 and 2.7-20 from Snyder[39] are east-to-west and north-to-south cross sections across the vicinity of the WIPP facility. Figure 2.7-21 is an index map showing the lines and drillholes for Figures 2.7-19 and 2.7-20. These sections indicate minor faulting of the Bell Canyon-Castile contact and the occurrence of salt flowage and deformation features in the Castile Formation. These features are manifested by only slight warping of the overlying formations.

2.7.3.3 Salt Deformation

2.7.3.3.1 Subregional Structure of Evaporite Beds

Throughout the northern Delaware Basin, the uniform southeastward homoclinal dip is practically the only structural feature that is common to all levels of the evaporite section.[17] Conclusive evidence has not yet been found to establish the time of regional tilting of the Delaware Basin. At least one episode of regional tilting apparently occurred after Triassic deposition and before Ogallala time (lower Pliocene).[3] Further eastward tilting occurred with the major uplift of the Guadalupe Mountains in late Cenozoic time (Section 2.6.4.2.5).[32] Superimposed on this homocline is a rather complex system of flow features attributable to the mass migration of salt.

Immediately towards the basin of the reef is a structural trough paralleling the base of the reef and plunging southeastward. The most intense deformation in the evaporite sequence seems to be spatially related to this trough. The trough is expressed within the salt layers and the top of the clastic Delaware Mountain Group (Bell Canyon Formation).

Also present within the evaporite sequence are large mounds termed salt anticlines.[40] The most pronounced of these features in the WIPP facility vicinity is the anticline penetrated by drill hole ERDA-6. The lowest Castile salt member, Halite I, exhibits an increased thickness in this area (Figure 2.7-22). An isopach map[39] of the lower Castile Halite I unit shows an increase in thickness from about 350 feet at the WIPP site to about 1,000 feet at the anticline. The isopach lines define an elongate, sharply thickened bulge of Halite I. The axis of the anticline is drawn nearly parallel to, and on the basin side of, the buried Capitan reef front.

Structural detail within the salt anticline has been provided by the ERDA-6 core hole. The Anhydrite I unit underlying this deformed salt is not thought to be significantly deformed or to rest on deformed rocks (See Figure 2.7-23).[17] According to Anderson and Powers,[40] the middle anhydrite bed of the Castile that overlies Halite I has been pushed up by the rising salt. Since the stratigraphic sequence in the ERDA-6 hole passes directly from the Salado Infra-Cowden salt to the Castile Halite II, Anderson and Powers conclude that at this location, Halite I, Anhydrite II and Halite II have intruded and pushed aside the uppermost units of the Castile. The overlying Salado beds, though not breached by the intrusion, are arched over the Castile structure. It is therefore evident that the anticlinal arching effect is due to the presence beneath these anticlines of a salt core that rose from the lower part of the Castile and partly intruded the overlying rocks.The Infra-Cowden salt is the uppermost salt bed of the Castile-Salado sequence to thicken along the trend of the buried Capitan reef, and it is also the lowest major salt bed to overtop and extend beyond the reef margin in this part of the basin. Although no appreciable thickening of Salado salt above the Infra-Cowden is apparent over the Capitan reef,[26] structure contours at the top of the Castile Formation[17] and on Marker Bed 124 within the McNutt potash zone[26] document that the Salado is arched along and toward the basin edge of the reef.

2.7.3.3.2 Deformation of Salt in the Vicinity of the WIPP Facility

The structure of the evaporite strata beneath the WIPP facility has been investigated using drillhole and seismic reflection data.[38] As discussed in Section 2.7.3.2, development of structure contour maps from the WIPP seismic reflection data is impossible. Thus, the following discussion of the structure of the evaporite section in the vicinity of the WIPP facility is based primarily on structure contour maps developed from drillhole data and is augmented (where possible) by seismic reflection information.

Structure contour maps of the evaporite horizons in the vicinity of the WIPP facility indicate an easterly dip of about 50 to 130 ft/mi. Superimposed on this homocline are a number of salt deformation features, particularly in the Castile formation, where the lower halite beds have been most mobile. Figures 2.7-23 through 2.7-32 show structure contours on stratigraphic horizons in the Castile, the top of the Castile, the base of the Cowden Anhydrite, the top of the lower unit of the Salado (near MB 126), the top of the McNutt potash zone, and the top of the Salado Formation. Figures 2.7-33 and 2.7-34 are seismic time structure maps of a mid-Castile horizon (probably near Anhydrite II) and the top of the Castile.

The structure contours of the top of Anhydrite I (Figure 2.7-23) indicate a southeasterly regional dip of about 65 ft/mi. Three faults are shown on this horizon. The two northeast-trending faults in the northern part of the site bound an apparently upthrown fault block. This interpretation resulted from intersection of the upper contact of Anhydrite I in borehole WIPP-11 about 250 ft above projections based on data from WIPP-12 and WIPP-13. The northwest-trending fault southwest of the WIPP facility is an interpretation by Snyder[39] to explain the abnormal thinning of Anhydrite I in this area. A difference in thickness of about 75 feet was observed in boreholes separated by less than one half mile. The structure contour map of the top of Anhydrite I generally mirrors the structure on the Bell Canyon Formation.

The structure contour map of the top of Halite I of the Castile Formation (Figure 2.7-24) shows the irregular distribution of halite that overlies the nearly planar surface of Anhydrite I. The isopach map of Halite I (Figure 2.7-22) shows a thinning of Halite I at the WIPP-13 and WIPP-11 locations, a slight thickening at WIPP-12 and a major thickening at ERDA-6. The faults indicated on the structure contour map of Anhydrite I are not observed on the top of Halite I, suggesting that the faulting of the anhydrite may have occurred prior to deposition of the overlying halite.

Overlying Halite I is Anhydrite II, a 110 to 120 feet thick anhydrite layer. The structure contour map of the top of Anhydrite II (Figure 2.7-25) is similar to that of Halite I because the thin anhydrite was carried along with the movements of the underlying halite. The surface of Halite II (Figure 2.7-26) overlying Anhydrite II, also shows a low in the area of WIPP-13 and a high at ERDA-6. Additionally, there is an oval high in the WIPP-11 area. It appears that halite from Halite II has moved from the areas of WIPP-13 and ERDA-6 toward WIPP-11.[39] The cross section (Figure 2.7-20) shows this interpretation.

The structure on the top of the Castile Formation is shown in Figure 2.7-27. The three areas of structure, highs at WIPP-11 and ERDA-6, an antiform at WIPP-12, and a low at WIPP-13, are apparent although there is some muting of the structures. The Anhydrite III isopach map (Figure 2.7-35) shows the thickness of the anhydrite unit at WIPP-13 to be excessive. The cross section (Figure 2.7-20) depicts the steep dip of the anhydrite at this location accounting for the excessive thickness observed in the borehole. At WIPP-11, Anhydrite III is about 200 feet thinner than normal. This thinning may be due to a combination of extension of the anhydrite as Halite

II rose underneath, and nondeposition if Halite II was rising prior to deposition of Anhydrite III. In the ERDA-6 area, the structure has been interpreted as a diapir. Anhydrite III has been breached by the upwelling of the underlying Halite I (Figure 2.7-20).[39]

The seismic time structure maps of a mid-Castile horizon and the top of the Castile are shown in Figures 2.7-33 and 2.7-34. The most notable feature on these maps is the "area of complex structure" north of the WIPP facility. This area produced chaotic, uninterpretable seismic reflections from the two Castile horizons. Thus, further definition of the structures near the WIPP-11, WIPP-13 and ERDA-6 is not possible by utilization of seismic reflection data. Some minor faulting in the Castile is shown on these maps that is not interpretable from available borehole data. Two east-west trending faults are indicated about one mile southwest of the WIPP facility at their closest point. These faults are thought to bound a shallow elongated syncline. The structural relief of this feature is about 210 feet 30 milliseconds of two-way seismic travel time (at a seismic velocity of 14,000 ft/s). If the fault indications are valid, this feature is a small graben.[41]

A third fault is indicated on the Castile structure contour maps and is located in the southeastern part of the site. The displacement of this fault is small at the top of the Castile (10 to 20 milliseconds two-way seismic travel time or 70 to 140 feet at a seismic velocity of 14,000 ft/s). The arcuate map trace, lack of consistent offset and the absence of fault indications to the northeast along the fault strike suggest that it is not a major through-going tectonic feature. Other minor fault indications are shown on the structure contour map of a mid-Castile horizon along the southeastern edge of the "area of complex structure." Whether these faults extend upward to the top of the Castile is indeterminable because the seismic reflection data are not interpretable at that horizon in this area.[41]

The structure contour map of the base of the Cowden Anhydrite of the Salado Formation (Figure 2.7-28) exhibits a remarkably smooth surface compared to the structure maps of the units in the Castile. There is a low structural near WIPP-13, very little structure at WIPP-11, a broad southeast-plunging nose at ERDA-6, and a south-westward trending antiform at WIPP-12. Southwest of the WIPP facility there is a small oblong structure high.[39]

The isopach of the interval between the base of the Cowden and the top of the Castile (Figure 2.7-36), when compared to the structure contour map of the top of the Castile, suggests that the interval was deposited on existing and developing structures. Thus, deposition of the interval tended to level the hundreds of feet of structure on the Castile Formation.[39]

The structure of the top of the lower member of the Salado Formation (Figure 2.7-29) bears almost no resemblance to the structure maps of the underlying units. A very slight high is indicated at WIPP-11 and an oblong northwest-trending high is shown at ERDA-6. The small closed high southwest of the WIPP facility is also evident. Most of the structural features seen on underlying horizons are not apparent at this level. Instead, a very broad northeast-plunging synclinal surface was developed east of the WIPP facility.[39]

The isopach of the Salado Formation lower member (Figure 2.7-7) suggests that existing structural highs and lows of the Castile were filled by deposition of the lower Salado. Structure on the McNutt potash zone surface (Figure 2.7-30) reflects only vaguely the underlying surfaces. The structures at WIPP-11 and WIPP-13 have disappeared, and the plunging structural nose at ERDA-6 is visible but significantly muted, and a minor high is present southwest of the WIPP facility. The isopach map of the McNutt indicates a thickness of about 100 feet over the vicinity of the WIPP facility.[39]

The structure of the top of the Salado Formation (Figure 2.7-32) is very similar to that of the top of the McNutt. A broad southeast-dipping synclinal structure trends east of the WIPP facility. This structure appears on the top of the lower member of the Salado and becomes more pronounced upward. Neither the isopach map of the upper member of the Salado (Figure 2.7-9) nor the isopach maps lower in the Salado show a thickening in the formation over this synclinal feature. The rapid thinning of the upper Salado northwest of the WIPP facility is caused by dissolution of halite at the upper contact of the formation. The easternmost extent of this dissolution is shown in Figure 2.7-9.

Various intervals in the Salado (intervals bounded by sulfate Marker Beds) exhibit thickening and thinning across the vicinity of the WIPP facility. These variations in thickness may have resulted from deposition of the Salado on a slowly rising or subsiding surface. Alternatively, post-Triassic to pre-Pliocene deformation could have "squeezed" halite from some areas. The Castile structural high near ERDA-6 does not seem to have affected the lower Salado by thinning the halite. The formations overlying the Castile, however, are arched, indicating that at least some of the upward movement of the Castile occurred after deposition of these younger formations. Similar arching of post-lower Salado sediments near WIPP-11 is not evident. The lack of deformation of the younger sediments at this location suggests that no post-lower Salado movement has occurred or that the lower Salado halites were "squeezed out" over the structure, absorbing the vertical movement. The mechanism of such gravity-driven salt deformation is probably similar to that described by Sena and Jackson in the East Texas Diapir Province.[42]

2.7.3.4 Dissolution of the Salado in the Vicinity of the WIPP Facility

No epigenetic removal of the Salado salt by dissolution at the storage horizon appears to have occurred within the vicinity of the WIPP facility. However, just to the west, in the vicinity of Nash Draw, near-surface dissolution within the upper part of the Salado Formation has locally had a structural effect. This dissolution has involved the leaching of the more soluble constituents from the lower part of the Rustler and upper member of the Salado, which has resulted in the progressive thinning of the units to the west across the affected area.

The effect of dissolution is discussed in detail in Section 2.5.9.1. Where dissolution occurs, the evaporite section is thinned and a residual rubble zone develops. The feathered edge of the residual material, the "evaporite solution front," marks the easternmost extent of dissolution of the upper member of the Salado Formation (Figure 2.7.9).[15,17,18,24] It is located about 2.5 miles west of the WIPP facility.

2.7.3.5 Shallow Structures

Shallow structures include the structural features of the Rustler Formation and higher strata beneath the WIPP facility. Figures 2.7-37 through 2.7-39 are structure contour maps on the tops of the Rustler, Dewey Lake, and Dockum Group. Figure 2.7-14 is an isopach map of the Gatuna Formation. These structure maps and the isopach map were constructed from the data obtained from drill holes at the WIPP facility. As discussed in Section 2.7.3.1.2, a distinction may be made in the area of the WIPP facility between structural features exhibited by rocks occurring above unleached salt beds and structural features of all other strata. The rocks above the Salado have been weathered and display secondary structures related to surficial dissolution and subsidence. Shallow structures at the WIPP facility display greater irregularity and complexity than the structures that occur at depth.

2.7.3.5.1 Shallow Subsurface Structure

The top of the Dewey Lake Redbeds (Figure 2.7-38) is the oldest horizon that does not show the eastward gradient of the Delaware Basin shown by lower horizons. The structure and thickness (Figure 2.7-12) of the Dewey Lake is more a result of surficial erosion then underlying structure. Figure 2.7-38 shows the influence of surficial erosion west of the WIPP facility where the overlying Dockum has been stripped off, allowing erosion to occur. East of the WIPP facility, the surface of the Dewey Lake reflects some of the structure of the underlying Rustler Formation.

The structure map of the top of the Dockum (Figure 2.7-39) exhibits little of the underlying structure and shows that the formation has been eroded west of the WIPP facility. The isopach map (Figure 2.7-13) indicates that the underlying synclinal feature east of the WIPP facility may have been filled by thicker deposits of Dockum material. The southwest-plunging trough southeast of the WIPP facility may reflect a drainage channel that developed on the Dockum penecontemporaneously with deposition.

The isopach map of the Gatuna Formation (Figure 2.7-14) shows the channel-like depositional pattern of the formation. In general, the Gatuna was deposited in topographic lows on the Dockum and Dewey Lake. Comparison of the Dewey Lake and Gatuna isopach maps indicates that the Gatuna channel and the lowland south of the WIPP facility drained and eroded the Triassic rocks exposed at the surface.[34] Gatuna streams flowed westward across both Triassic and Dewey Lake strata.

A gravity survey[41] detected negative anomalies extending in an east-west direction across an area north of the WIPP facility. These anomalies were first detected on detailed grid surveys over closed topographic depressions in the area. Barrows et al.,[41] interpreted the negative anomalies to be caused by a rock density decrease primarily in the Rustler Formation.

2.7.3.5.2 Surficial Structures

Surficial sand deposits cover the area around the WIPP facility and obscure any surface geologic structures that may exist. A study of aerial photographs at a scale of 1:6000 covering an area of about 8.5 mi^2 centered on ERDA-9 was undertaken to delineate any collapse features. Numerous depression-like features were identified from the photos. These low areas are generally circular to elliptical in configuration and range from about 50 feet to more than 400 feet in diameter. All of these depressions have been interpreted to be caused by deflation around the sparse vegetative cover at the WIPP facility.

A depression, located about one and a half mile northeast of ERDA-9, has been investigated. The depression is about 1,000 feet in diameter and 30 feet deep. Resistivity studies conducted by Elliot[43] indicate very shallow surficial fill within the feature and no disturbance of underlying beds, pointing to a probable surface rather than subsurface origin. This feature and others identified on aerial photos are common in southeastern New Mexico and are generally considered to be sand blowouts. Bachman[34] has described numerous other wind-blown features close to the WIPP facility. One exception is the depression at WIPP-33, where thinning of the Rustler Formation may be attributed to dissolution of salt and gypsum. Bachman[34] notes that this feature is actively being filled in today by alluviation and states that it is a local feature near the eastern margin of Nash Draw, which was probably caused by spring-sapping and associated cliff retreat. These processes are not active at this location.

The solution processes through which areas of collapse have developed may also produce associated faults. The closest such fault as mapped by Vine[1], involves Rustler offsets in Nash Draw some nine miles southwest of the WIPP facility, in Section 18, T.23 S., R. 30 E. Subsequent field investigations by Bechtel showed no surface faults within five miles of the WIPP facility. Mapped surface faults in the area are distant from the WIPP facility and are usually related to collapse features. (Section 2.9 presents a detailed discussion of the surface faults).

Nash Draw, about four milesrthwest of the WIPP facility, is a location where surface expression of dissolution can be observed. Dissolution of salt in the rocks beneath Nash Draw has caused widespread slumping of the surface rocks. In some places, not only the salt but also considerable gypsum has been dissolved.[43] As a result, the Magenta and Culebra Dolomite Members of the Rustler are inferred to be in contact in Nash Draw. Normally, when leached of salt only, they are separated by 120 feeof gypsum. In general, it is impossible to construct a meaningful stratigraphic section from outcrops in Nash Draw.[17] According to Jones,[17] the exposed rocks are porous, friable, strongly jointed, cavernous and locally brecciated.

Thus, stratification in Nash Draw is obscured or obliterated and the attitude of bedding can rarely be determined with any degree of confidence. Even where bedding can be seen, it cannot be traced far without encountering disruptions due to local collapse.

2.7.4 GEOLOGIC MAPPING

2.7.4.1 Surface Mapping

The WIPP facility is located within the Nash Draw 15 minute topographic quadrangle,which also encompasses Livingston Ridge and the area of Nash Draw nearest the WIPP facility. This area was geologically mapped at a scale of 1:62,500 by Vine[1] and by Bachman.[3] Bachman[44] later remapped the area at a scale of 1:24,000. Figure 2.5-1 incorporates geological information from these maps.

2.7.4.2 Underground Mapping

Geological characterization of the underground at the WIPP facility is an ongoing process. Each shaft has been geologically mapped, and geomechanical instrumentation has been installed to monitor the condition of the shafts, drifts, and underground rooms (Sections 2.10.1.5, 2.10.2.2.5, and 2.10.13).[27,28,45]

At the underground storage and experimental level, 124 vertical core holes have been drilled to a nominal depth of 50 feet., usually in pairs (one up and one down). The purpose of these core holes is threefold:

- To confirm the thickness, lateral extent, mineralogy and stratigraphic continuity of the host rock beyond the limits of excavation;
- To confirm the continuity of structure and the absence of any unusual features within the immediate zone of influence of the excavations; and
- To obtain stratigraphic information in order to determine extensometer anchor depths.[43]

Geologic mapping was undertaken to characterize, demonstrate continuity, and provide permanent documentation of the geology exposed in underground excavations.[46,47,48,49] Mapping was done to the north-south and east-west extremities of the underground. Drifts and rooms not mapped were visually inspected by site geologists to verify that the rocks exposed are laterally continuous and similar to those exposed in mapped areas of the underground. Descriptions of the fifteen lithologic units identified in the underground excavation are found in Table 2.7-1.[45]

2.7.5 GEOLOGIC HISTORY

Between one billion and one and a half billion years ago a granitic basement complex formed the cratonic crust beneath the WIPP facility. Although little is known about the Precambrian history of the region, sometime between 1,000 and 500 m.y. ago, the area was eroded to a level plain.[32] This Precambrain basement is overlain by a nearly continuous sequence of Paleozoic marine sediments.

For the next 260 m.y. (between 500 m.y. and 240 m.y. ago) gentle epeirogenic movement and almost continuous marine submergence existed. Shelf and basin sediments accumulated, including a thick evaporite sequence, until late Permian time.

Near the end of the Permian, uplift and oxidizing conditions recurred at the site, causing the evaporites to be blanketed by the Dewey Lake Redbeds. With the exception of a marine inundation during the Cretaceous, terrestial deposition alternated with erosional episodes until the present, producing a series of non-marine deposits separated by unconformities. (For a detailed discussion of the geologic history of the area, see Section 2.6.2)

In the vicinity of the WIPP facility, sedimentation was continuous from Pennsylvanian into Early Permian time. During Permian time, the Delaware Basin subsided at a greatly accelerated pace, partly by downwarping and partly by downfaulting along pre-existing basin margin faults. About 9,000 feet of Wolfcampian, Leonardian and Guadalupian shales, limestones and sandstones were deposited.

Basin margin reef buildup was active in both Leonardian and Guadalupian time. During the latter part of Guadalupian time, continuous massive reefs accreting rapidly to keep pace with continued basin subsidence nearly encircled the basin. This process ulminated with the deposition of the massive Capitan Limestone, which stood 1,000 to 1,500 feet above the contemporaneous Bell Canyon Formation, its equivalent in the WIPP facility area. Eventually, the Capitan reef closed off the Delaware Basin from the sea, setting the stage for the precipitation of Ochoan evaporites.

As the seawater evaporated, gypsum and limestone, followed by gypsum and halite, were precipitated. Several incursions of seawater refilled the basin, producing a series of thick gypsum-calcite beds separated by thick halite members. At some time the gypsum was dewatered to form anhydrite, and these evaporites, comprising the Castile Formation, filled the basin to the crest of the surrounding Capitan Limestone. The overlying Salado Formation extended over the top of the reef, burying it and extending outward onto the shelf (from the Delaware Basin). Although the basin continued to subside, reef organisms could not survive in the briny environment and burial of the reef by the Salado Formation resulted in the disappearance of the Delaware Basin.

The Salado Formation was more susceptible to clastic influx because it formed in a broad, regionally extensive brine basin not bounded by protective reefs. Nearly 2,000 feet of evaporites, primarily halite, accumulated before an increase of clastic inflow resulted in the deposition of the Rustler Formation, which consists of anhydrite and halite, with significant amounts of clastics. Subsidence ended gradually, and the Dewey Lake Redbeds were deposited over the Rustler in a shallow, less saline sea, on marginal mudflats or in playa lakes.

The Early Triassic was a time of general epeirogenic uplift and erosion. Lower Triassic strata do not occur at the WIPP site. In later Triassic time, inland basin streams laid down the floodplain deposits of the Dockum Group. Erosion and dissolution were active processes along the western margin of the Delaware Basin during Triassic time, with streams flowing easterly across the Basin.[18] Jurassic deposits are not present in the Basin and it may be assumed that erosion and dissolution were active processes during that time.[18]

By the end of the Jurassic, regional eastward tilting had occurred, producing salt flow accompanied by widespread erosion.[26,40] This flow may have continued while the region was submerged by the Cretaceous marine incursion. Bachman[18] points out that the Salado Formation appears to have been removed completely in a belt along the western margin of the basin in New Mexico before Cretaceous time, allowing the Culebra Dolomite to rest on the Castile Formation. Rocks above the Culebra Dolomite were also partially removed in the vicinity of the modern Pecos River before Cretaceous time.[18]

Cretaceous epicontinental marine transgression probably lasted until early in Late Cretaceous time. During the remainder of late Cretaceous time, the area was probable of low relief and only slightly above sea level.[32] Early or middle Tertiary deposits are not found in the vicinity of the WIPP facility. As a result, geologic events are poorly understood for the 66 m.y. after the end of Cretaceous time. Major uplift is believed to have taken place during late Cretaceous or early Tertiary time, concurrent with the Laramide orogeny that occurred farther north and west. According to Hayes, "... the entire region was elevated by broad epeirogenic uplift and tilted slightly to the northeast."[32] The Cretaceous rocks were eroded to expose Triassic rock in the eastern half of the Delaware Basin, and Permian rock in the western half of the basin. Today the Cretaceous rocks exist only as the slumped or sunken fragments of a once-extensive cover. These rocks were well-lithified long before collapse. It is obvious that much post-Cretaceous erosion and dissolution has also taken place, most of which is associated with Cenozoic features.[18] This erosion subjected Permian halite to additional dissolution and produced yet another erosional truncation of the late Triassic Dockum sediments.[17]

No record of early Tertiary events remains in the vicinity of the WIPP facility. Oligocene (35 m.y.b.p.), lamprophyre dikes were intruded along a northeast-southwest trend, passing about nine miles northwest of the WIPP facility (Figure 2.6-12).[24]

By late Miocene time, conditions were less arid, and eastward flowing streams from the uplifted areas to the west deposited sand and gravels of the Ogallala Formation over an irregular erosion surface. The Ogallala Formation is as much as 400 feet thick at places in southeastern New Mexico.[34] The nearest Ogallala occurrence is at "the Divide:, six miles northeast of the WIPP facility, where only a thin remnant 26 feet thick is preserved." This may represent the western depositional wedge-edge of the Ogallala across a relatively high surface.[3,34] Since the Ogallala Formation thins westward, it is not known whether these sediments were deposited in the vicinity of the WIPP facility. When Ogallala deposition ceased in late Pliocene time, the WIPP facility area was unusually stable, the climate was arid to semiarid and a caliche caprock had developed on the Ogallala surface.[3,34]

Basin and Range tectonic activity to the west of the WIPP facility occurred in late Tertiary time. During this period the Guadalupe, Sacramento, and Delaware Mountains formed and eastward tilting occurred. Regional tilting probably increased during the Late Pliocene to Early Pleistocene in conjunction with the major uplift of these mountain ranges (Section 2.6.4.5.3).

During early Pleistocene time, following the major part of Basin-and-Range uplift and tilting to the west, the climate became more humid and renewed erosion took place. This uplift and erosion caused yet more dissolution to occur in the vicinity. Active stream erosion incised one more erosional surface into the late Triassic sediments. In Nash Draw, this erosion cut deep into the Dewey Lake Redbeds at the same time that Nash Draw was collapsing due to subsurface dissolution. Some of the channels and sinks became filled with the Gatuna Formation, probably during Kansan time, prior to 600,000 years ago.[3,34] The Gatuna was locally derived from reworked Ogallala, Triassic, and Dewey Lake sediments.[34]

In mid-Pleistocene time, probably between 400,000 and 500,000 years ago,[31,34] the Mescalero caliche caprock began to form on the Gatuna surface in a semiarid environment. The Mescalero caliche is an ancient petrocalcic soil horizon and formed parallel to the landscape surface that existed at the time it formed.[34]

From late Pleistocene time to the present, a nearly continuous cover of windblown sand and sand dunes has formed over the area. The sand apparently eroded from the Ogallala Formation during wet climatic intervals and has shifted across the area during dry intervals. Most of the sand is now stabilized.[34]

2.7.6 PLOT PLANS

A plan showing the location of shallow subsurface exploration along with the major surface structures is shown in Figure 2.5-11. The locations of drill holes, test pits, holes drilled for geophysical purposes, and seismic refraction survey lines are also shown in this plan. The logs of all borings and test pits are given in a reference document.[50] A total of 45 shallow borings were cored or augered, totaling 1,370.3 feet, to investigate near-surface foundation conditions. Also, nine borings, totaling 900 feet, were drilled and cored to collect uphole and cross hole geophysical data.[51] Core hole B-25 was continuously cored to a depth of 901.8 feet. The total shallow exploration program at the WIPP facility consists of 56 bore holes, totaling 3,372.1 feet.

Seismic refraction data were collected in December 1978, covering a grid of 2,000 by 3,000 feet surrounding ERDA-9. About 24,000 feet of reversed profile data were collected, with shot points at 600-feet intervals.[52]

Figure 2.7-40 is a location plan of borings drilled within five miles of the WIPP facility. Additional data for these borings are listed in Table 2.7-1.

2.7.7 GEOLOGIC PROFILES

Geologic profiles in generally east-west and north-south directions, across part of the WIPP site, are shown in Figure 2.7-19 and 2.7-20.

These profiles were constructed using drillhole information. A generalized cross section of the WIPP facility underground storage and experimental area is shown in Figure 2.7-41.

A more detailed stratigraphic profile between DOE-1, southeast of the WIPP facility, and WIPP-12, 1 mile north of the WIPP facility, is shown in Figure 2.7-42. Eight bore holes, including ERDA-9, B-25, WIPP-18, 19, 21, 22, and the Site and Preliminary Design Validation (SPDV) ventilation and exploratory shafts were used to construct this section. A detailed correlation section of DOE-1, ERDA-9, the two SPDV shafts, WIPP-12, and vertical core holes drilled in the underground excavations is shown in Figure 2.7-43. A structure contour map of the top of the Mescalero caliche (Figure 2.7-44) has been constructed from the shallow borings drilled within the WIPP facility area.

A detailed description of the soil and rock strata in the vicinity of the WIPP facility is given in Section 2.7.2. The logs of ERDA-9, WIPP-12, DOE-1, and the SPDV ventilation and exploratory shafts are presented in Appendix 2C.

2.7.8 NEAR SURFACE EXCAVATIONS

Figures 2.7-45 and 2.7-46 are near-surface soil profiles across the vicinity of the WIPP facility. Plans for the excavations for the facility structures are presented in Section 2.10.3.

2.7.9 ENGINEERING GEOLOGY OF PLANT FACILITIES

The WIPP facility surface and subsurface materials have been studied for behavior in present static and/or dynamic environments. These have included studies of aerial photographs, geologic mapping and examination and analysis of all subsurface data obtained from the WIPP facility site exploration.

During construction of the Design Class II surface structures, all overburden sand was removed to the Mescalero caliche. These structures were founded on well-cemented caliche overlying the Gatuna Formation, on the Gatuna Formation, or on compacted backfill. Overburden removal was required for the shallow segments of the shaft excavations. Continuous support for the shaft through the caliche and Gatuna sandstone was necessary to prevent ravelling due to exposure. Shallow excavations for the surface structures did not require support.

2.7.9.1 Behavior During Previous Earthquakes

No accounts are known of either permanent or transient effects associated with historic earthquakes in the vicinity of the WIPP facility. The maximum estimated site intensity of V (Modified Mercalli Scale) is consistent with the presumption that no permanent and only minor transient historic earthquake effects have occurred. There is no evidence that the bedrock at the WIPP facility has undergone permanent deformation as the result of prior earthquakes. The seismic monitoring network has recorded air-blasts from construction activities at the Brantley Dam site north of Carlsbad and disturbances along the Central Basin Platform to the east that probably were caused by secondary oil recovery techniques.

2.7.9.2 Zones of Deformation, Alteration, Weathering, or Structural Weakness

2.7.9.2.1 Deformation

Zones of deformation such as folds, fissures, faults and shears have not been found in the near-surface rocks in the vicinity of the WIPP facility. The nearest known surface fault of nontectonic origin is located about nine miles southwest of the WIPP facility. The nearest large-scale subsidence feature is Nash Draw, whose closest point is about four miles from the WIPP facility. Weathered rock is limited to the upper few feet of the near-surface rocks.

Joints and fractures within the deeper strata below the WIPP facility were observed in some cores. The fractures are generally closed or filled with anhydrite or gypsum. Many of the rock cores exhibited clayey zones and these required special consideration during shaft excavations.

Salt flowage has occurred within the Salado and Castile Formations near the WIPP facility. The zone of salt deformation, adjacent and parallel to the Capitan reef front, comes within five miles of the WIPP facility. Also, there are a few known isolated salt anticlines within the Castile Formation, one of which was penetrated by WIPP-12 (Figure 2.7-27). They are the apparent result of salt flow.

2.7.9.2.2 Alteration

The effects of alteration in the vicinity of the WIPP facility are minor. Alteration affecting surface structure foundations is restricted to the weathering profile. Close to the surface, calcic soil horizons improve the strength of the generally poorly consolidated materials.

The hydroalteration of anhydrite to gypsum forms thin seams of altered rock within the Rustler and deeper strata. These zones are infrequent, and they consist of thin seams of altered rock near changes in lithology and have been identified principally in drill cores.

2.7.9.2.3 Weathering

The weathering profile throughout the area is irregular, primarily due to differential weathering of the bedrock. The weathering profile generally does not extend below the Gatuna Formation. The effects of weathering generally decrease with depth and manifests themselves as the degree of iron-oxide cementation, the frequency of fractures, the depth to which stained fractures are observed, and the friability of the rock.

The weathering product in the area is a fine-grained, loose, light brown sand. The sand was probably derived from the Ogallala Formation during humid intervals of Pleistocene time. The occurrence and characteristics of the sand are discussed in Section 2.7.2.4.2.

2.7.9.2.4 Structural Weakness

Rocks in the vicinity of the WIPP facility are basically sound, dense, and have no features that render them unsuitable for sound foundation conditions. The upper few feet of the Gatuna Formation are generally highly weathered and fractured, but the rock quality improves with depth. Rock cores have been tested for their engineering properties, and these are presented in Section 2.10.2.

2.7.9.3 Unrelieved Residual Stresses in Bedrock

Residual stresses in bedrock are discussed in Section 2.10.1.4. Geologic conditions in the rock formations overlying the salt rock that would support the possibility of residual stresses do not appear to exist. The uppermost rock formations at the WIPP facility are essentially undeformed and there has been no removal of great thicknesses of overburden, either of which could have been a mechanism for creating residual stresses. Therefore, no residual stresses of significance are expected at the WIPP facility.

2.7.9.4 Unstable Rock or Soils

There are no rocks in the foundations that might be unstable due to mineralogy, lack of consolidation, or response to seismic events. Although the upper portion of the Gatuna Formation is poorly to moderately cemented, the rock is adequate to support the loads anticipated for surface structures.

2.7.10 EFFECTS OF HUMAN ACTIVITIES ON GEOLOGIC CONDITIONS

The Carlsbad district produced 86 percent of the potash produced in the United States in 1975, and it has 65 percent of the potash resources that are exploitable by proven procedures or methods under existing economic conditions. With an annual output of slightly more than 2.2 million tons of potash, the mines in the district supplied about 40 percent of all the potash used in the U.S. (including potash from foreign sources) in 1975.[20]

Four active potash mines are located within 12 miles of the WIPP facility, with the closest one, the Western Ag Mineral Company Nash Draw mine, about five and a half miles southwest (Figure 2.6-14).

Several economic minerals are found in the area. These minerals include sylvite and langbeinite, which are potassium compounds used as fertilizers. Numerous industry holes have been drilled around the WIPP facility, and 21 drill holes were drilled by the DOE to determine the quality and extent of these minerals. The middle member of the Salado Formation, known as the McNutt potash zone, is the ore-bearing part of the formation from which potassium salts have been extracted.

In the Carlsbad mining district, there has been subsidence during and after underground mining. Areas within the district where subsidence has occurred, irrespective of origin, are shown in Figure 2.7-2. Areas where there is a potential for subsidence are shown in Figure 2.7-47. The nearest likely subsidence to the WIPP facility is about four miles southwest, within Nash Draw. The maximum subsidence noted in the Carlsbad district is about two-thirds of the height of the mined ore zone. Maximum subsidence directly over a mined zone ranges from about 2.7 to 5.3 feet.[53] Subsidence from these distant mines is not anticipated to affect the WIPP facility.

Gas and oil have been extracted close to the WIPP facility but not close enough to cause subsurface subsidence. The Los Medanos field is the nearest producing field and is about three and a half miles southwest. Five wells were drilled in this field, each producing erratically from small lenticular reservoirs of limited size.

Cabin Lake field, about five miles northwest of the WIPP facility, has had a sharp decline in gas production since 1968. The Cabin Lake field and the Zonne field (six miles east of the WIPP facility) appear to be on the "Cabin Lake trend," which extends across the north and northeastern edge of the WIPP site boundary. The producing reservoirs from which the wells in this trend are producing are areally limited, therefore, the recoverable gas from these reservoirs will be limited.[10] No large-scale well flooding or fluid extraction is expected within the area of the WIPP facility site, and subsidence is not anticipated.

2.7.11 SITE GROUNDWATER CONDITIONS

Groundwater above the Salado Formation in the vicinity of the WIPP facility is limited in quantity and is commonly of such poor quality that it is not usable. Below the Salado, the Bell Canyon Formation may yield small quantities of water to wells, but it is a brine of poor quality. The characteristics and occurrence of ground water at the WIPP facility are described in detail in Section 2.5.

2.7.12 GEOCHEMISTRY OF UNDERGROUND FLUIDS

Examination of Salado evaporite samples taken from core holes in the vicinity of the WIPP facility indicates that the most common minerals are halite, anhydrite and polyhalite. Silicate minerals in the Salado Formation are quartz, illite, feldspar, chlorite, talc and serpentine.

The amounts and composition of volatile constituents in the evaporite minerals have been determined. Except for samples rich in hydrous minerals, most halite contains less than 0.5 weight percent total volatiles. The most abundant volatile constituent is water, with nitrogen the next most abundant, followed by carbon dioxide.

Fluid inclusions have been studied in core samples from 19 horizons within the Salado. The most common type of inclusion consists of liquid that was trapped during several stages of recrystallization of the primary salt. Some inclusions consist of a small vacuum bubble and/or unidentified daughter crystals. The fluid inclusions in these 19 samples ranged from 0.1 to 1.7 weight percent. The temperature at which these inclusions were trapped ranged from about 20 to 45C.[13] When the host crystal is uniaxially stressed, the geometry of the inclusion walls changes within several minutes. These changes may be due to solution, redeposition or deformation. Internal fracturing of the inclusion walls, generally without leakage, occurs with freezing.

Water samples taken from various rock types in the Delaware Basin of southeastern New Mexico and west Texas have been analyzed for their solute content.[2,13,54,55] Fluid samples were collected from wells in the Capitan, Morrow, and Delaware Mountain Group, and the Castile, Salado Formation, Rustler Formation, and Dockum Group.[56] The major solute chemistries of the fluids suggest that the dominant solute (NaCl) in most was derived from nearby rocks. Salado and saline Capitan waters contain solutes of primary evaporite mineral assemblages. Bell Canyon and Morrow brines contain less magnesium but more calcium than primary evaporite assemblages and have probably participated in ion exchange reactions. Stable isotope measurements indicated that sampled waters from the Dockum, Rustler, and Capitan Formations were meteoric, while samples from the Salado, Bell Canyon, Morrow and Castile (except for the Pokorny well, which was meteoric[56]) Formations have undergone episodes of low-temperature isotopic exchange with oxygen and hydrogen bearing minerals.

More recent preliminary work by Stein[57] shows that although the fluid-inclusion compositions in the Delaware Basin appear to be best represented by NaCl brine, the chemistry is very complex and deserves additional investigation. Stein concludes that the water in the Castile Brine Reservoirs is unrelated to the fluid inclusions in the Salado Formation, and that the fluid inclusions are, for the most part, situated in the location of their formation, with relatively little movement through the host rock.

The geochemistry and mineralogy of the halite at the WIPP facility is relatively simple. The evaporites have been recrystallized, resulting in some different mineral assemblages from those precipitated from the original solutions. The last recrystallization apparently took place more than 200 m.y. ago and resulted in evaporite mineral assemblages, which may have reached thermodynamic equilibrium.

The nature, distribution, geochronology and composition of the fluid inclusions, clay minerals and isolated accumulations of aqueous solutions in the evaporites show no evidence of movement of surface-derived water through the WIPP evaporites. The brine observed to weep locally from the walls of the underground excavations (see Section 2.5) becomes less noticeable with time, and most weeps are dry after several weeks; however, some have remained moist for more than three years.[45] The fact that the weeps eventually stop suggests the weeps probably represent porous salt with bubbles of brine in the salt that are interconnected by capillary passageways and open fractures around the individual salt crystals, and they do not tap an external source of water. The brine observed to weep into vertical boreholes drilled in the roof and horizontal boreholes in the walls of the drifts usually evaporates forming a salt efflorescence and soda straw stalactites at the borehole collar. In some vertical downholes, less susceptible to evaporation, brine collects and can be observed as standing fluid.

Not every uphole weeps, and some of the downholes are dry. However, it is estimated that 75 percent of the accessible underground boreholes encountered some brine.[58] Additionally, not all rib areas weep, and very few weeps are observed on the exposed rock surface of the back.

Gas has been observed at the collars of underground boreholes and at the underground working face. The gas occurrences detected at the boreholes are indicated on the geologic drill logs reported in two geotechnical field data reports.[59,60] Transient pressure testing and sampling of gas were carried out in several holes in the roof and floor of the facility (see Section 2.5). Seven occurrences of gas at the working face have been documented.[45,58] Several occurrences were noted during excavation with the continuous mining machine. Two occurrences involved drilling into gas pockets. In all of these cases, the gas pocket consisted of a small fracture containing pressurized gas.[45] In the latter two cases, degassing could be heard at the face for only short periods of time.[60] Gas is not observed at all boreholes. The flow monitored from core holes is very low and erratic and generally reveals a declining flow pattern. The emission of gas appears to be associated with fractures in anhydrite beds and their underlying clay layers.

2.7.13 GEOPHYSICAL SURVEYS

Before 1978, various geophysical surveys were conducted in the vicinity of the WIPP facility. Seismic reflection data totalling about 150 survey miles, and gravity data covering about 3,000 mi^2 were collected in the area as part of various hydrocarbon exploration programs.[38] These data have been analyzed[61] to identify potential geologic hazards and the economic impact of withdrawing lands around the WIPP facility from exploitation. Magnetic, resistivity, and additional gravity and vibroseis surveys were conducted during earlier investigations. The results of these surveys are reported by Mining Geophysical Surveys,[62] Elliot,[43,63-64,66,66] and G. J. Long.[59]

On the basis of earlier reconnaissance surveys (conducted for SNL) a survey program consisting of about 75 miles of seismic reflection (vibroseis) was designed and run to provide detailed subsurface information (with close line spacing) in the four by four mi area including the WIPP facility

Seismic survey parameters were chosen to provide data for subsurface mapping of the Ochoan formations that host the underground storage and experimental areas. A seismic signal was produced using three to four vibroseis sources swept in tandem from 100 to 25 Hz. Twelve-fold reflection data were collected using geophone stations at 110-feet intervals with some additional data collected at 55-feet station intervals. The locations of the seismic survey lines are shown in Figure 2.7-48. Detailed discussion of the recording and processing parameters used is included in the work of Bell and Murphy and Associates,[67] M. Dobrin,[68] and in Borns et al.[38] Interpretation of the vibroseis data is shown in the seismic time structure maps of the Bone Spring, Cherry Canyon, mid-Castile, and top of Castile (in Figures 2.7-15 and 2.7-16 and 2.7-33 and 2.7-34, respectively).

Seismic refraction data were collected in December 1978, covering a 2,000 by 3,000 feet grid surrounding ERDA-9. About for and a half lines miles of reversed profile data were collected using dynamite as a seismic source with shot points at 600-feet intervals.

Cross hole seismic surveys were run in three different sets of three borehole arrays to determine compressional and shear wave velocities of the materials underlying the surface structures.

Gravity surveys[41] were performed in a rectangular area two by four and a third miles covering all of WIPP Zone II, and 4 2/3 mi^2 of the "Disturbed Zone[38]." Additionally, three smaller areas were surveyed in fine detail. One of the detailed areas was in the southeast corner of Section 21, T22S, R31E. The second detailed area was centered over a closed topographic depression along the east-west line between Sections 9 and 16. The third area was the southeast quarter of Section 28 where two positive elliptical/gravity anomalies were indicated. The area surveyed, and additional detailed surveys, are indicated on Figure 2.7-49.

Two additional projects were also undertaken during the gravity survey described above. These were a network of reconnaissance profiles over and around borehole WIPP-33, and two reconnaissance profiles over Bell Lake Sink in T24S, R33E. These additional surveys were to explore the relation between the gravity anomalies and karstification.[41] The locations of the profiles around WIPP-33 are indicated on Figure 2.7-49. Bell Lake Sink is located about 15 miles southeast of the WIPP facility.

Two controlled-source audio-frequency magnetotelluric (CSAMT) surveys[69] were performed in an attempt to map the deep brine occurrence encountered by the WIPP-12 borehole within Anhydrite III of the Castile Formation. One survey was performed with a grounded-dipole transmitting antenna 8,000 feet long (oriented east-west), located two miles south of WIPP-12. The other survey was performed in December 1982, with a grounded-dipole transmitting antenna 4,000 feet long (oriented north-south), located three miles east of WIPP-12. The locations of the CSAMT transmitting antennae are indicated on Figure 2.7-49.

2.7.14 STATIC AND DYNAMIC ROCK AND SOIL PROPERTIES

The static and dynamic soil and rock properties are presented in Section 2.10.

2.7.15 ANALYSIS OF FOUNDATIONS

The design criteria, analysis techniques, and factors of safety for Design Class I and II surface structures are given and discussed in detail in Section 2.10. The structures have shallow spread footings and mat foundations and are supported on the caliche layer or on compacted sand backfill placed on the caliche.

The performance of foundation materials under loading is evaluated based on two criteria:

- The ability of the ground to support loads transferred through the structural foundation, with an ample factor of safety against soil failure
- The ability of the foundation to support structural loads with tolerable settlements

All structural foundations are embedded to a depth greater than the depth of frost penetration or zone of seasonal volume changes.

The first criterion is related to the strength of the supporting foundation materials. The second criterion is related to the "stress-deformation" characteristics of the foundation material and its influence on the structure.

In the case of a structural foundation on sand backfill or caliche, the allowable bearing pressure is limited by tolerable settlements rather than the bearing capacity criterion, because of the high strength of the material.

Any foundation design must satisfy the following safety requirements:

- The factor of safety for bearing capacity must be at least three for dead plus normal live loading.
- The factor of safety must be at least two for dead plus maximum live loading, including wind or seismic loading.
- Settlements under static plus dynamic conditions should be tolerable in order not to create distress in the superstructure.
- Although ground water is very deep, and the sand backfill is not likely to become saturated, foundation grade will be at least two feet below the ground surface, which is below the depth of frost penetration.

The design parameters required to evaluate the allowable bearing capacity and settlements are:

- Effective angle of internal friction
- Total unit weight of soil
- E - modulus of elasticity

The angle of internal friction was determined from consolidated undrained or consolidated drained triaxial compression tests made on undisturbed samples of the in situ material and on compacted samples of the sand backfill. Because of sample disturbance in the caliche and Gatuna layers, engineering judgment was used in selecting strength parameters for design.

The total unit weight of soil was determined from laboratory tests made on representative undisturbed samples of the foundation materials or on compacted samples of the sand backfill.

The modulus of elasticity of the in situ foundation material was determined from plate load tests, and in the case of the structural backfill from consolidated drained triaxial tests. The design properties were selected from tests made at optimum or natural moisture content since saturation of foundation materials is not foreseen.

The ultimate bearing capacity was determined by the Vesic equation[70] for ultimate bearing capacity of shallow foundations, and this is discussed in detail in Section 2.10.10. Settlements under static conditions were calculated based on integration of strains in the foundation under structure loads, which is also discussed in Section 2.10.10.

Settlement under dynamic load was computed using procedures proposed by Seed and Silver[71] and as discussed in Section 2.10.7.

The static and dynamic lateral earth pressures for sand backfill are found in Section 2.10.

Because all slopes in the vicinity of Design Class I and II structures are temporary, only static stability was considered. All temporary slopes were analyzed using the infinite slope approach. A minimum factor of safety for stability of 1.15 was used. Slope stability is discussed further in Section 2.11.

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Table 2.7-1

DESCRIPTION OF GEOLOGIC MAP UNITS 0 THROUGH 15

Unit(1)	Description(2)
15	Halite: Clear to grayish orange-pink (10R 8/2) tint; transparent to translucent; coarsely crystalline; trace of dispersed polyhalite and intercrystalline clay; scattered white to light gray (N7) anhydrite pods; unit extends into roof; lower contact with Unit 14 is sharp based on prominent clay seam at top of Unit 14.
14	Halite: Clear to grayish orange-pink (10R 8/2) tint; transparent to translucent; coarsely crystalline; locally medium crystalline; trace of dispersed polyhalite; discontinuous stringers of medium gray (N5) clay; medium gray (N5) clay seam I at top of unit; discontinuous occurrences of anhydrite along top of clay seam; lower contact with Unit 13 is diffuse and is based on increase in polyhalite content in Unit 13 and color change from grayish to reddish-brown.
13	Halite: Clear to moderate reddish-brown and orange (10R 4/6; 6/6); translucent to transparent; fine to coarsely crystalline; trace to some dispersed polyhalite and polyhalite blebs; trace of gray and brown clay; continuous and discontinuous polyhalite stringers near top of unit; lower contact with Unit 12 is gradational based on increase in polyhalite content and decrease in clay content.
12	Polyhalitic halite: Clear to moderate reddish-orange (10R 6/6); translucent to transparent; coarsely crystalline; some dispersed polyhalite and polyhalite blebs; several anhydrite stringers in lower half of unit; lower contact with Unit 11 is sharp.
11	Anhydrite (anhydrite "a"): Light brownish-gray (5YR 6/1), medium light gray (N5), some grayish orange-pink tint (10R 8/2); microcrystalline; partially laminated; contains scattered halite growths; clear, coarsely crystalline halite layer up to two-in wide found within anhydrite underlain by thin gray clay seam.
10	Halite: Clear to moderate reddish-brown and orange (10R 4/6; 6/6); translucent to transparent; medium to coarsely crystalline; locally finely crystalline; trace to some dispersed polyhalite; discontinuous stringers of light gray clay (N7); contact with lower Unit 9 is diffuse based on absence of clay and lesser amounts of polyhalite.
9	Halite: Clear to grayish orange-pink (10R 8/2) tint; transparent to translucent; coarsely crystalline; lower contact with Unit 8 is sharp.
8	Anhydrite (anhydrite "b"): Medium light gray (N6); microcrystal- line; locally in stringers separated by clear halite; underlain by medium light gray (N6) clay seam; contact with lower Unit 7 is sharp.
7	Halite: Clear to moderate reddish orange/brown (10R 4/6; 6/6) to light and medium gray (N7, N5); medium crystalline; locally finely crystalline; trace of dispersed polyhalite and intercrystalline light gray (N7) clay; discontinuous light gray (N7) clay stringers; unit extends into floor in experimental area; contact with lower Unit 6 is gradational based on absence of clay.
6	Halite: Clear, with grayish orange-pink (10R 8/2) tint; transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; unit extends into the roof; lower contact with Unit 5 is gradational and/or diffuse.
5	Halite: Clear, transparent to translucent; coarsely crystalline; trace of argillaceous material; bluish white (5B 9/1) to light bluish gray (5B 7/1), occurs in pods (1/2 inch diameter), discontinuous laminations and interstices; lower contact with Unit 4 is generally sharp and is based on prominent color change of argillaceous material (gray to red-brown) from Unit 5 to Unit 4.
4	Argillaceous halite: Clear and transparent, to moderate reddish-brown (10R 4/6), moderate brown (5YR 3/4), less frequently light bluish-gray (5B 7/1); coarsely crystalline; trace of dispersed polyhalite; trace to abundant argillaceous material (decreasing downward) consisting of clay containing a trace of slit and fine crystals of halite; occurs as discontinuous laminations in upper half of unit, and interstitially in lower half; lower contact with Unit 3 is gradational, and is based on absence of argillaceous material in Unit 3.
3	Halite: Clear to moderate reddish-orange (10R 6/6); transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; polyhalite content commonly increases downward; lower contact with Unit 2 is sharp.

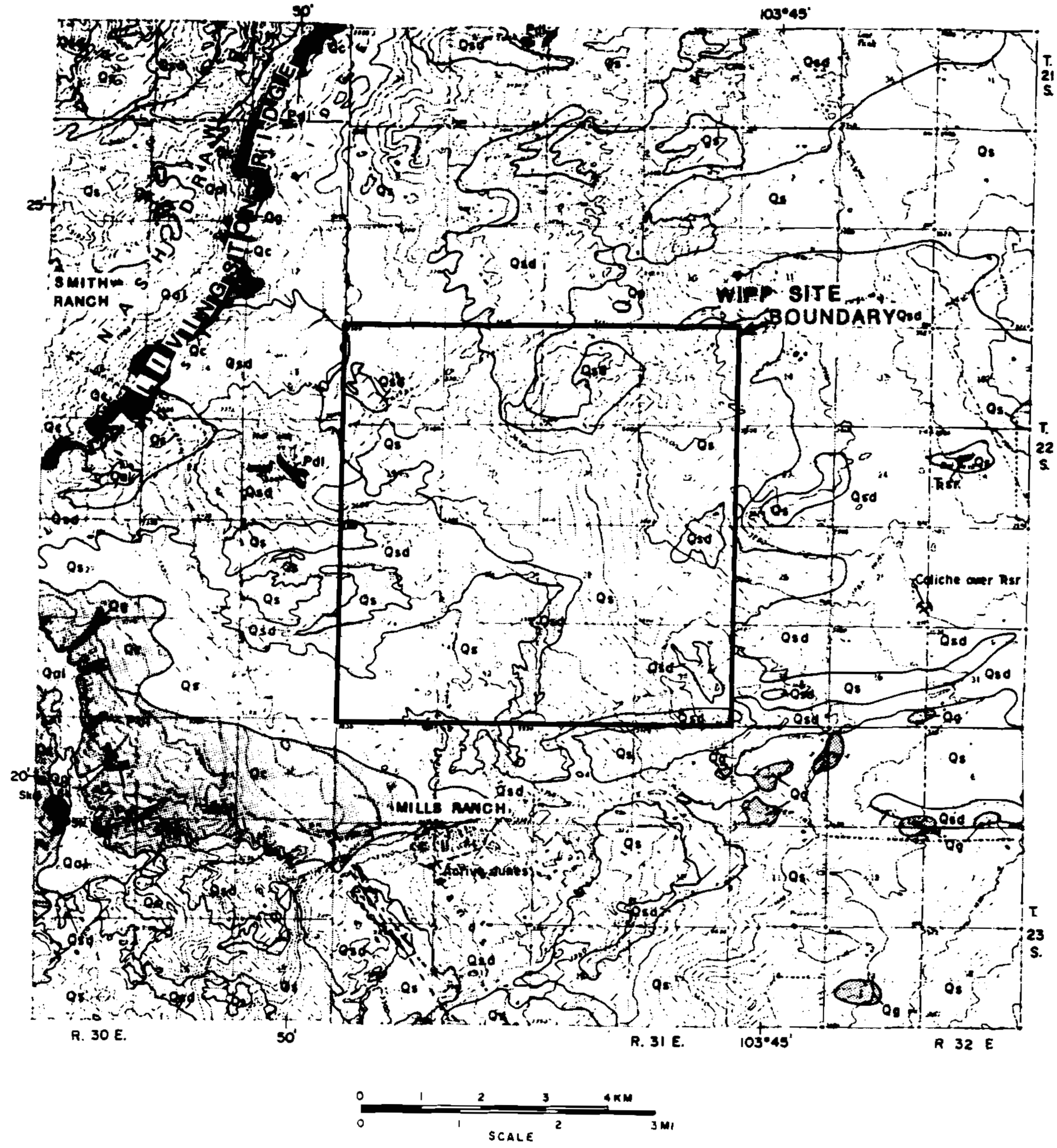
Table 2.7-1

DESCRIPTION OF GEOLOGIC MAP UNITS 0 THROUGH 15

Unit(1)	Description(2)
2	Argillaceous halite: Moderate reddish-brown (10R 4/6), less frequently light bluish gray (5B 7/1) and medium gray (N5); medium to coarsely crystalline; argillaceous material which occurs primarily interstitially and as discontinuous laminations; lower contact with Unit 1 is generally sharp, less frequently gradational.
1	Halite: Light reddish-orange (10R 8/6) to moderate reddish-orange (10R 6/6), less frequently clear; translucent to transparent; medium to coarsely crystalline; trace of dispersed polyhalite; lower contact with Unit 0 is sharp.
0	Halite: Clear to moderate reddish-orange (10R 6/6), moderate reddish-brown (10R 4/6), moderate brown (5YR 3/4), and grayish- brown (5YR 3/2); medium to coarsely crystalline; trace of dispersed polyhalite; some argillaceous material, occurs in discontinuous laminations, blebs, and interstices; upper part of unit is argil laceous, decreasing downward in argillaceous material; contains finely crystalline halite; unit extends into the floor.

(1) Units listed in descending order from roof to floor.

(2) Descriptions are based on geologic mapping of exposures in rooms and drifts throughout the facility, including the waste experimental rooms.



REFERENCE

Modified from:

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This illustration for Information Purposes only.

FIGURE 2.7-1
Surface Geology

LEGEND

QUATERNARY

RECENT

Qs / Qsd — SAND – Eolian sand plains (Mescalero sand); Qsd, conspicuous dunes, generally stabilized or partly stabilized.

Qal / Qp — ALLUVIUM – Sand and silt, locally conglomeratic, deposited on gentle slopes and depressions; Qp, playa deposits of sand and silt in shallow intermittent ponds or lakes.

PLEISTOCENE

Qc — CALICHE – Limestone (Mescalero caliche), dense to travertine-like, with included sand grains and rock fragments. Has been assigned to Yarmouth interglacial stage.

Qg — GATUNA FORMATION – Gravel, sand, silt and clay deposited as alluvium; dominantly reddish-orange, grading to pink, gray or yellow. Has been assigned to Kansan glacial stage.

TRIASSIC

UPPER TRIASSIC

R̶sr — * SANTA ROSA SANDSTONE – Conglomeratic sandstone, moderate reddish-brown to light brown, poorly sorted, cross-bedded; interbedded locally with moderate reddish-brown claystone and siltstone.

PERMIAN

OCHOAN

Pdl — DEWEY LAKE REDBEDS – Fine sandstone and siltstone, moderate reddish-orange to reddish-brown, conspicuous thin laminae generally less than 1/4 inch thick, locally clayey and with light greenish-gray partings.

Pr — RUSTLER FORMATION – White, massive gypsum.

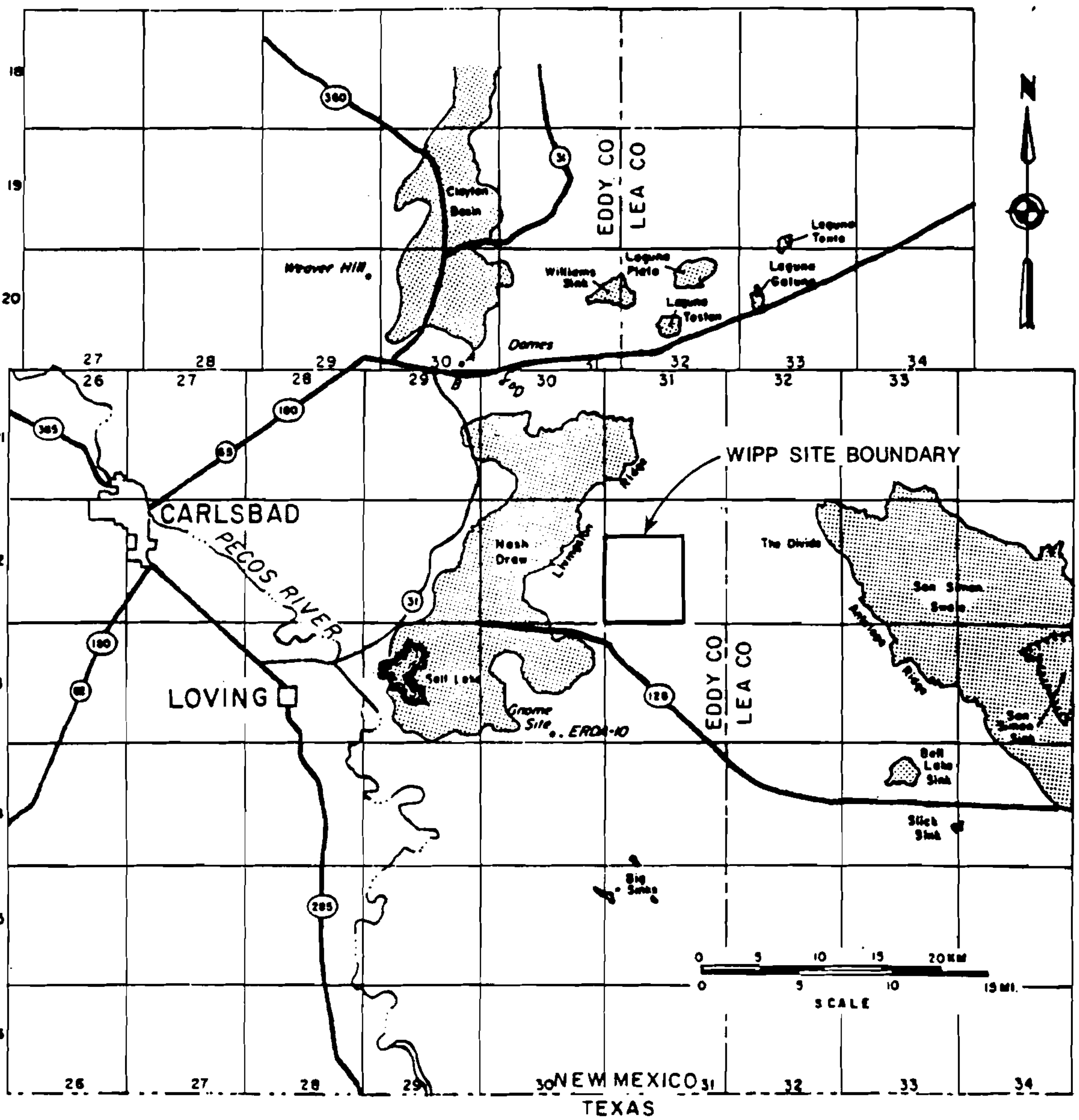
Sinkhole — ● SK

Quarry — ⚒

* Note:
The name "Santa Rosa Sandstone" is no longer used in the vicinity of the WIPP Facility. The sandstone is included in the Dockum Group, undivided. See discussion in Section 2.7.2.3.1.

This illustration for Information Purposes only.

Explanation to Figure 2.7-1



REFERENCE

Modified from:

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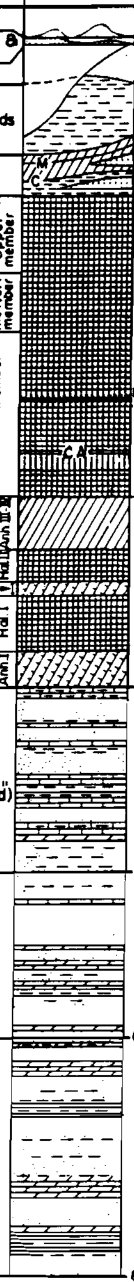
NOTE This figure prepared by compiling selected topographic and cultural features from the references cited

This Illustration for Information Purposes only.

FIGURE 2.7-2
Area of Surface Subsidence



ERA	SYSTEM	SERIES	FORMATION	APPROX. DEPTH TO CONTACT AT SITE	PRINCIPAL LITHOLOGY	APPROX. THICKNESS (feet)
CENOZOIC	HOLOCENE		Surficial sand		BLANKET SAND AND DUNE SAND. SOME ALLUVIUM INCLUDED	0-100
CENOZOIC	QUATERNARY	PLEISTOCENE (Kansan?)	Mescalero caliche & Gatuna Fm.	10 / 40	PALE REDDISH-BROWN, FINE GRAINED FRIABLE SANDSTONE, CAPPED BY 5-10 FT HARD, WHITE CRYSTALLINE CALICHE (LIMESTONE) CRUST.	0-35
MESOZOIC	TRIASSIC	UPPER TRIAS	Dockum Group	50	PALE RED TO GRAY, CROSS BEDDED, NON MARINE, MEDIUM TO COARSE GRAINED FRIABLE SANDSTONE. PINCHES OUT ACROSS SITE.	0-250
PALEOZOIC	PERMIAN	OCHOAN	Dewey Lake Redbeds	540	UNIFORM DARK RED-BROWN MARINE MUDSTONE AND SILTSTONE WITH INTERBEDDED VERY FINE GRAINED SANDSTONE, THINS WESTWARD	100-550
PALEOZOIC	PERMIAN	OCHOAN	Rustler	850	GRAY, GYPSIFEROUS ANHYDRITE WITH SILTSTONE INTERBEDS IN UPPER PART; REDDISH BROWN SILTSTONE OR VERY FINE SILTY SANDSTONE IN LOWER PART, HALITIC NEAR BASE. CONTAINS 2 DOLOMITE MARKER BEDS: MAGENTA (M) IN UPPER PART AND CULEBRA (C) IN LOWER PART. THICKENS EASTWARD DUE TO INCREASING CONTENT OF UNDISSOLVED HALITE	275-425
PALEOZOIC	PERMIAN	OCHOAN	Salado (Upper member; McNutt member; Lower member; REPOSITORY HORIZON)	2825	MAINLY HALITE (85-90%) WITH MINOR INTERBEDDED ANHYDRITE, POLYHALITE AND CLAYEY TO SILTY CLASTICS. TRACE OF POTASH MINERALS IN MC NUTT ZONE. THE MINOR INTERBEDS ARE THIN AND OCCUR IN COMPLEXLY ALTERNATING SEQUENCES. THICKEST NON-HALITE BED IS THE COWDEN ANHYDRITE (CA), 17 FT. THICK. MULTIPLE ANHYDRITE INTERBEDS ARE MOST COMMON IMMEDIATELY BELOW THE COWDEN AND IMMEDIATELY ABOVE BASE OF SALADO.	1750-2000
PALEOZOIC	PERMIAN	OCHOAN	Castile (Anh I; Hal I; Anh II; Hal II; Anh III-V)	4100±	THICK MASSIVE UNITS OF FINELY INTERLAMINATED ("VARVED") ANHYDRITE-CALCITE ALTERNATING WITH THICK HALITE UNITS CONTAINING THINLY INTERBEDDED ANHYDRITE. TOP ANHYDRITE UNIT LACKS CALCITE INTERLAMINATIONS.	1250±
PALEOZOIC	PERMIAN	GUADALUPIAN	DELAWARE MOUNTAIN GROUP: Bell Canyon ("Delaware sand")	5300±	MOSTLY LIGHT GRAY FINE-GRAINED SANDSTONE WITH VARYING AMOUNT OF SILTY AND SHALY INTERBEDS AND IMPURITIES; CONTAINS CONSIDERABLE LIMESTONE INTERBEDS AND LIME-RICH INTERVALS. TOP UNIT IS LAMAR LIMESTONE MEMBER, A PERSISTENT SHALY LIMESTONE	1200±
PALEOZOIC	PERMIAN	GUADALUPIAN	DELAWARE MOUNTAIN GROUP: Cherry Canyon	6400±	MOSTLY GRAY TO BROWN, FINE TO VERY FINE GRAINED SANDSTONE SIMILAR TO BRUSHY CANYON, INTERBEDDED WITH SHALE, DOLOMITE AND SOME LIMESTONE.	1100±
PALEOZOIC	PERMIAN	GUADALUPIAN	DELAWARE MOUNTAIN GROUP: Brushy Canyon	8000±	PREDOMINANTLY FINE-GRAINED, GRAY TO BROWN SANDSTONE INTERBEDDED WITH MINOR BROWN SHALE AND DOLOMITE.	1600±

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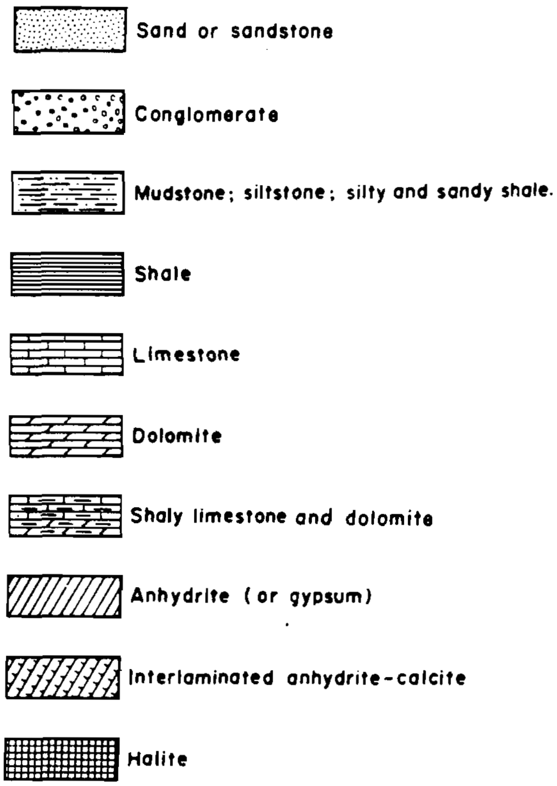
FIGURE 2.7-3

Site Stratigraphic Column

EXPLANATION



REFERENCE

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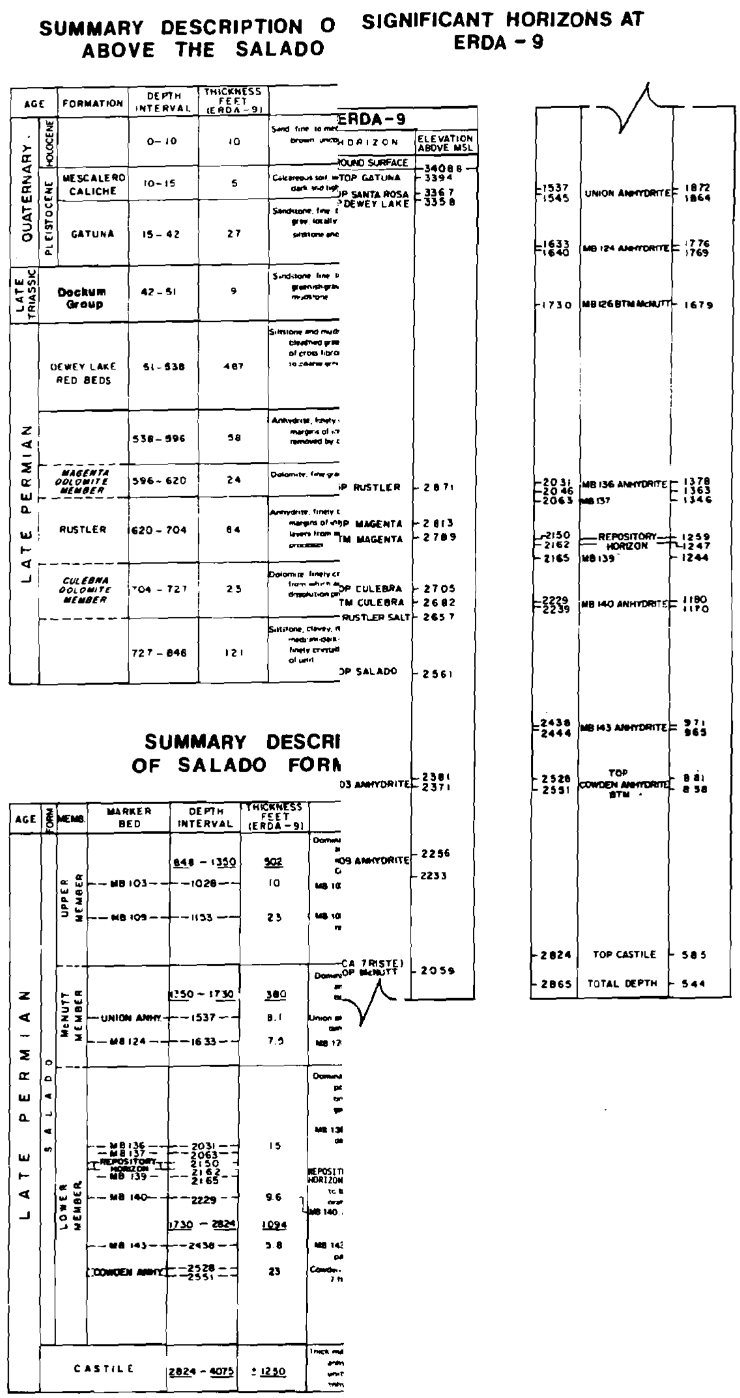
This illustration for Information Purposes only.

Explanation to Figure 2.7-3



REFERENCE

Prepared for U.S. Department of Energy,
Report by Bechtel National, Inc. from Sl
Core and Trench Photographs.

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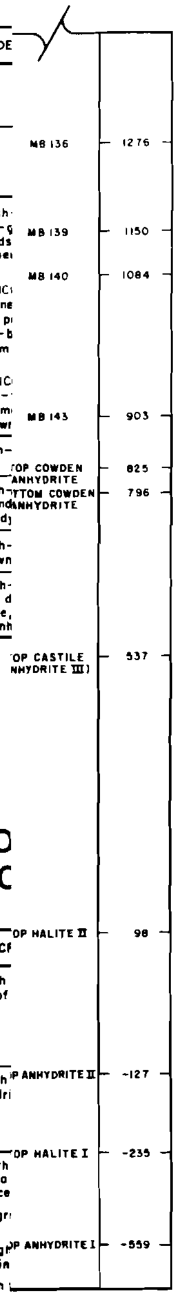
FIGURE 2.7-4
General Lithology of ERDA-9

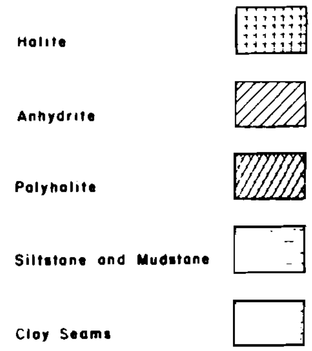
SUMMARY DESCRIPTION OF R ZONS ABOVE THE SALADO FORI

AGE		FORMATION	DEPTH INTERVAL	THICKNESS FEET(DOE-1)	DE
QUATERNARY	HOLO-CENE	EOLIAN SANDS	-	-	Not Described
QUATERNARY	PLEISO-CENE	GATUNA FORMATION	-	-	Not Described
LATE TRIASSIC		Dockum Group	46-133	87	* Claystone, reddish-ence of greenish-g bedded with sands to very fine grainer
LATE PERMIAN		DEWEY LAKE RED BEDS	133-668	535	UNC * Sandstone, siltstone very fine grained; p ologies is reddish-b gray zones; gypsum percent).
LATE PERMIAN		RUSTLER FORMATION	668-722	54	UNC * Anhydrite, grayish-trace of gypsum; m dark reddish-brown
LATE PERMIAN		*Magenta Dolomite Member*	722-745	23	* Dolomite, greenish-drite.
LATE PERMIAN		RUSTLER FORMATION	745-829	84	* Anhydrite, greenish-trace of gypsum and greenish-gray sand
LATE PERMIAN		*Culebra Dolomite Member*	829-851	22	* Anhydrite, greenish-dark reddish-brown
LATE PERMIAN		RUSTLER FORMATION	851-977	126	* Anhydrite, greenish-mudstone, grading d mudstone, siltstone, of dolomite and anh

** Description based on examination of cuttings samples*



LEGEND



SUMMARY DESCRIPTIO OF SALADO FORMATIC

AGE	FORM.	MEMB.	MARKER BED	DEPTH INTERVAL	THICKNESS FEET(DOE-1)	DESCI
LATE PERMIAN	SALADO FORMATION	UPPER MEMBER		977-1486	509	*Dominantly halite with and minor amounts of sandstone.
			MB 103	1169	10	Not Described
			MB 109	1310	24	Not Described
		McNUTT MEMBER		1486-1880	394	*Dominantly halite with polyhalite and anhydri
			UNION ANHY.	1694	13	Not Described
			MB 124	1784	11	Not Described
		LOWER MEMBER		1880-2937	1057	Dominantly halite with and polyhalite, fine to gray to brown argillace
			MB 136	2197	5	Anhydrite, greenish-gr orange polyhalite
			MB 137	2209	-	Anhydrite, medium lig halite and polyhalite in
			DISPOSAL HORIZON			Dominantly halite with and polyhalite, mediur of argillaceous halite.
			MB 139	2324	-	Anhydrite, medium gra
			MB 140	2389	14	*Anhydrite, very light g
			MB 143	2571	7	Not Described
			COWDEN ANHY.	2648-2677	29	*Anhydrite, very light gr moderate orange pink
	CASTILE FORMATION			2937-4032 T. D.	-	Alternating sequence of halite units

** Description based on examination of cuttings samples.*

This Illustration for Information Purposes only.

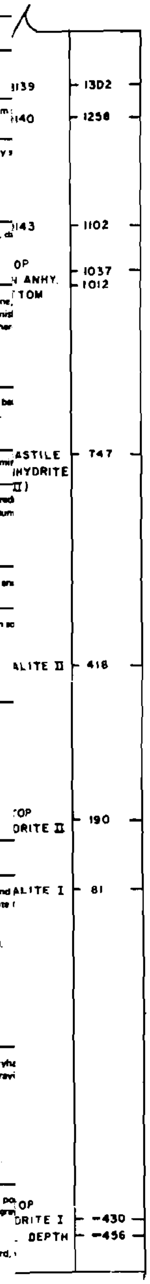
FIGURE 2.7-6
Generalized Lithology of DOE-1

SUMMARY DESCRIPTION OF ROCK UI AT ABOVE THE SALADO FORMATION

AGE		FORMATION	DEPTH INTERVAL	THICKNESS FEET	DESCRIPTION
QUATERNARY			0.0 - 4	4	Sand, reddish brown unconsolidated, eolian
	MIOCENE	MESCALERO CALICHE	4 - 7	3	Caliche, calcareous cemented sand, pale to medium and orange — UNCONFORMITY —
	PLEISTOCENE	GATUNA	? - 12	5	Sandstone, medium grained, well rounded, poorly dark reddish-brown, weak to medium hard. — UNCONFORMITY —
LATE TRIASSIC		Dockum Group	12 - 154	142	Sandstone and siltstone, fine to medium grained, d reddish-brown with trace of bluish-gray — UNCONFORMITY —
LATE PERMIAN		DEWEY LAKE RED BEDS	154 - 628	474	Predominantly interbedded siltstone and sandstone, dark reddish-brown to grayish-red with greenis gray reduction spots and bands of selenite, har medium hard, some mudstone. — UNCONFORMITY —
			628 - 690	62	Anhydrite, light olive-gray with white horizontal ba hard to soft, with gypsum seams, some clay.
		MAGENTA DOLOMITE	690 - 715	25	Dolomite, vuggy, brown, with gypsum veins and mi clay.
		RUSTLER	715 - 812	97	Anhydrite, light grayish-brown, dense with dark red brown mudstone, and yellowish-brown gypsum
		CULEBRA DOLOMITE	812 - 835	23	Dolomite, vuggy, massive, light gray, argillaceous an brecciated in part.
			835 - 954	119	Mudstone, grayish, olive green and anhydrite with sc sandstone and gypsum seams.

SUMMARY DESCRIPTION OF SALADO FORMATION

AGE	FORMATION	MEMBER	MARKER BED	DEPTH INTERVAL	THICKNESS FEET	DESCRIPTION
LATE PERMIAN	SALADO	UPPER MEMBER		954-1434	480	Predominantly halite with polyhalite and red orange-brown and grayish-white some clay seams.
			MB 103	1118		MB-103; Anhydrite, medium gray, hard.
			MB 112	1328		MB-112; Polyhalite
		McNUTT MEMBER		1432-1787	355	Predominantly halite with zones of polyha anhydrite, brownish-orange and gray clear, some clay seams.
			UNION ANHY.	1604		Union Anhydrite; gray,
			MB 124	1696		MB-103, anhydrite, medium gray, hard.
		LOWER MEMBER		1787-2728	941	Predominantly halite with interbeds of po anhydrite, red orange-brown and gra to clear, some clay seams.
			MB 136	2060		MB-136, anhydrite, dark olive-gray, hard, orange polyhalite.
			MB 139	2170		MB-139, anhydrite, light gray, with halite
			MB 140	2214		MB 140, anhydrite, light gray, halitic.
			MB 143	2370		MB-143, anhydrite, gray, with clay and hal
			COWDEN ANHY.	2435 - 2457		Cowden anhydrite, light gray, some halite
	CASTILE			2728-2778	50	Anhydrite, light olive-gray to medium gray massive, hard, fine horizontal varves, cross bedding, occasional dark gray ba organic matter



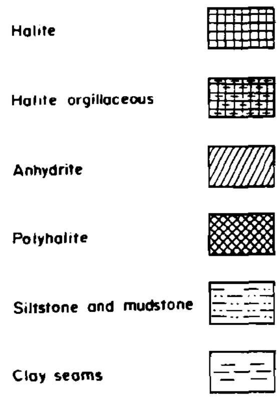


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FIGURE 2.7-5

General Lithology of WIPP-12

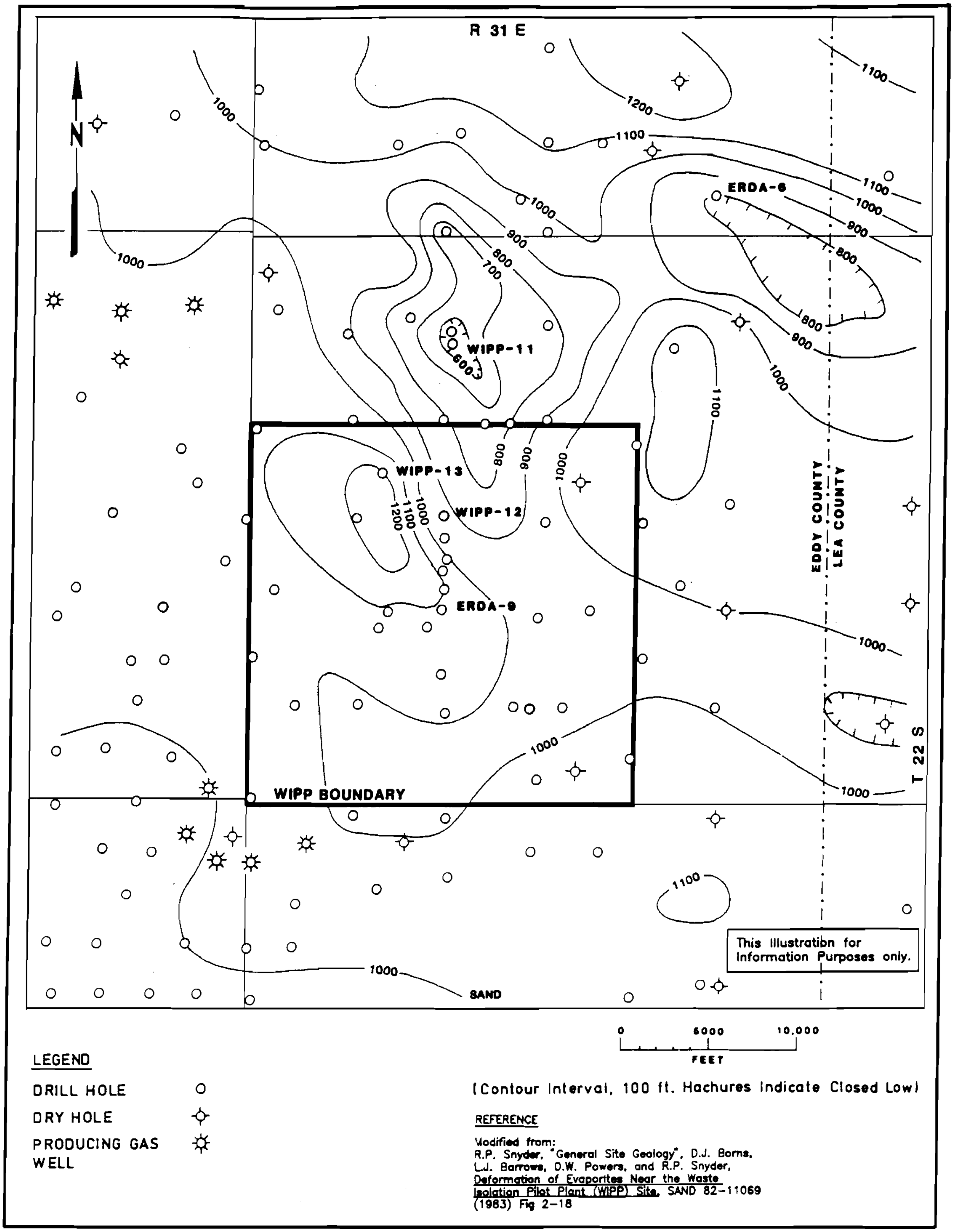
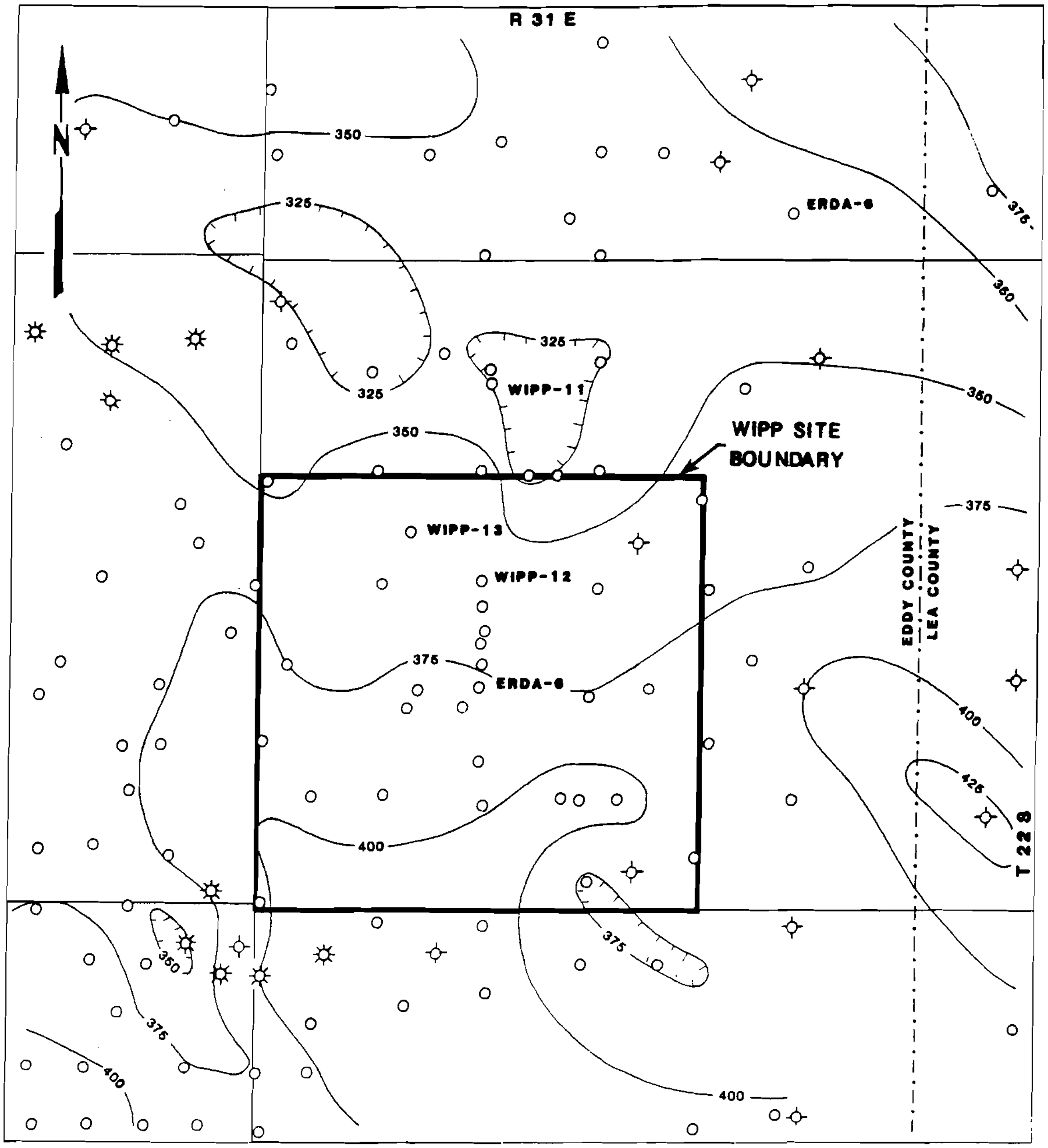


FIGURE 2.7-7
Isopach Map, Lower Unit, Salado Formation



LEGEND

DRILL HOLE ○

DRY HOLE

PRODUCING GAS WELL

0 5000 10,000

FEET

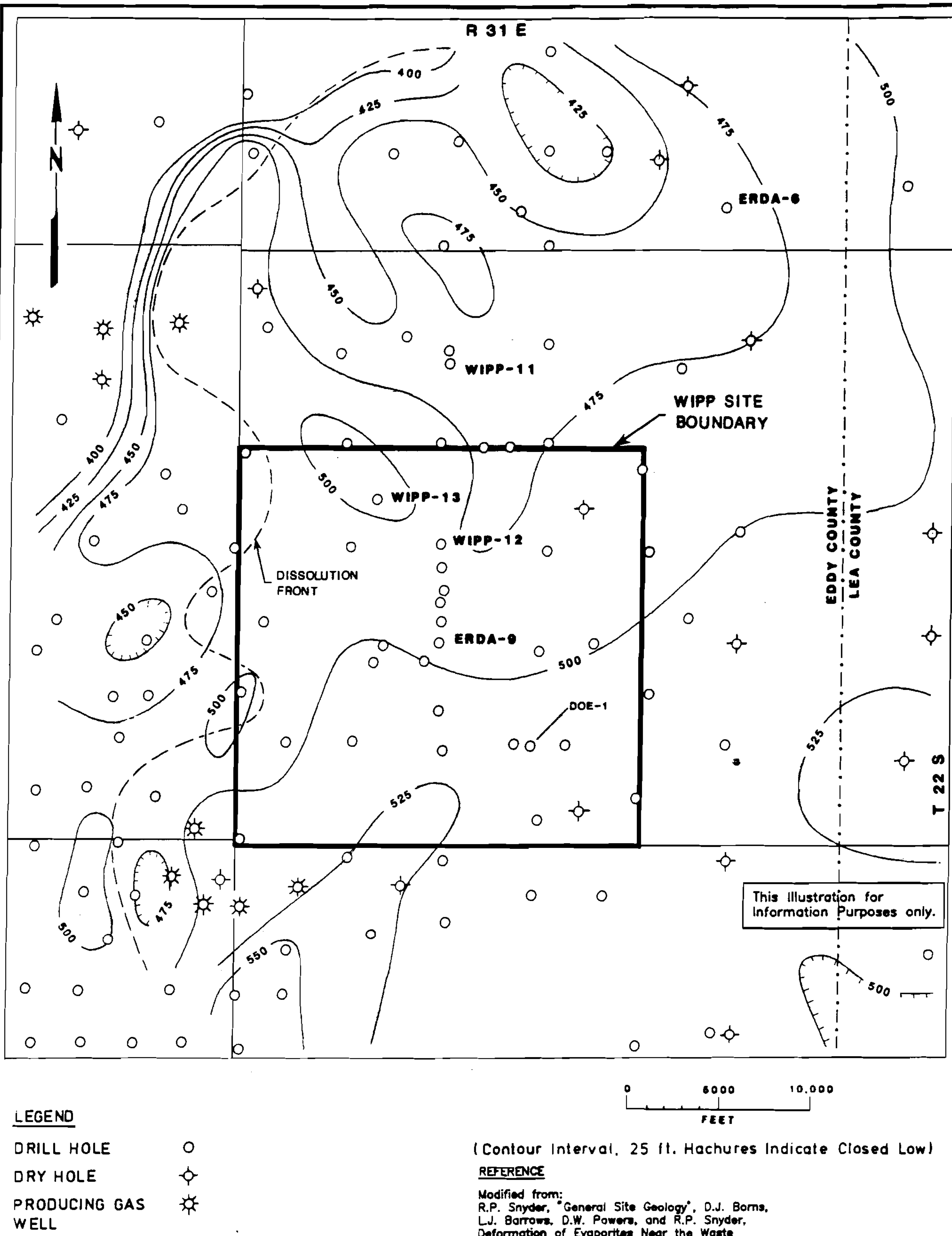
(Contour Interval, 25 ft. Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-20

This Illustration for Information Purposes only.

FIGURE 2.7-8
Isopach Map, McNutt Potash Member, Salado Formation

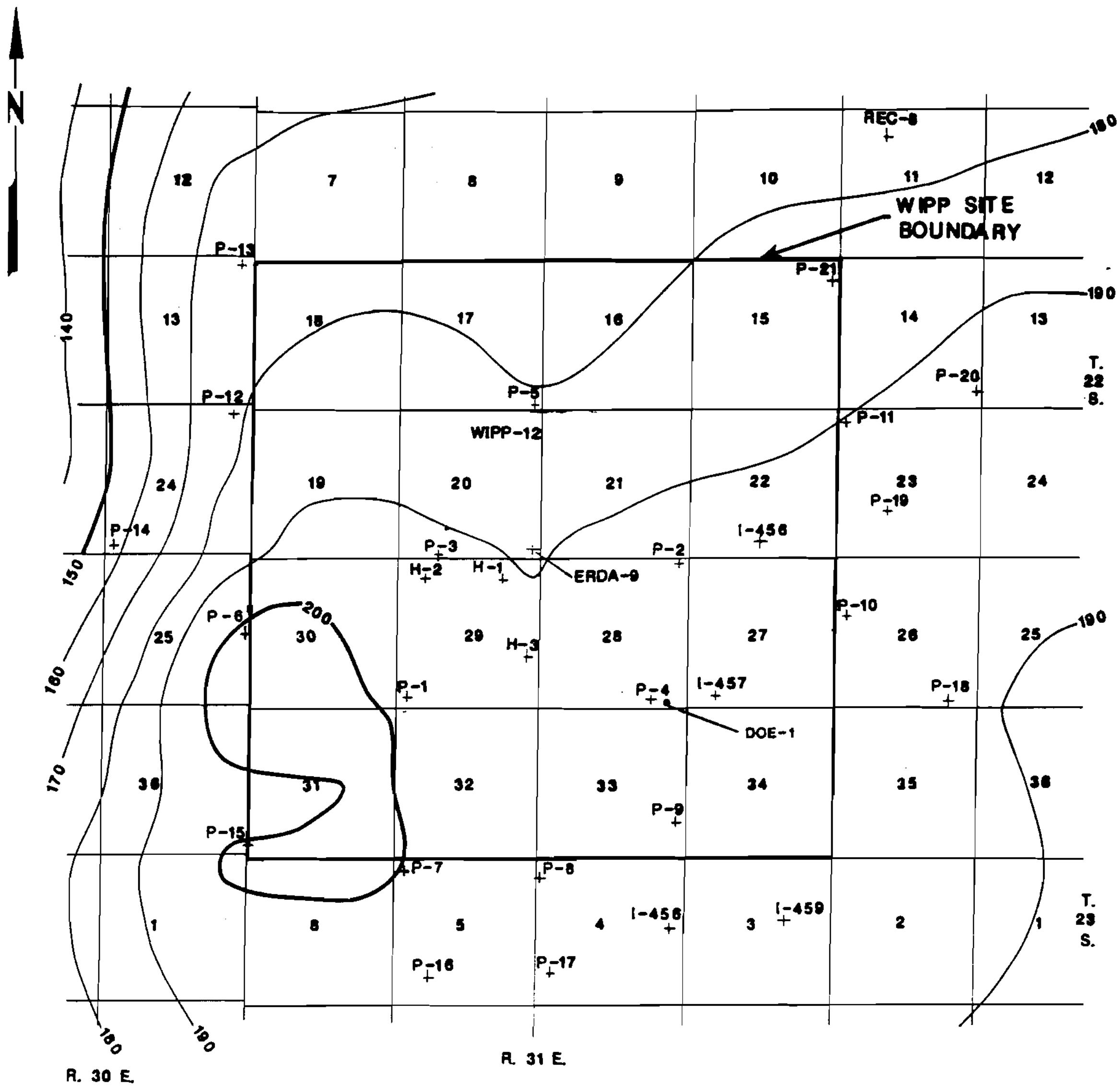


(Contour Interval, 25 ft. Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-22

FIGURE 2.7-9
Isopach Map, Upper Member, Salado Formation



NOTES

1. Isopach interval, 10 feet
2. Isopachs based on data from geophysical logs of WIPP and industry potash exploration holes.

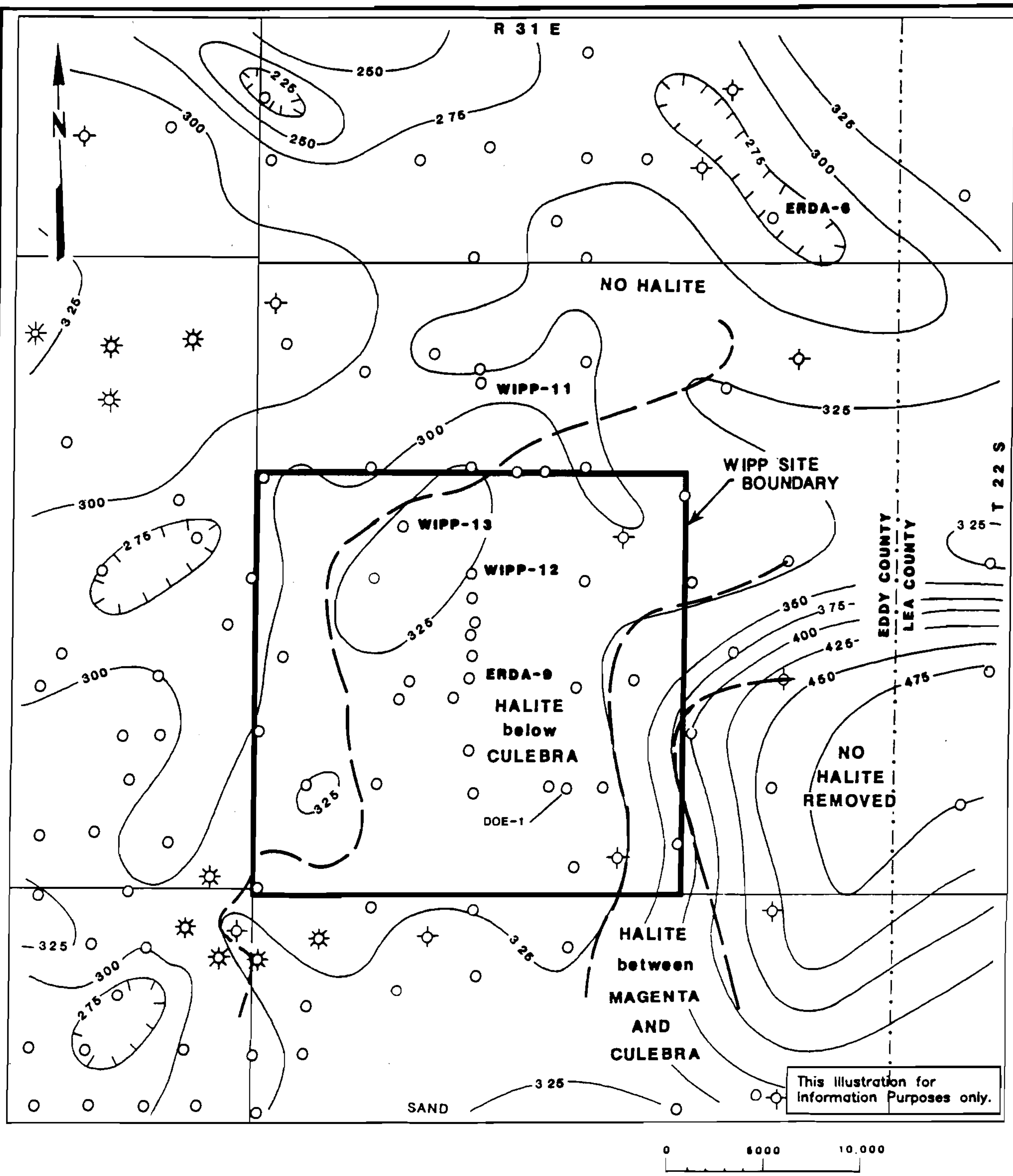
This illustration for Information Purposes only.

REFERENCE

Modified from:

Griswold, G.B., Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Las Medaños, Eddy County, N.M., SAND 77-0946 Fig 11

FIGURE 2.7-10
Isopach Map Top of Salado to MB 103



LEGEND

DRILL HOLE ○

DRY HOLE

PRODUCING GAS WELL

(Contour Interval, 25 ft. Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-25

FIGURE 2.7-11
Isopach Map, Rustler Formation

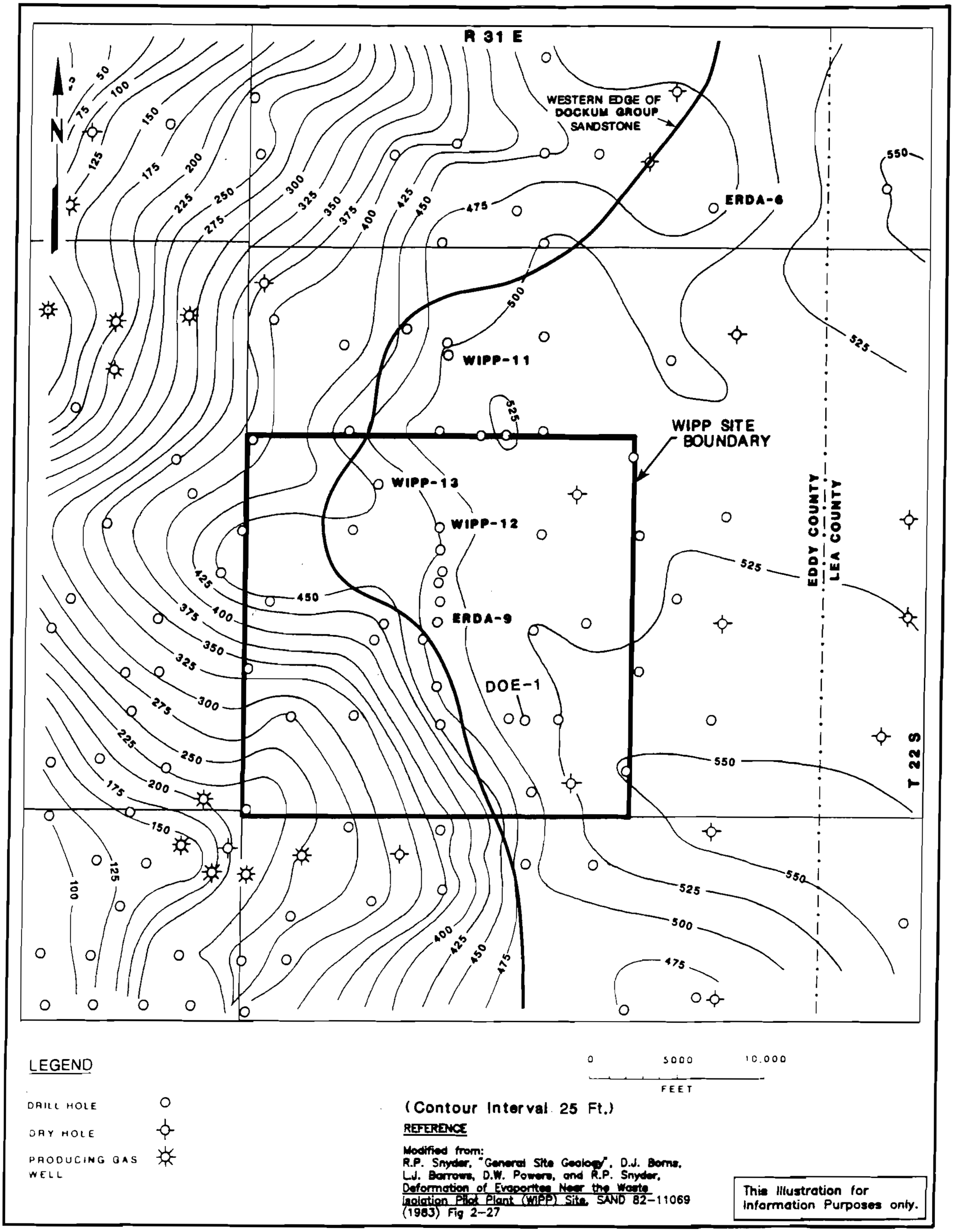
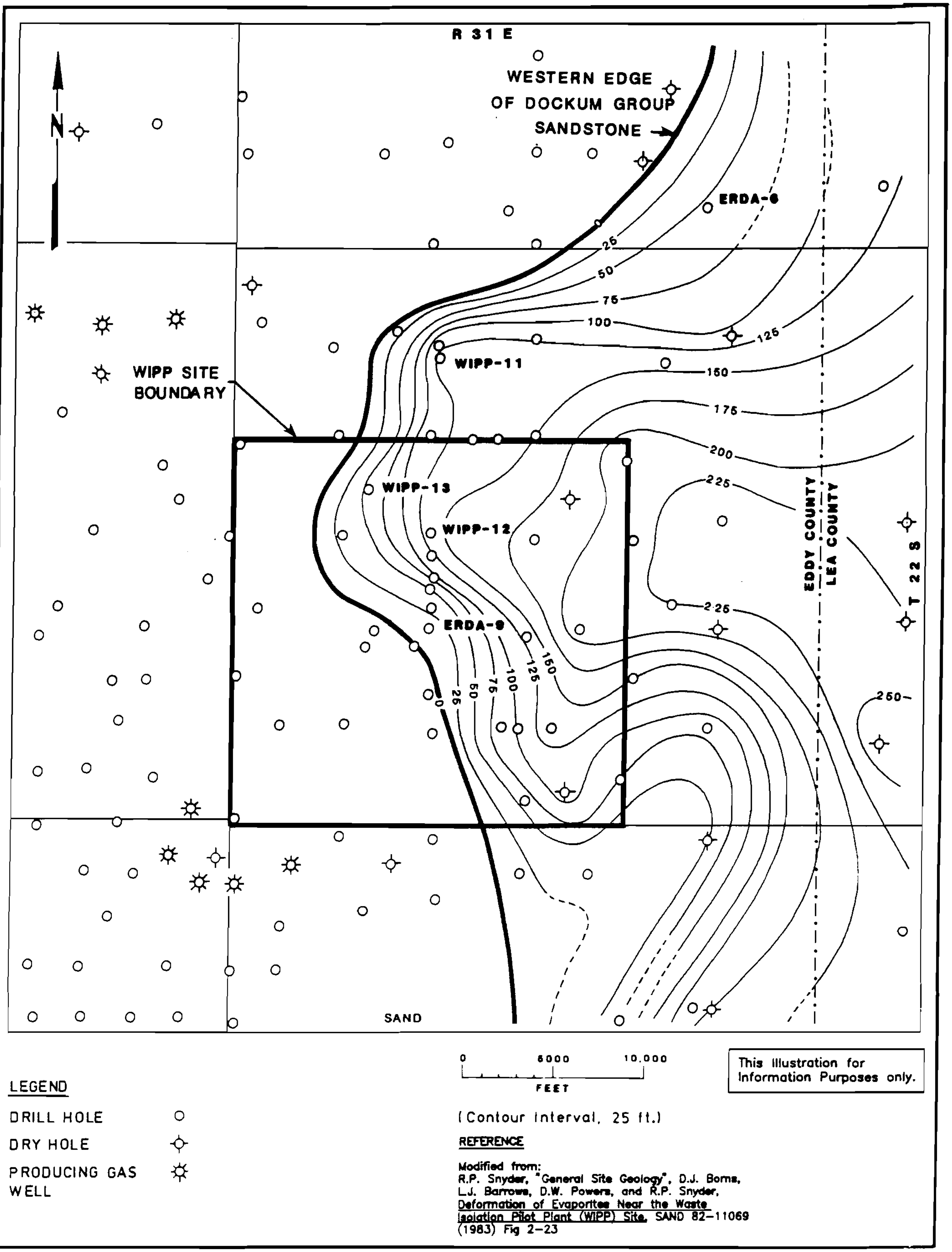


FIGURE 2.7-12
Isopach Map, Dewey Lake Redbeds



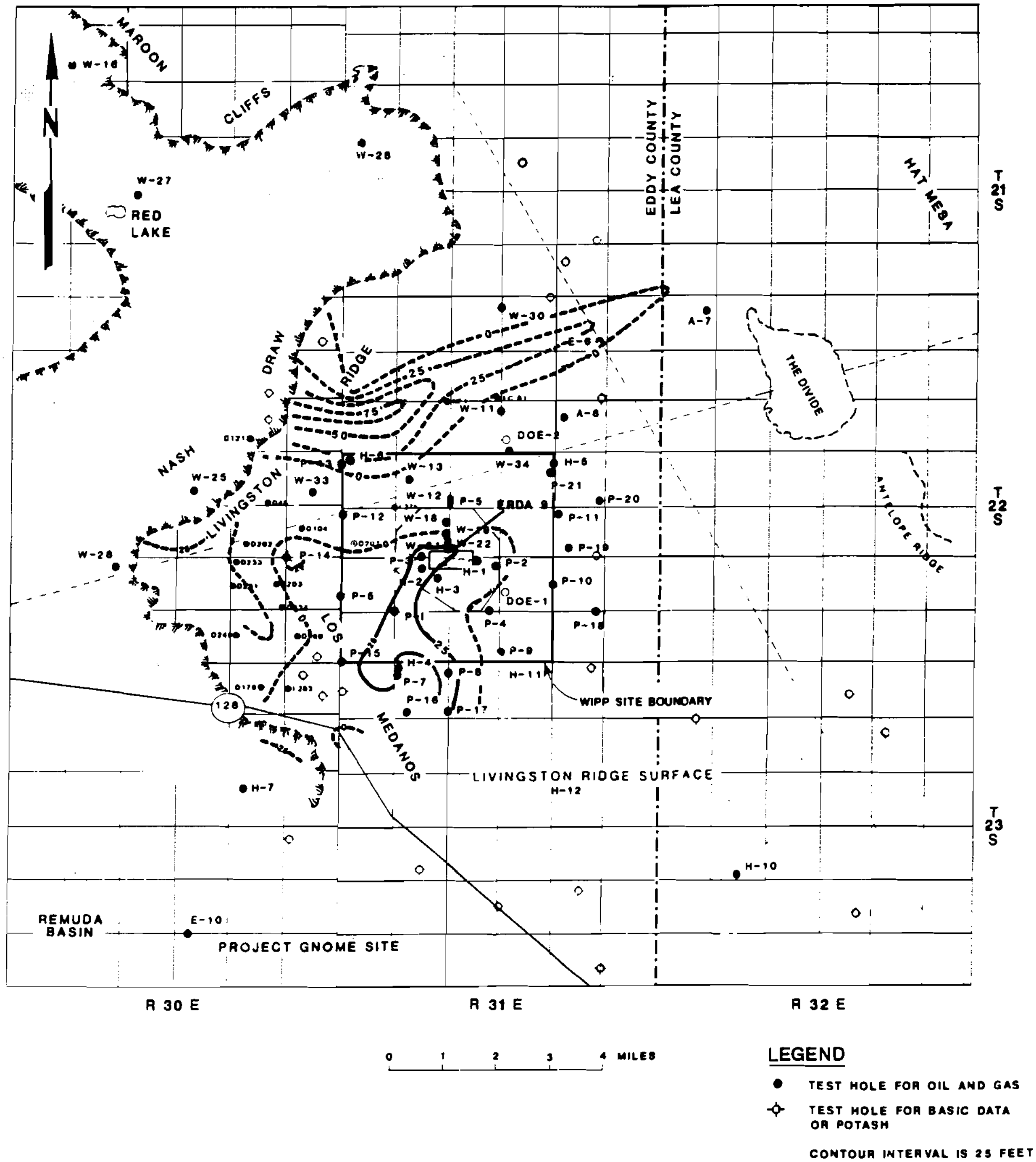
This Illustration for Information Purposes only.

(Contour Interval, 25 ft.)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-23

FIGURE 2.7-13
Isopach Map, sandstone in the Dockum Group

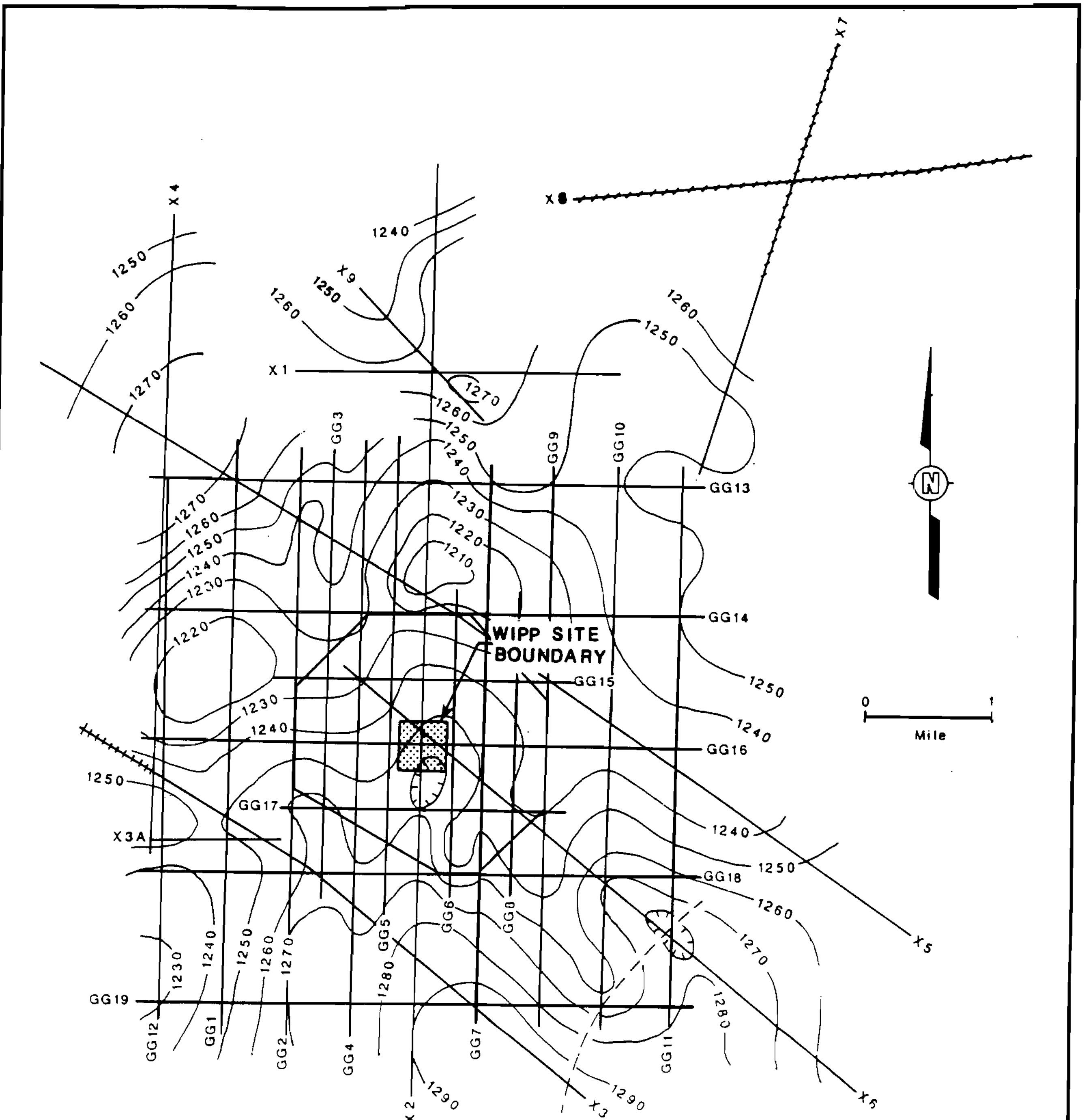


REFERENCE

Modified from:
G.O. Bachman, Assessment of Near-Surface Dissolution At and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico, Sand 84-7178 (1984) Fig 4
Base Map modified from:
J.W. Mercer, Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico, U.S. Geological Survey, Water-Resources Investigations Report 83-4016 (1083) Fig 1a

This Illustration for Information Purposes only.

FIGURE 2.7-14
Isopach Map of Gatuna Formation



LEGEND

Milliseconds Two-Way Time —1250—

Seismic Line GG13 ——
(Crossed Where Ambiguous)

Possible Fault

NOTE

Contour Interval: 10 Milliseconds
Datum: 3356 Ft. a.o.l.
Prepared by Larry Barrows, Nov, 1980
Rev. Feb, 1981

REFERENCE

Modified from:
D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig A-5

This illustration for Information Purposes only.

FIGURE 2.7-15
Seismic Time Structure-
Top of Bone Spring Formation

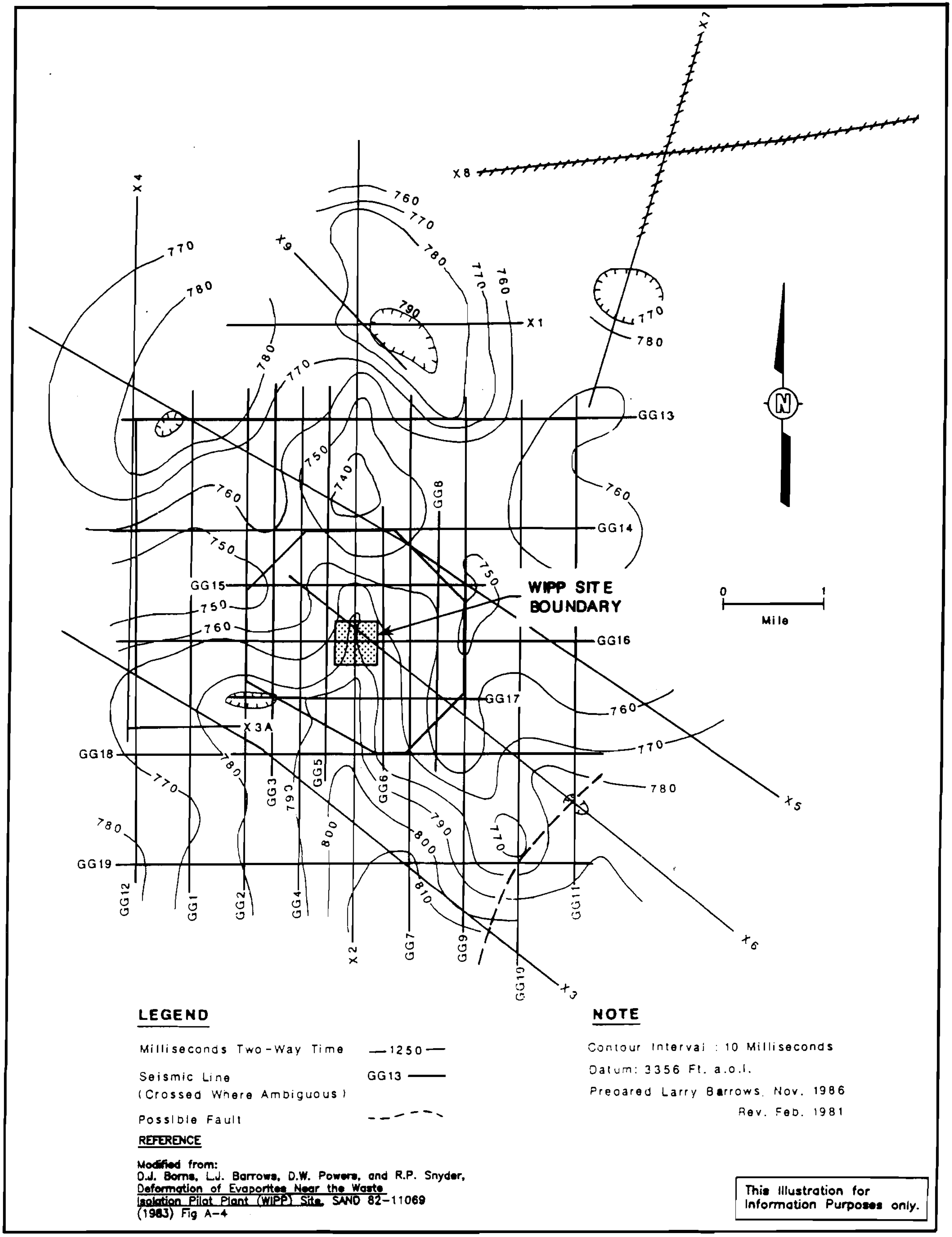


FIGURE 2.7-16
Seismic Time Structure-
Top of Cherry Canyon Formation

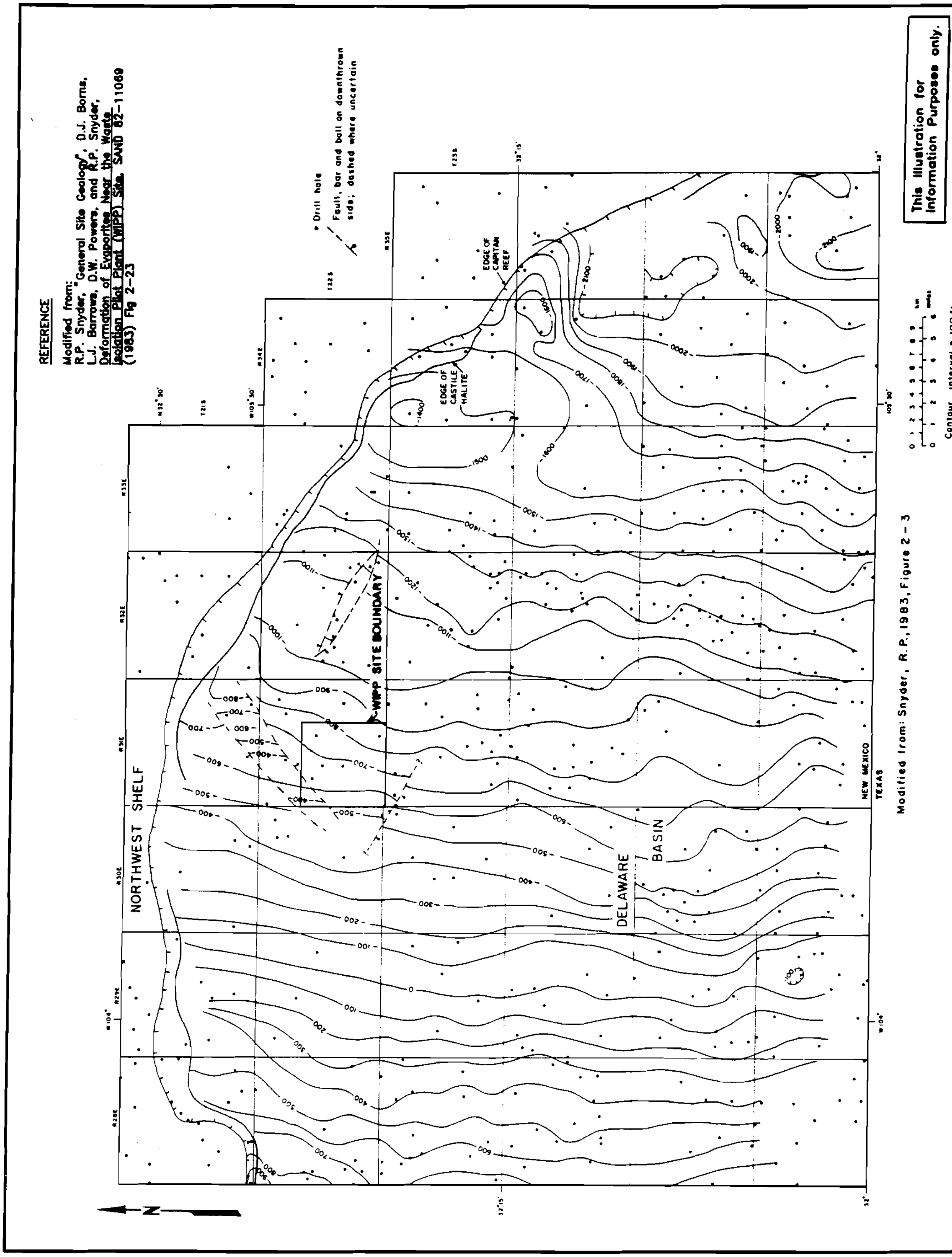
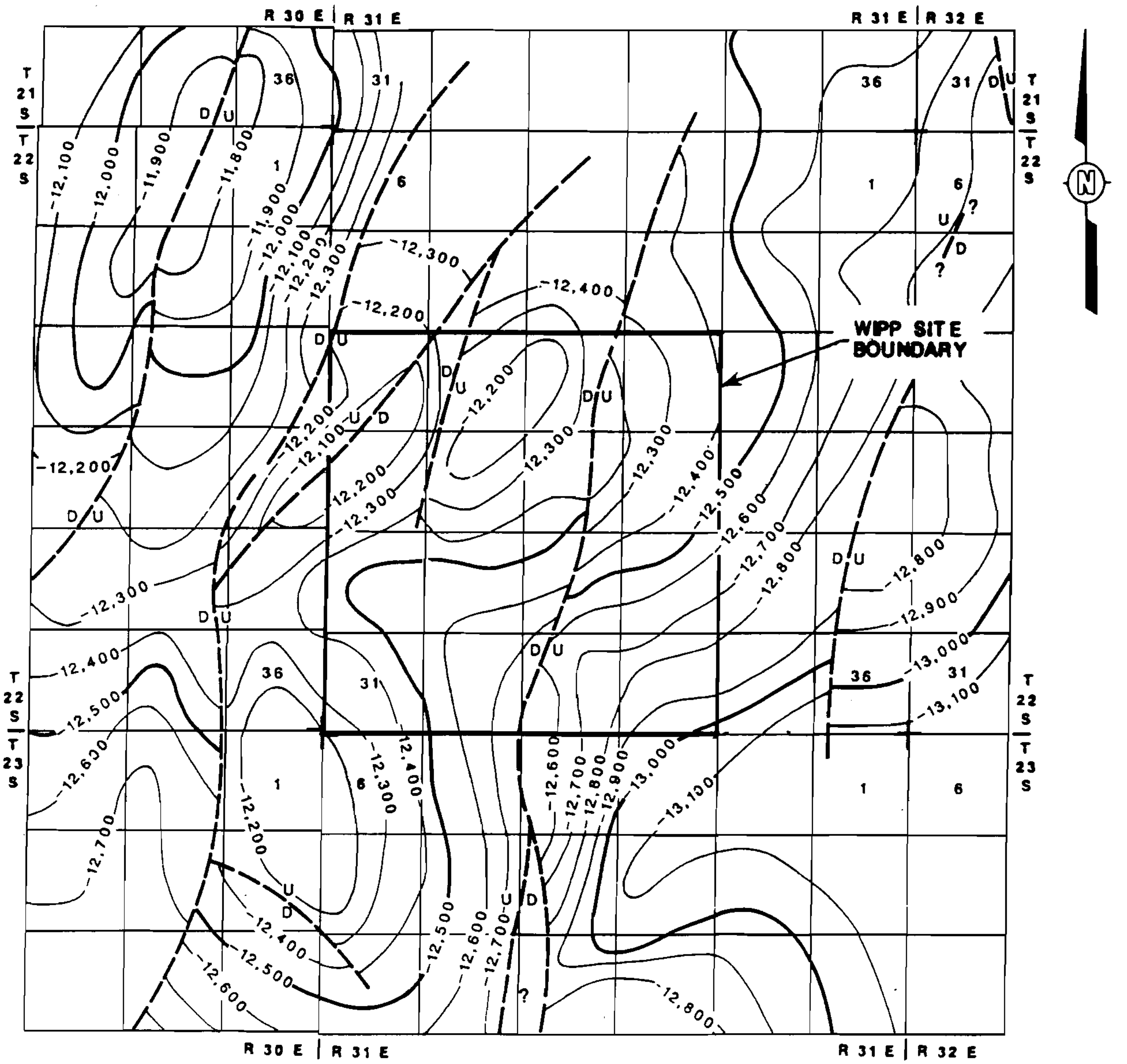


FIGURE 2.7-17
Structure Contour Map, Top of
Bell Canyon Formation,
Northern Delaware Basin



NOTES

1. Contour interval, 100 feet
2. Datum base is mean sea level
3. Contours based on data from seismic profiles of G. J. Long and Associates, Inc., Dec., 1977
4. The horizon shown on this figure corresponds to the Siluro-Devonian contact

LEGEND

Inferred faults
- U — Upthrown side
- D — Downthrown side

D U

This Illustration for Information Purposes only.

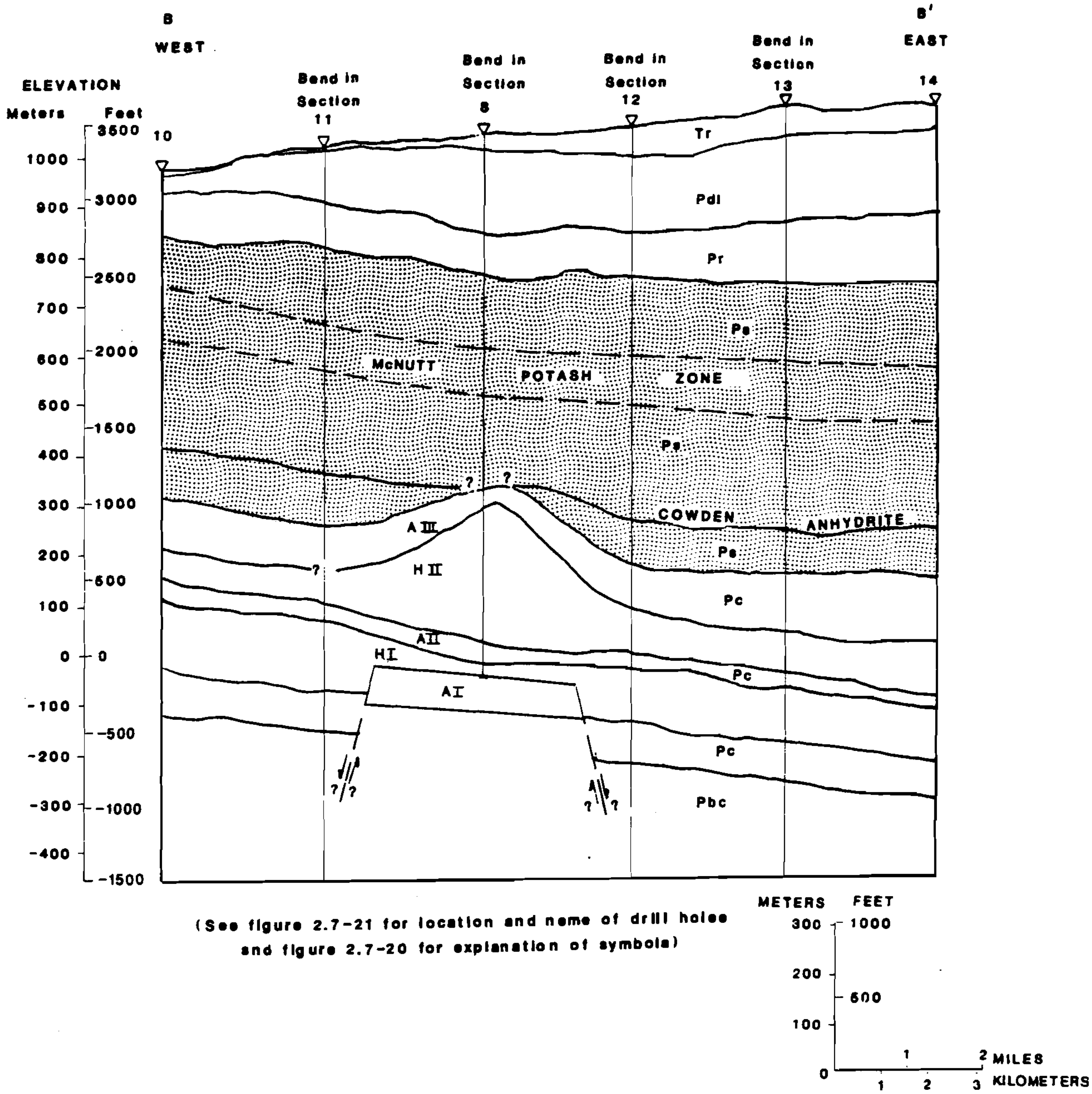
REFERENCE

Modified from:

Griswold, G.B., Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Las Medaños, Eddy County, N.M., SAND 77-0946 Fig 17

0 1 2 3 4 KM
0 1 2 3 MI
SCALE

FIGURE 2.7-18
Structure Contours on a Devonian Horizon



(See figure 2.7-21 for location and name of drill holes and figure 2.7-20 for explanation of symbols)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-6

This illustration for Information Purposes only.

FIGURE 2.7-19

East-West Cross Section, WIPP Facility

WIPP FSAR

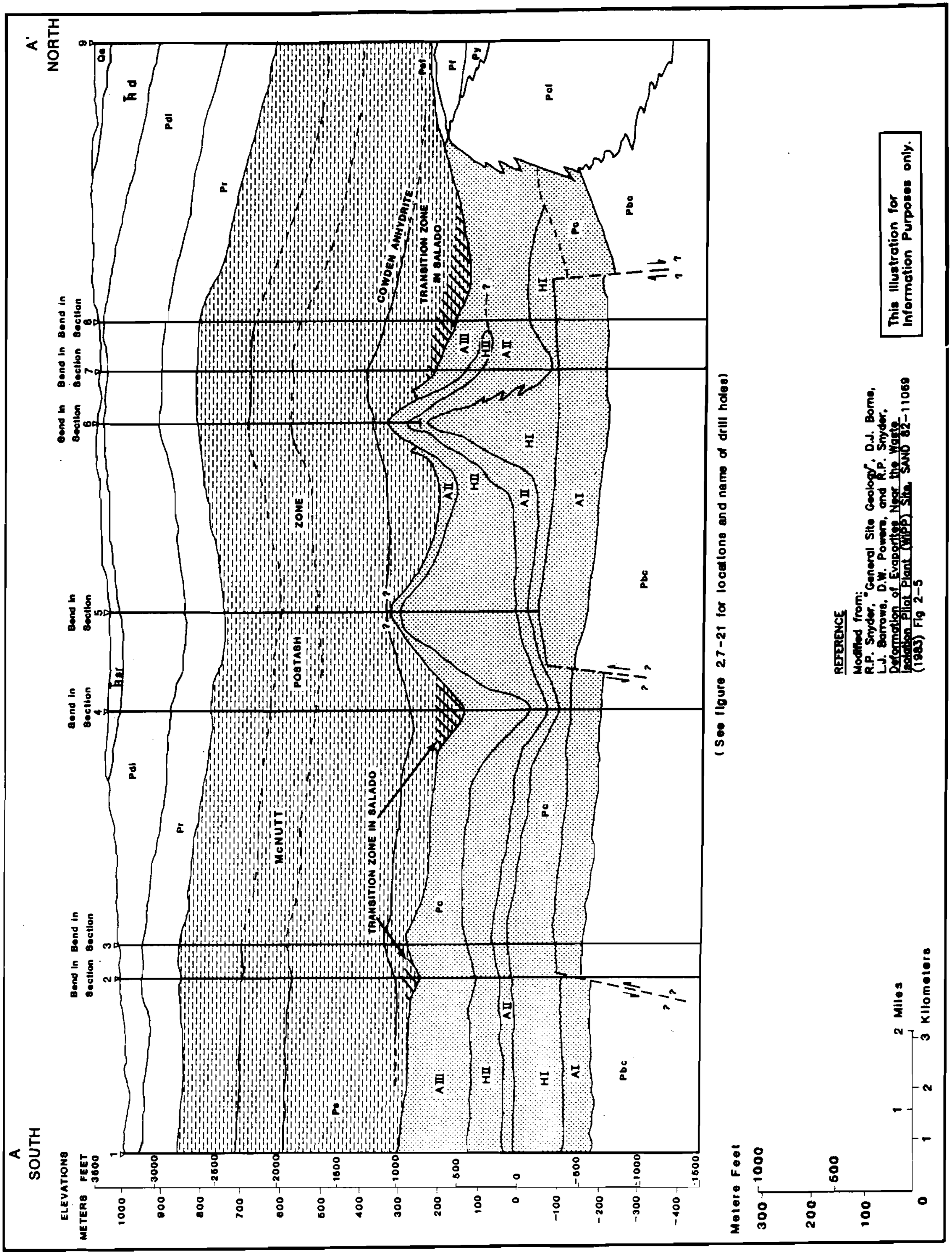


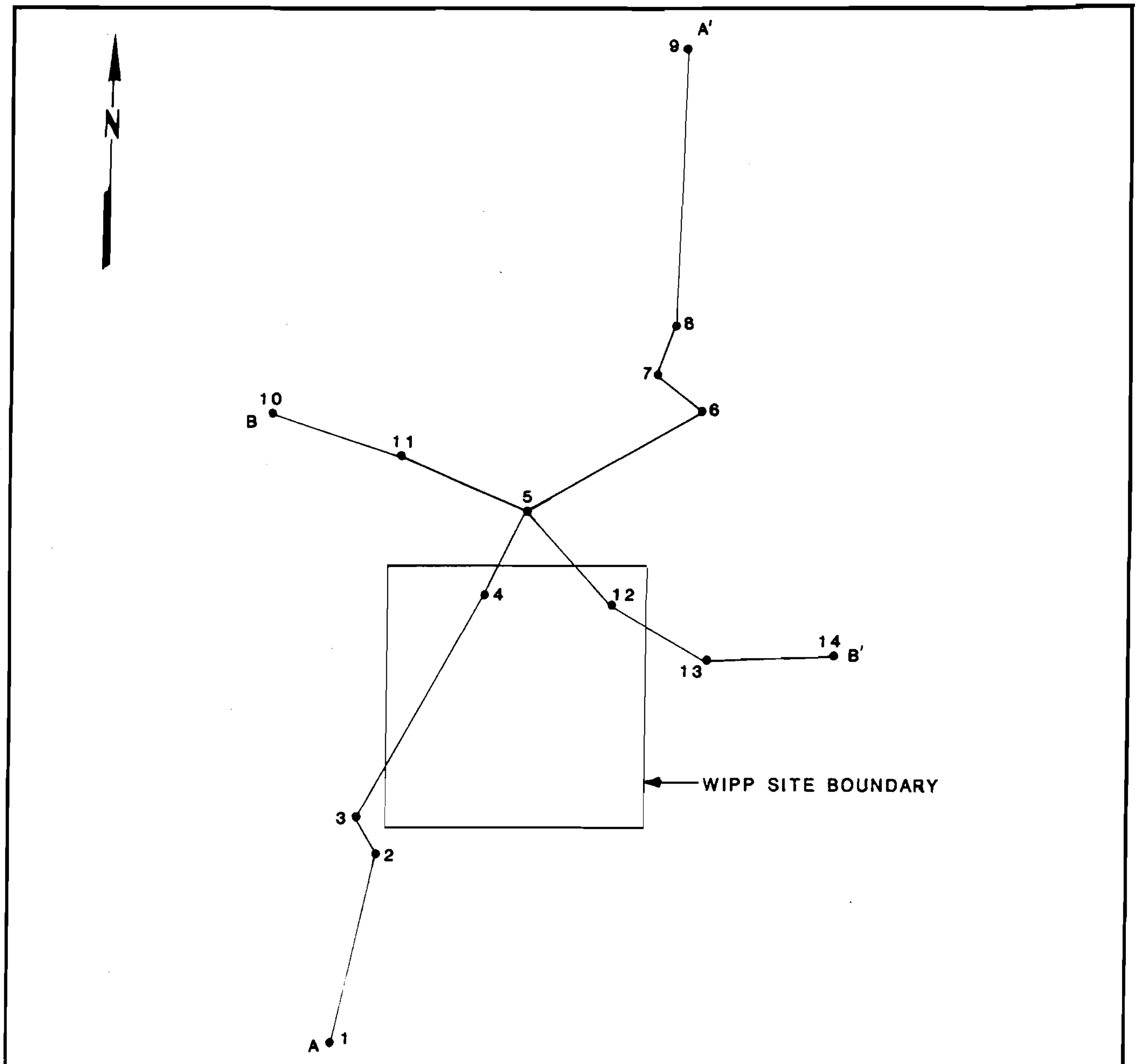
FIGURE 2.7-20
North-South Cross Section,
WIPP Facility

LEGEND

Symbol	Unit	Age
Qa	Alluvium, caliche, sand dunes, and Gatuna Formation	Quaternary
Ꞧd	Dockum Group	Triassic
Pdl	Dewey Lake Red Beds	Permian (Ochoan)
Pr	Rustler Formation	Permian (Ochoan)
Ps, Psf	Salado Formation Psf-Fletcher Anhydrite in backreef Transition zone - interbedded halite and anhydrite at base of unit	Permian (Ochoan)
AIII, HII, AII, HI, AI, Pc	Castile Formation A Anhydrite H Halite	Permian (Ochoan)
Pbc, Pt, Py, Pcl	Pbc - Bell Canyon Formation Pcl - Capitan Limestone (reef) Pt - Tansill Formation Py - Yates Formation	Permian (Guadalupian)

This illustration for Information Purposes only.

Explanation To Figure 2.7-20



This illustration for Information Purposes only.

LEGEND

1. Phillips Pet. Co., Sandy Unit #1
2. Belco Pet. Corp., James Ranch #10
3. Shell Oil Co., James Ranch Unit #1
4. WIPP 13
5. WIPP 11
6. ERDA 6
7. Union Oil of California, Federal FI #1
8. Pogo Producing Co., Federal #1
9. Fred Turner Jr., AID Federal #1
10. Phillips Pet. Co., James "C" #1
11. Bryan McKnight, Compana #1
12. Clayton W. Williams Jr., Badger Unit Federal #1
13. Texas Crude Oil Co., Wright-Federal #1-23
14. Ralph Lowe, Bass Federal #1

0 1 2 MI
0 1 2 3 KM

REFERENCE
Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-4

FIGURE 2.7-21
Index Map Showing Lines and Drill Holes Used In Cross Sections Shown on Figures 2.7-19 and 2.7-20

GG117.2

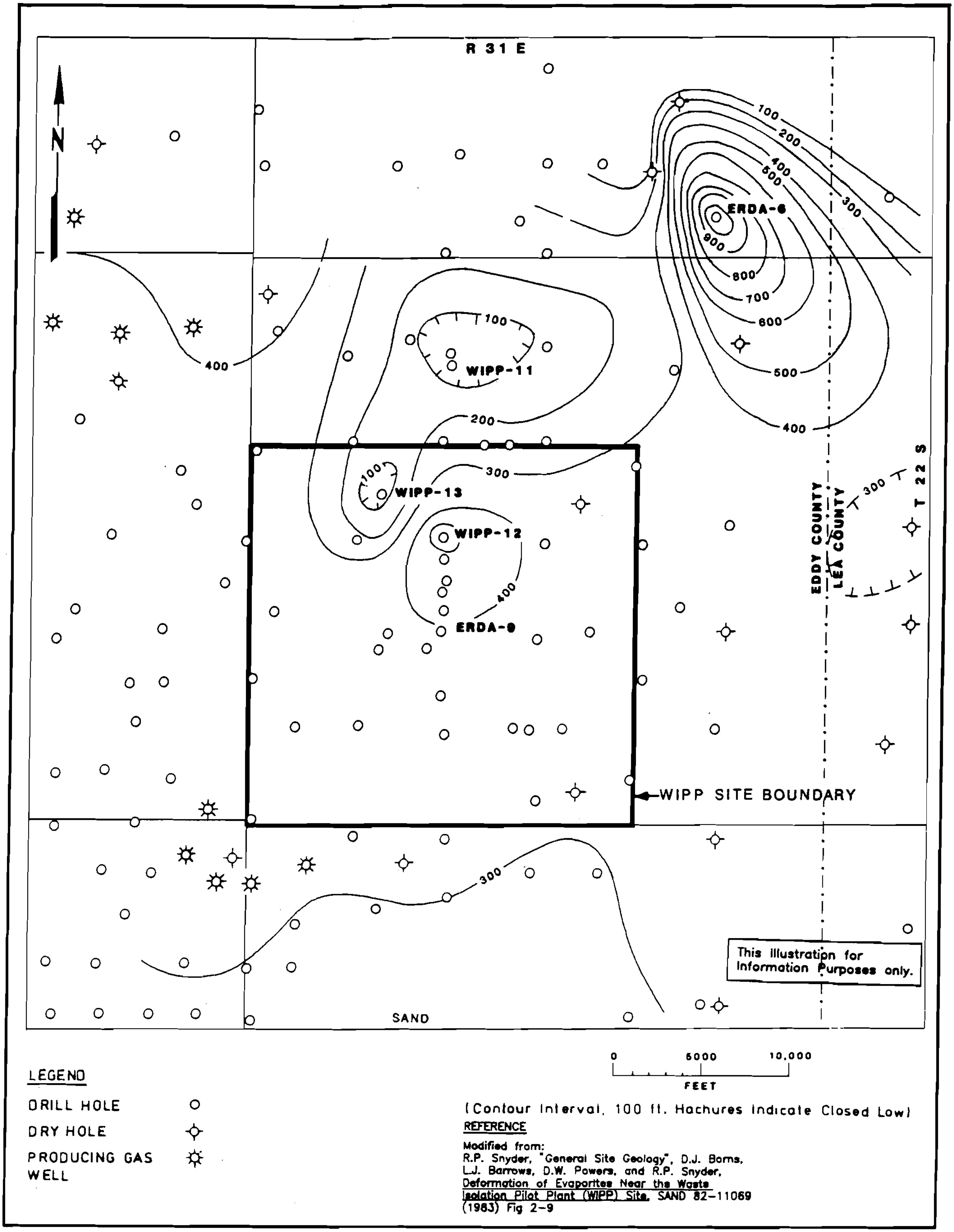
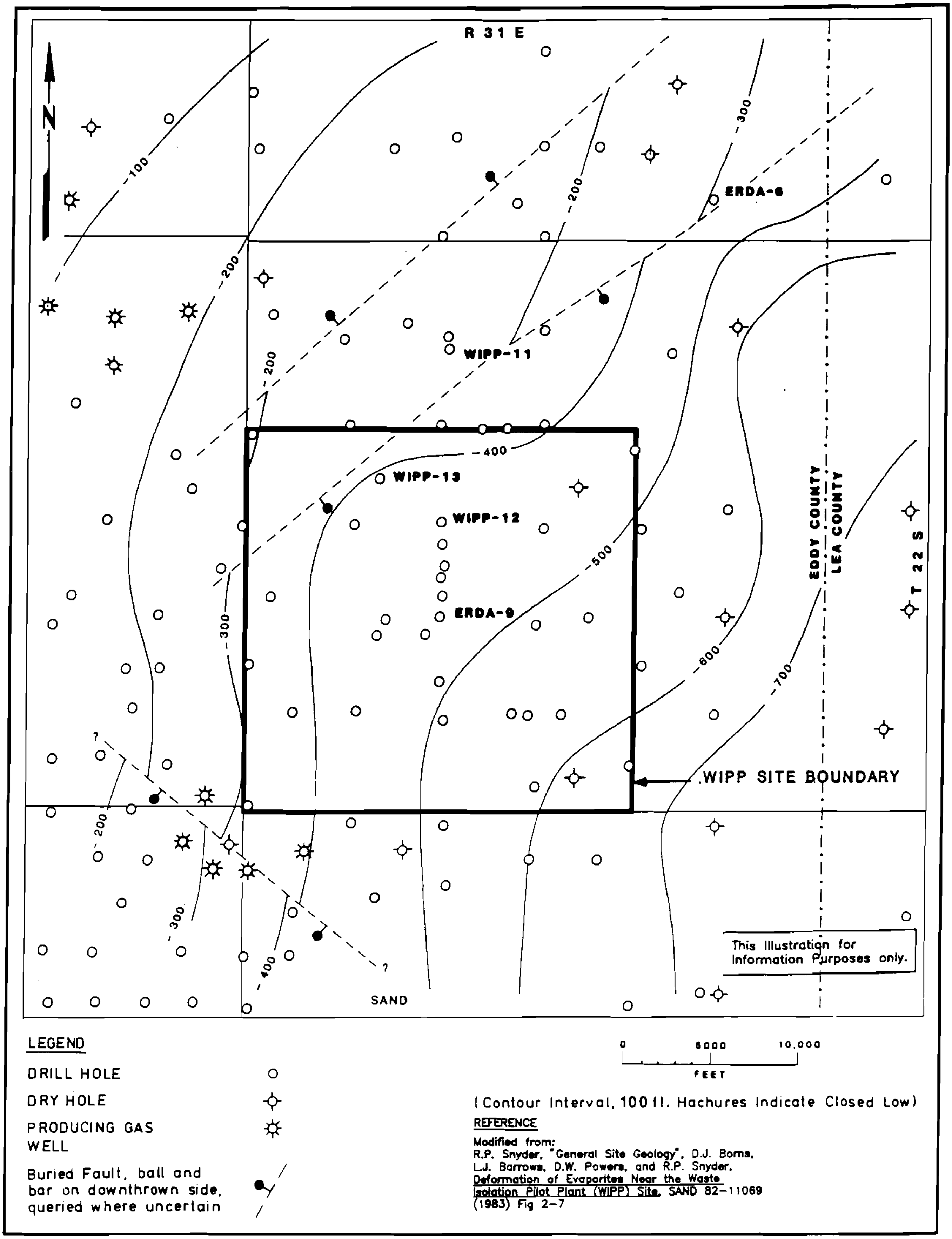


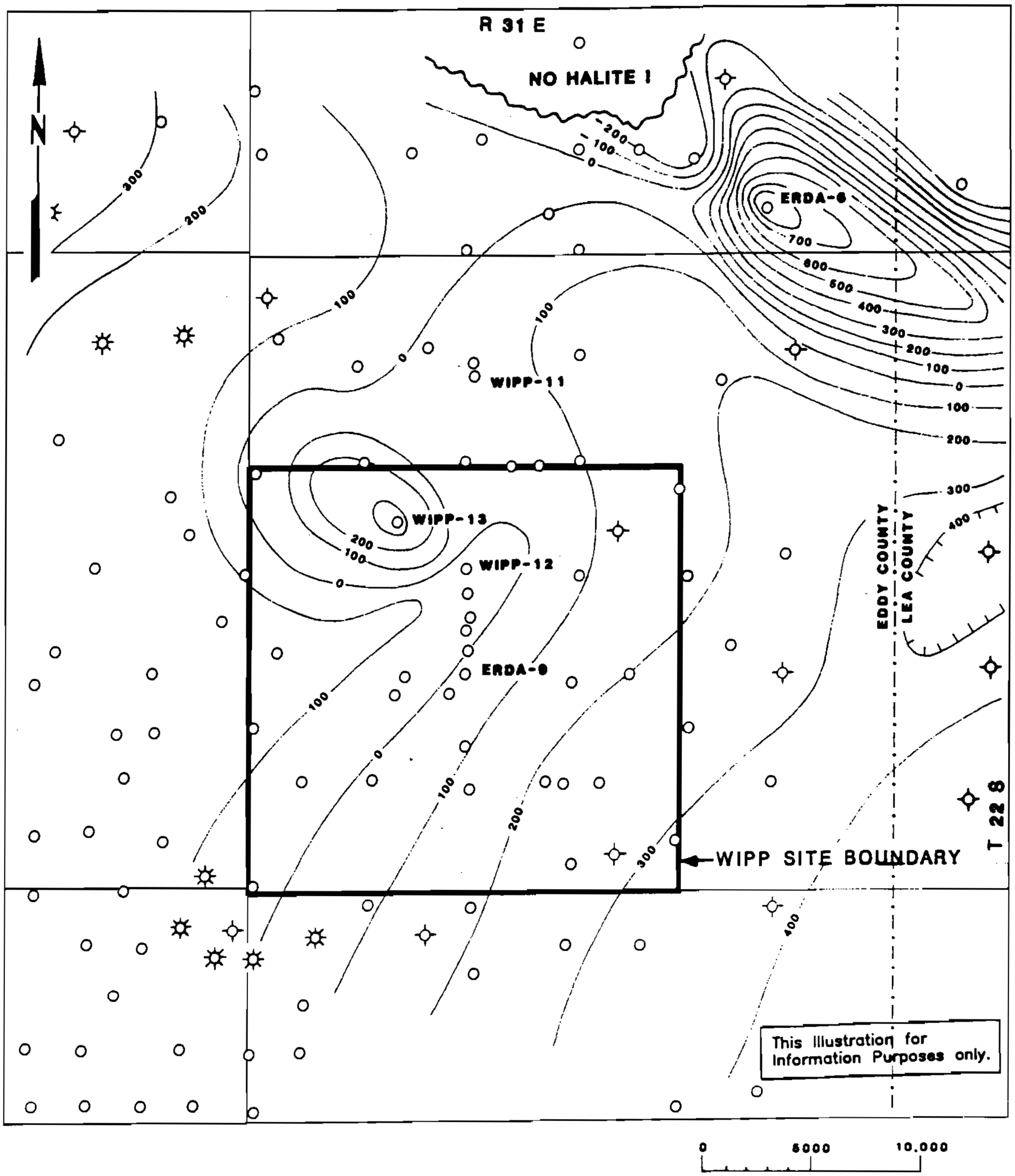
FIGURE 2.7- 22
Isopach Map, Halite Unit HI, Castile Formation



REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-7

FIGURE 2.7-23
Structure Contour Map, Top of Anhydrite Unit AI, Castile Formation



LEGEND

DRILL HOLE ○

DRY HOLE

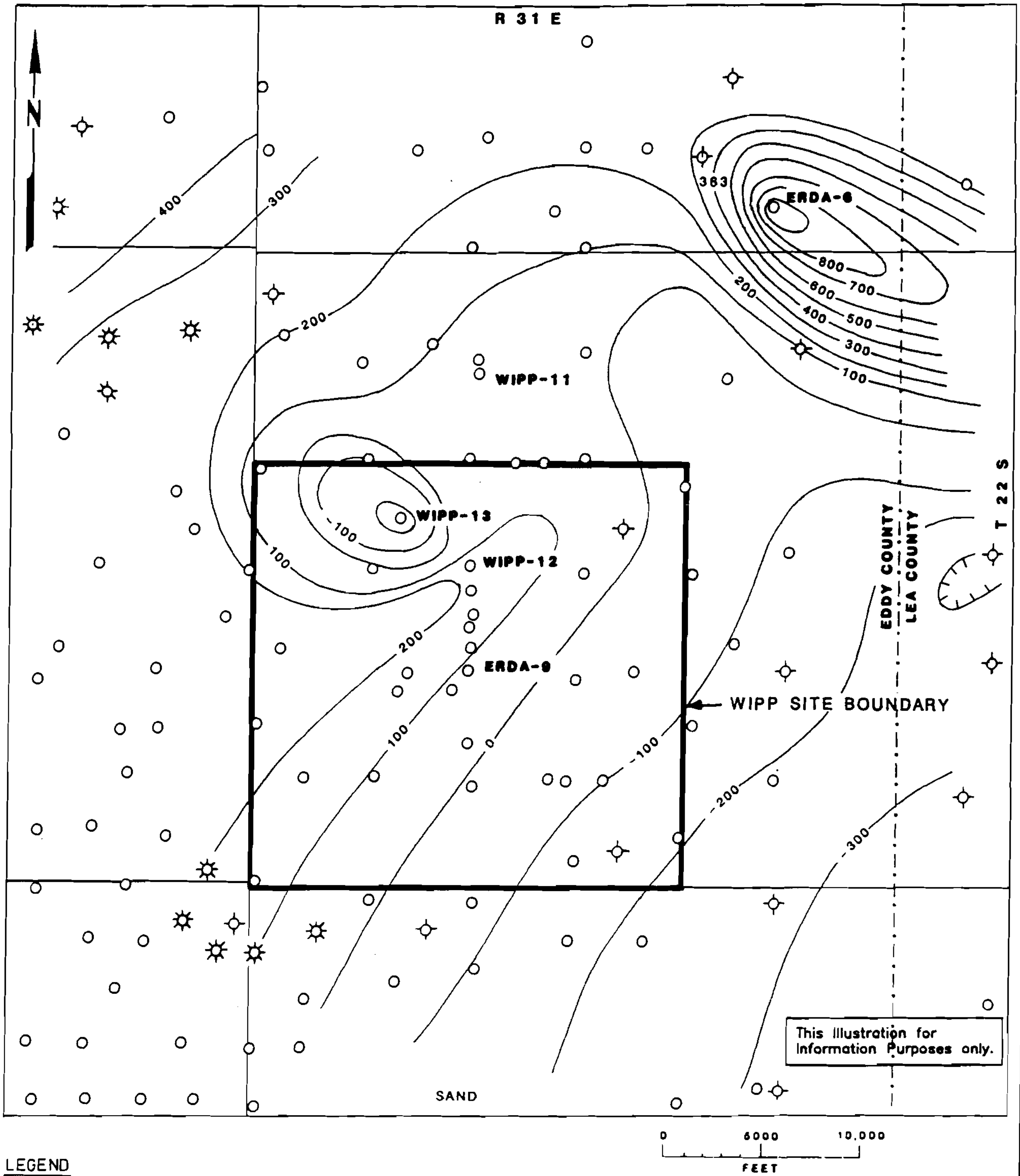
PRODUCING GAS WELL

(Contour Interval, 100 ft. Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-8

FIGURE 2.7-24
Structure Contour Map, Top of Halite Unit HI, Castile Formation



LEGEND

DRILL HOLE ○

DRY HOLE

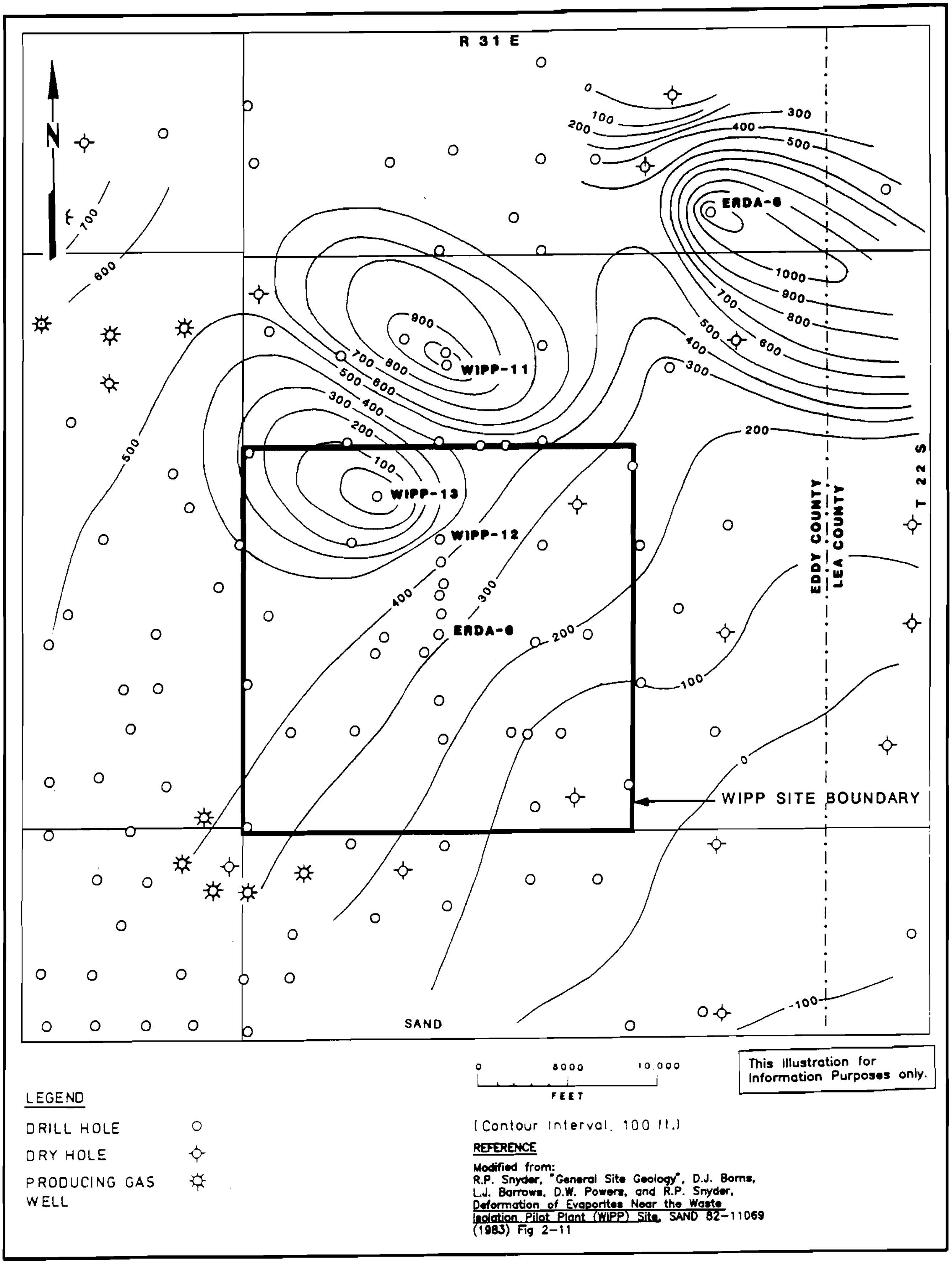
PRODUCING GAS WELL

(Contour Interval, 100 ft. Hachures Indicate Closed Low)

REFERENCE

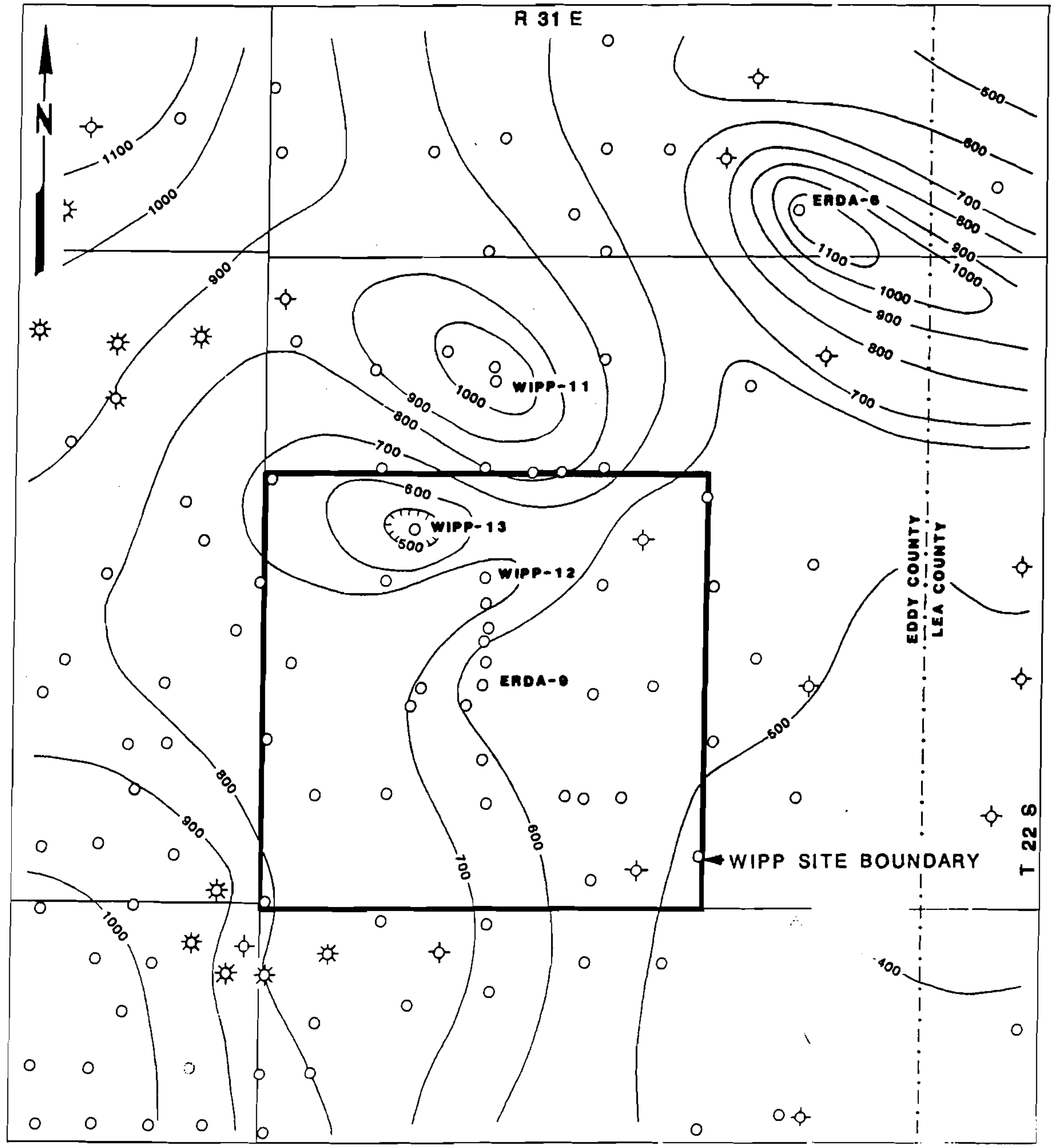
Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-10

FIGURE 2.7-25
Structure Contour Map, Top of Anhydrite Unit, AII, Castile Formation



REFERENCE
Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-11

FIGURE 2.7-26
Structure Contour Map, Top of Halite Unit HII, Castile Formation



LEGEND

DRILL HOLE ○

DRY HOLE

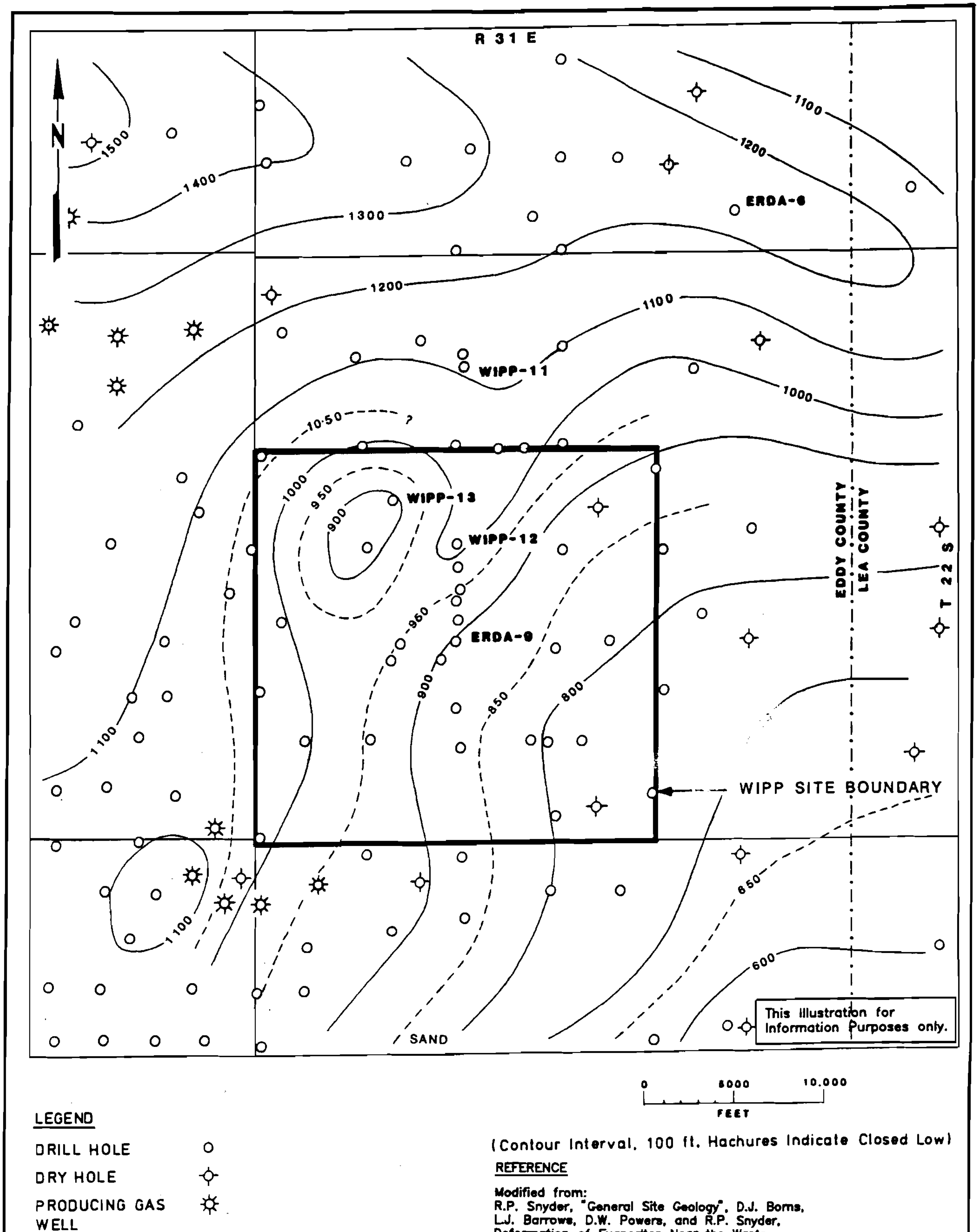
PRODUCING GAS WELL

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-13

This Illustration for Information Purposes only.

FIGURE 2.7-27
Structure Contour Map, Anhydrite Unit AIII, Top of Castile Formation

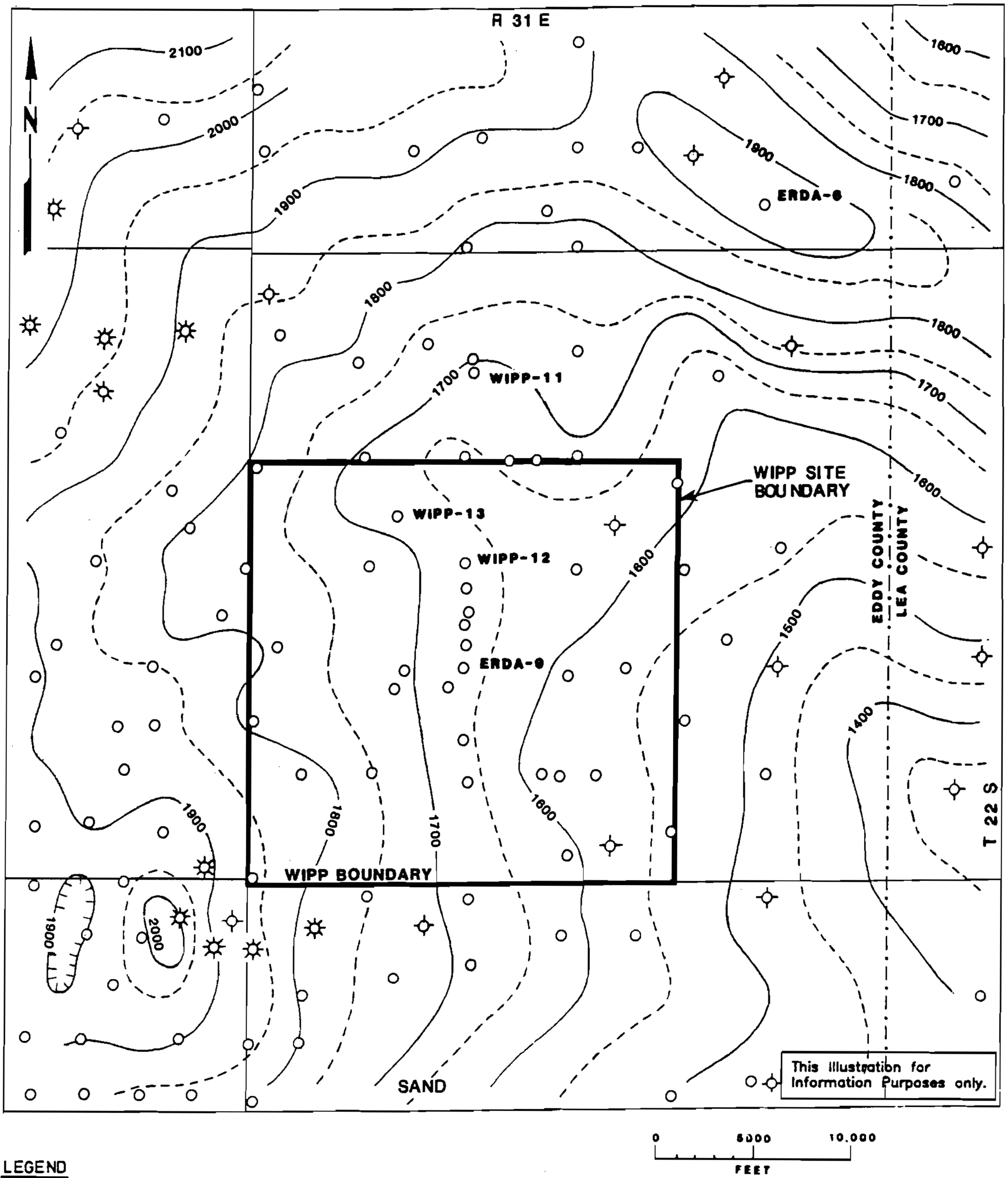


(Contour Interval, 100 ft. Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-15

FIGURE 2.7-28
Structure Contour Map,
Base of Cowden Anhydrite Member,
Salado Formation



LEGEND

DRILL HOLE ○

DRY HOLE

PRODUCING GAS WELL

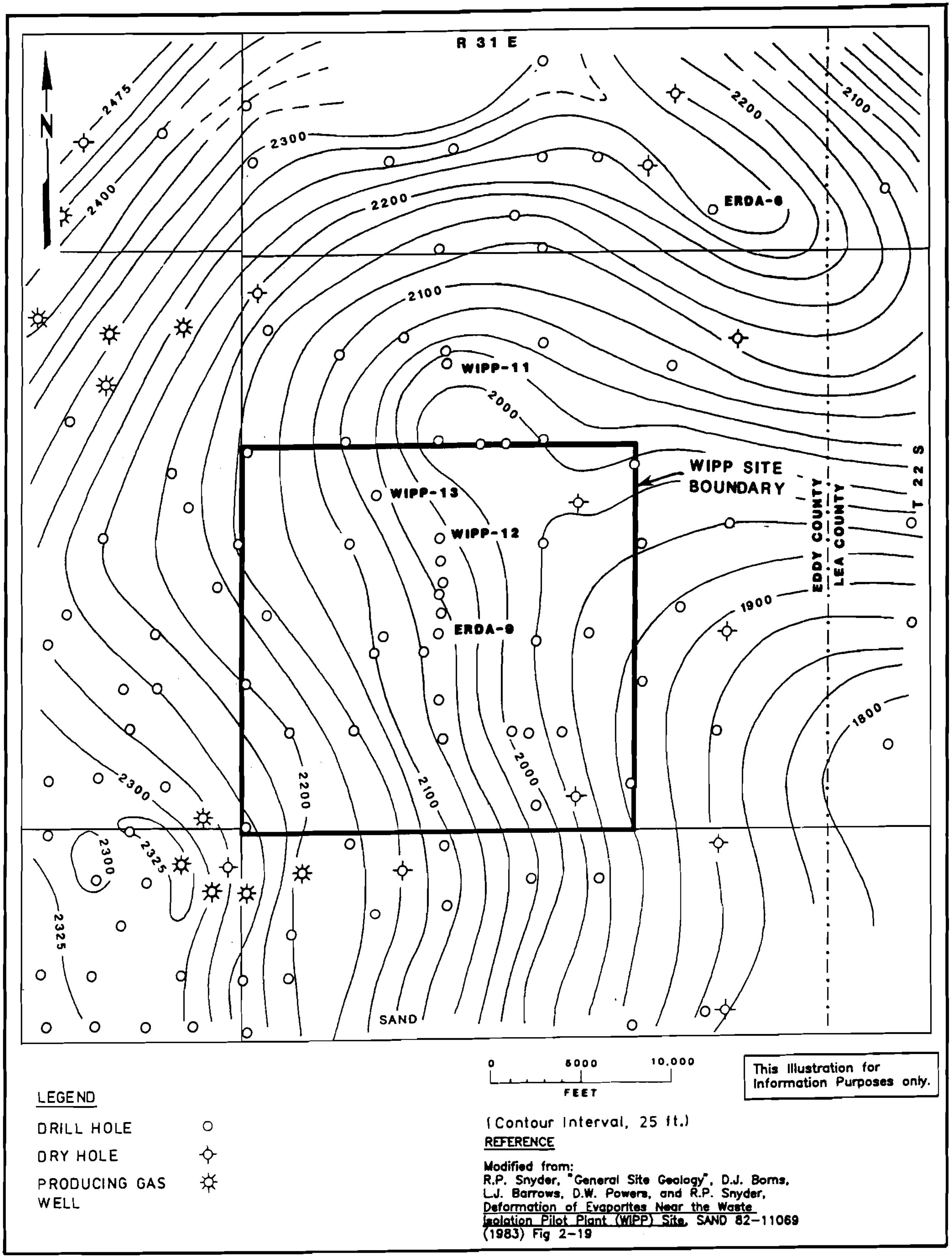
(Contour Interval, 50 ft. Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-17

FIGURE 2.7-29
Structure Contour Map,
Top of Lower Unnamed Unit, Salado Formation

WIPP FSAR



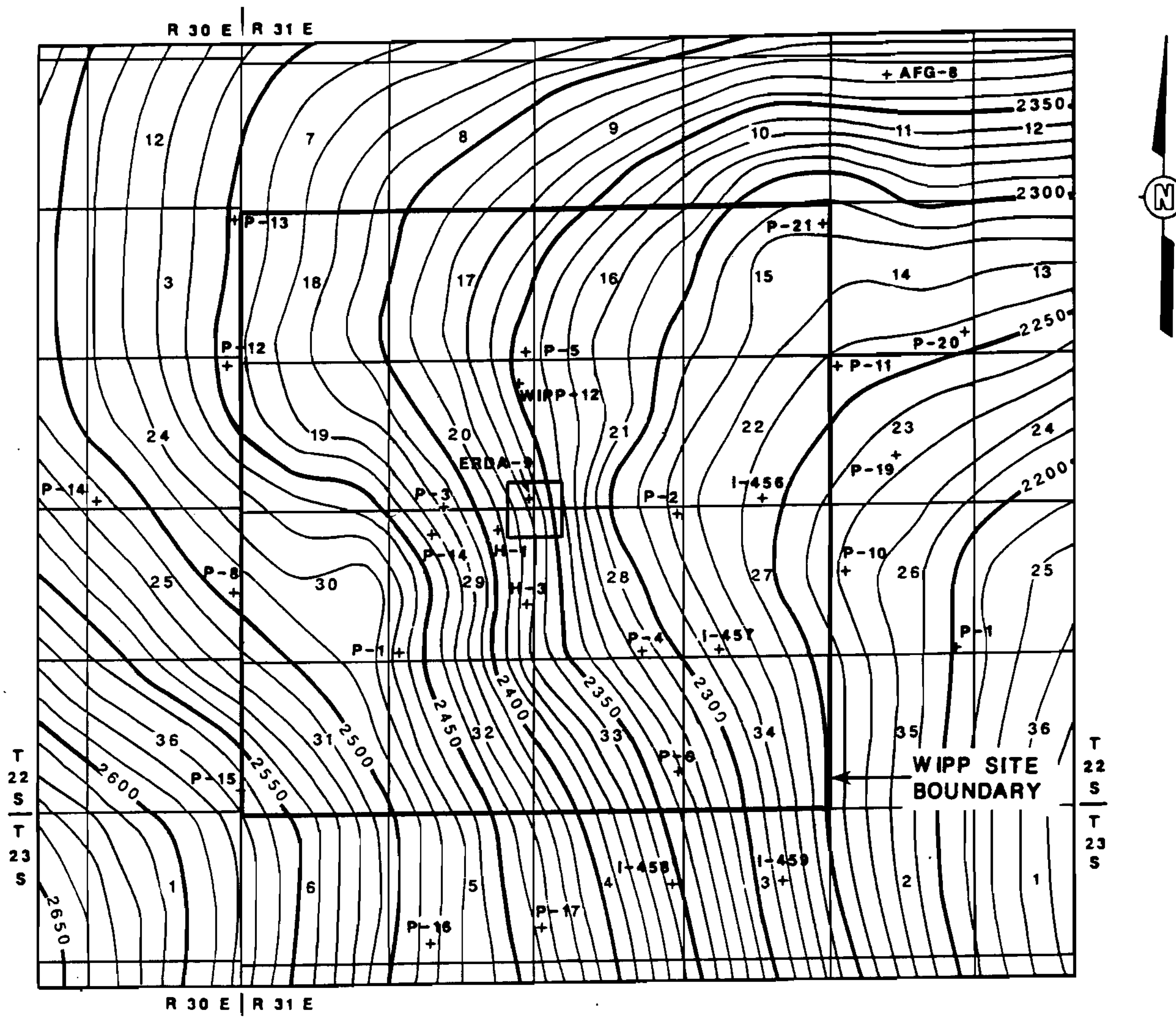
This Illustration for Information Purposes only.

(Contour Interval, 25 ft.)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-19

FIGURE 2.7-30
Structure Contour Map, Top of McNutt Potash Zone, Salado Formation



NOTES

1. Contour interval, 10 feet
2. Datum base is mean sea level
3. Contours based on data from geophysical logs of WIPP and industry potash exploration holes

SCALE: 0 1 2 3 4 KM; 0 1 2 3 MI

REFERENCE

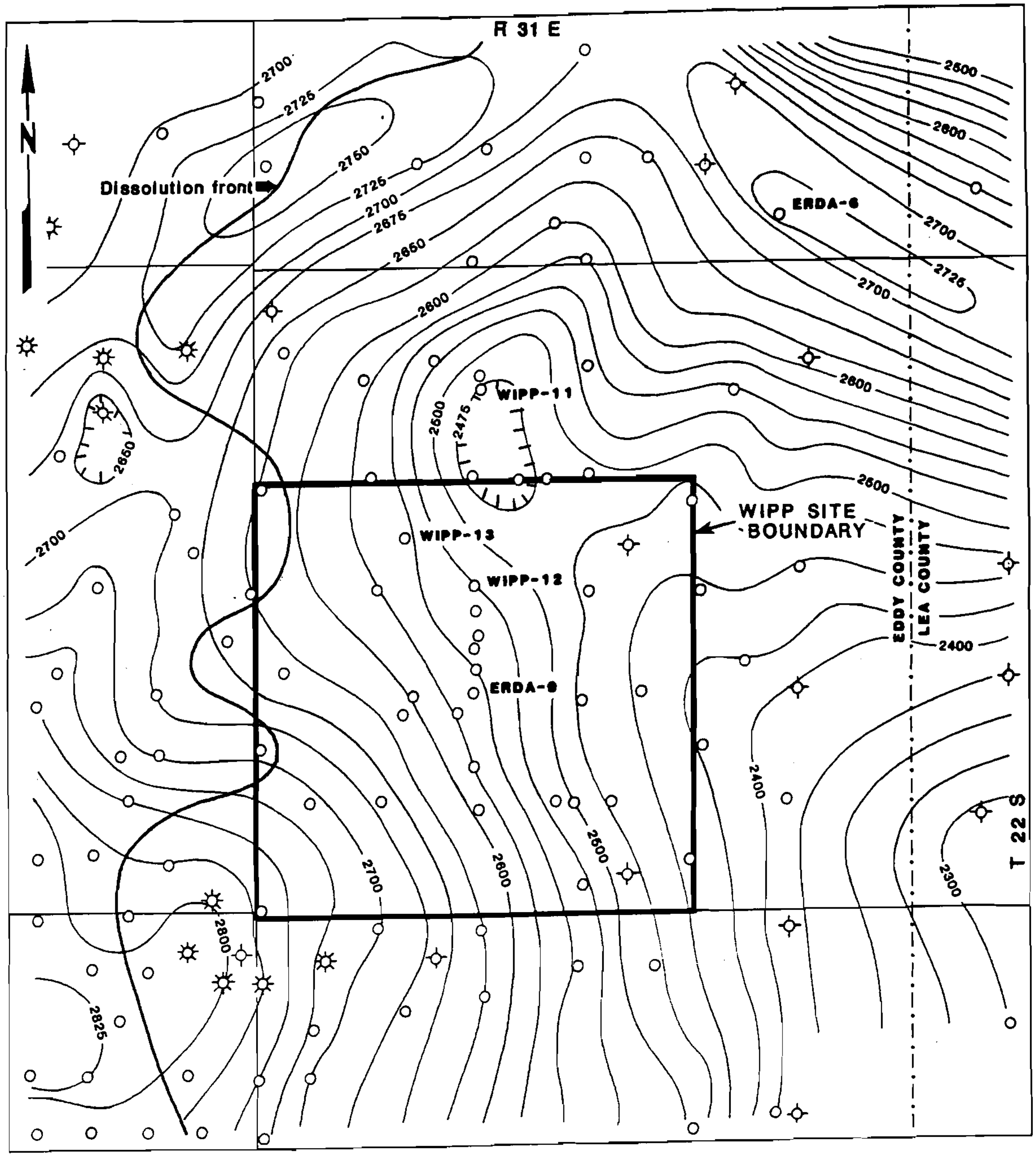
Modified from:

Griswold, G.B., Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Las Medaños, Eddy County, N.M., SAND 77–0946 Fig 9

This illustration for Information Purposes only.

FIGURE 2.7–31
Structure Contours on Base of MB 103

WIPP FSAR



LEGEND

DRILL HOLE ○

DRY HOLE

PRODUCING GAS WELL

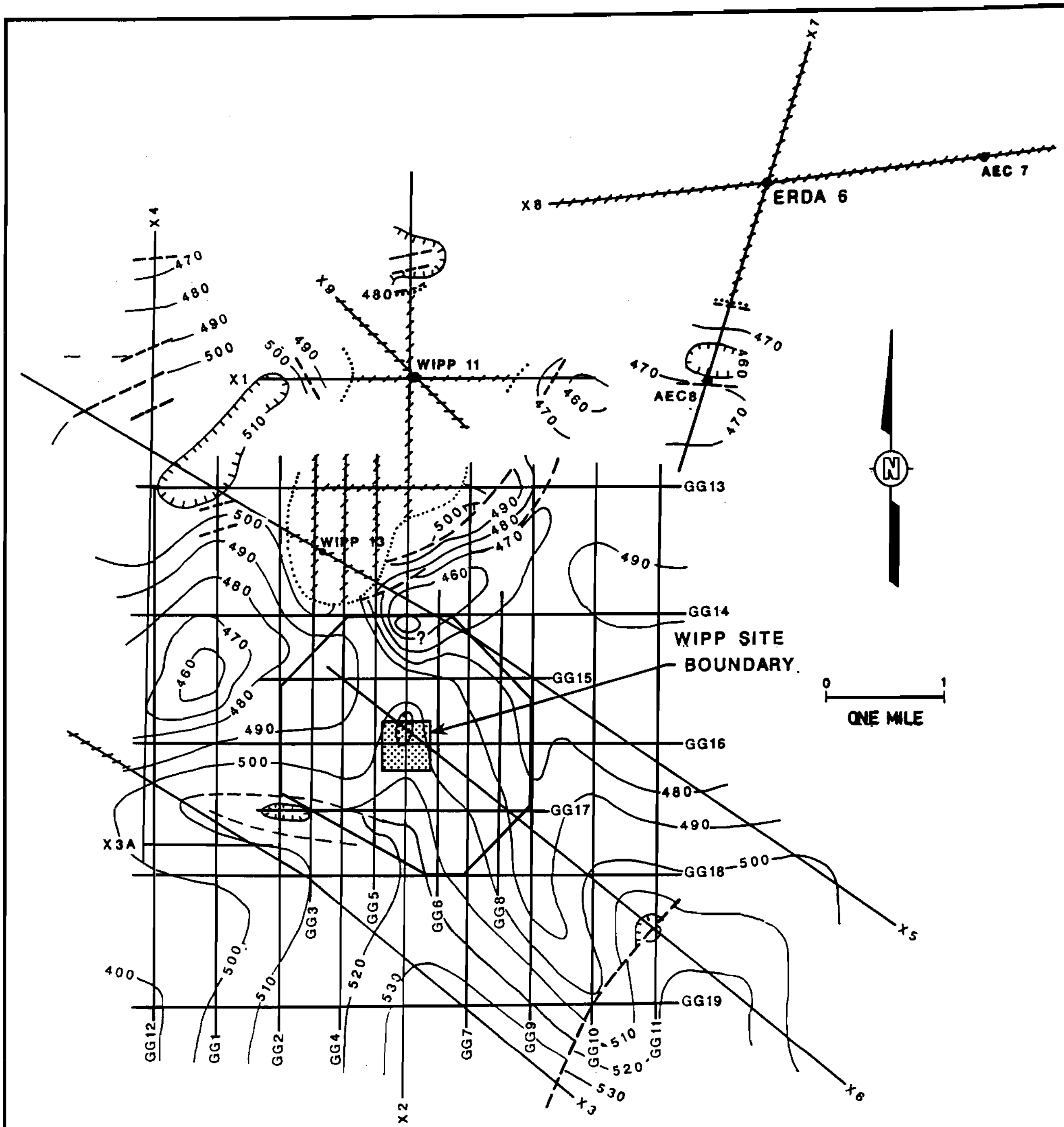
(Contour Interval, 25 ft, Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-21

This illustration for Information Purposes only.

FIGURE 2.7-32
Structure Contour Map,
Top of Salado Formation



LEGEND

Milliseconds Two-Way Time	420
Seismic Line (Crossed Where Ambiguous)	GG17
Area of Complex Structure	
Fault	
Borehole to Horizon	WIPP13

This Illustration for Information Purposes only.

NOTES

Contour Interval: 10 Milliseconds

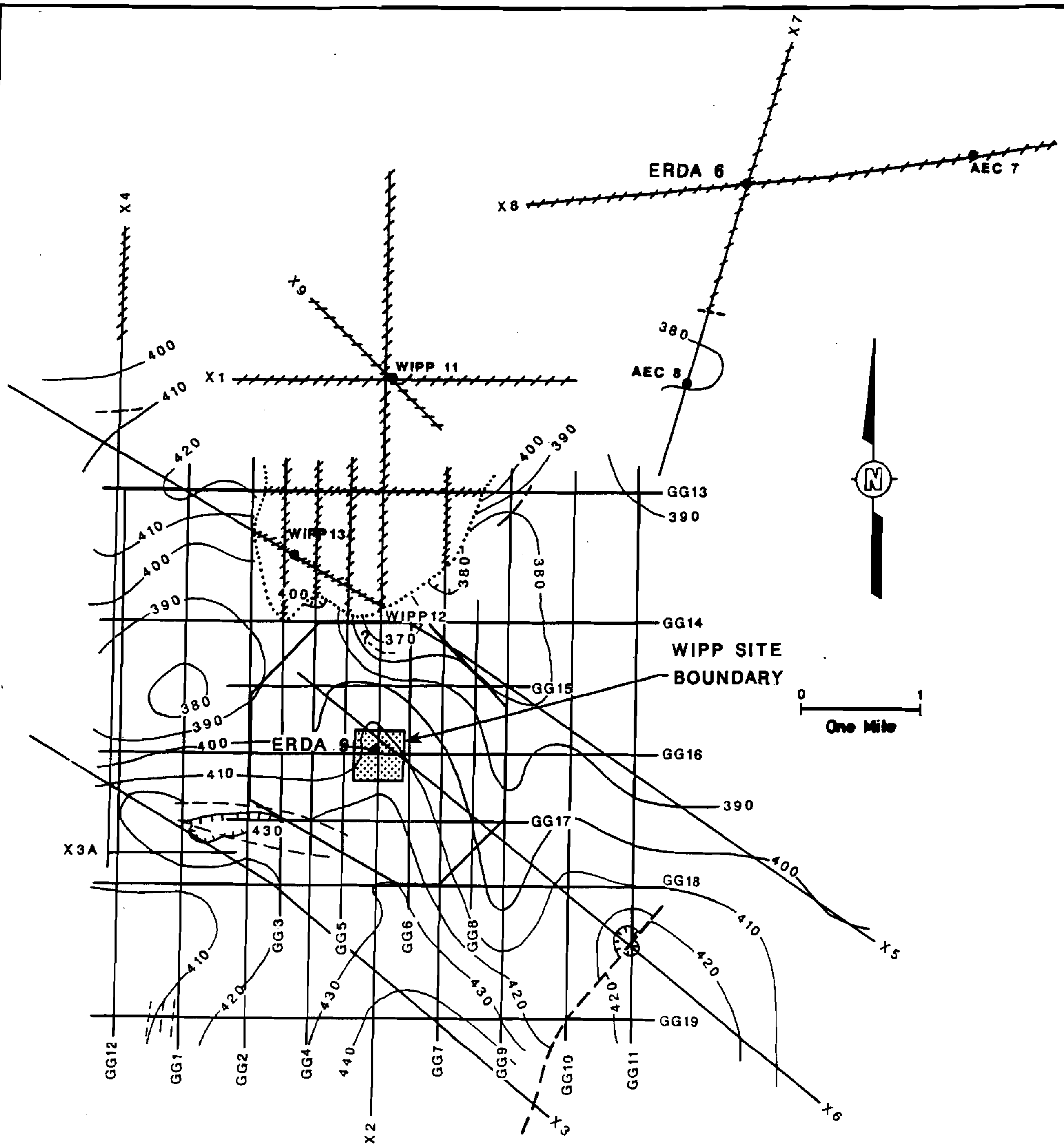
Datum: 3356 Ft. a.o.l.

Prepared by Larry Barrows, Nov. 1986
Rev. Feb. 1981

REFERENCE

Modified from:
D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig A-3

FIGURE 2.7-33
Seismic Time Structure
Mid-Castile Formation



LEGEND

Milliseconds Two-Way Time	420
Seismic Line (Crossed Where Ambiguous)	GG17
Area of Complex Structure	
Fault	
Borehole to Horizon	WIPP13

NOTES

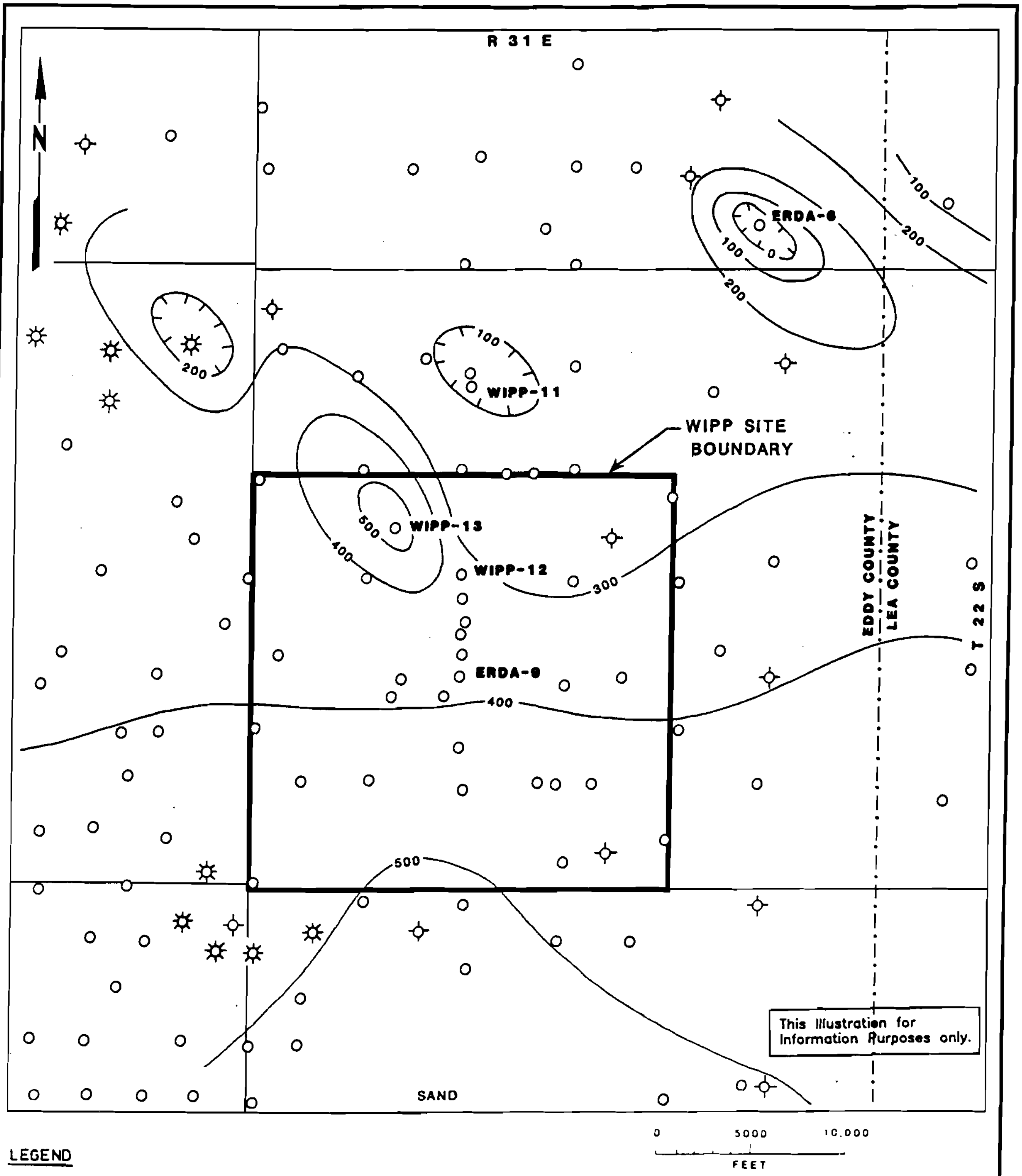
Contour Interval : 10 Milliseconds
Datum: 3356 Ft. a.o.l.
Prepared By Larry Barrows, Nov. 1986
Rev. Feb. 1981

This Illustration for Information Purposes only.

REFERENCE

Modified from:
D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig A-2

FIGURE 2.7-34
Seismic Time Structure-Top of Castile Formation



LEGEND

DRILL HOLE ○

DRY HOLE

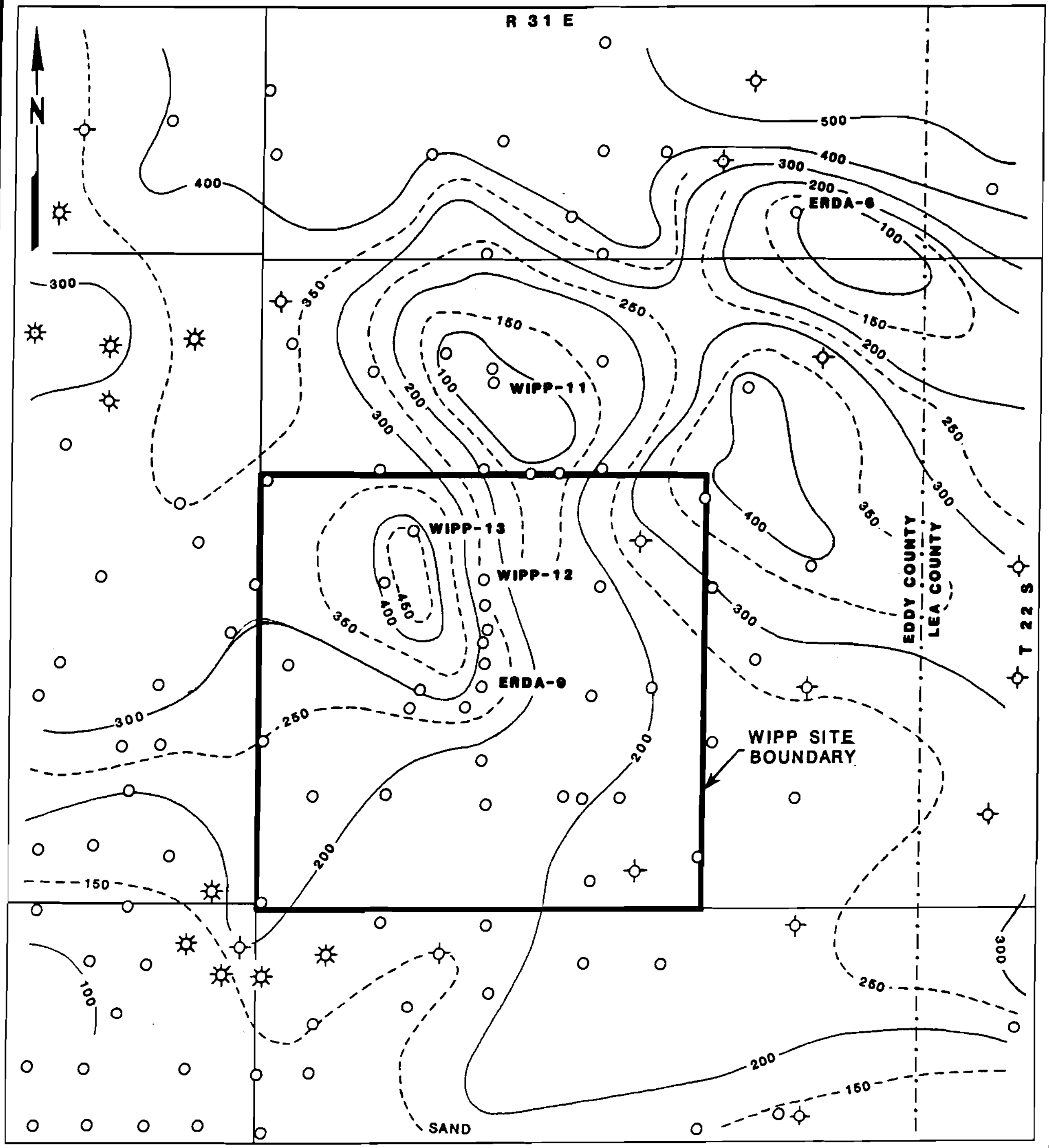
PRODUCING GAS WELL

(Contour Interval, 100 ft. Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-14

FIGURE 2.7-35
Isopach Map, Anhydrite Unit AIII, Castile Formation



0 5000 10,000
FEET

This illustration for Information Purposes only.

LEGEND

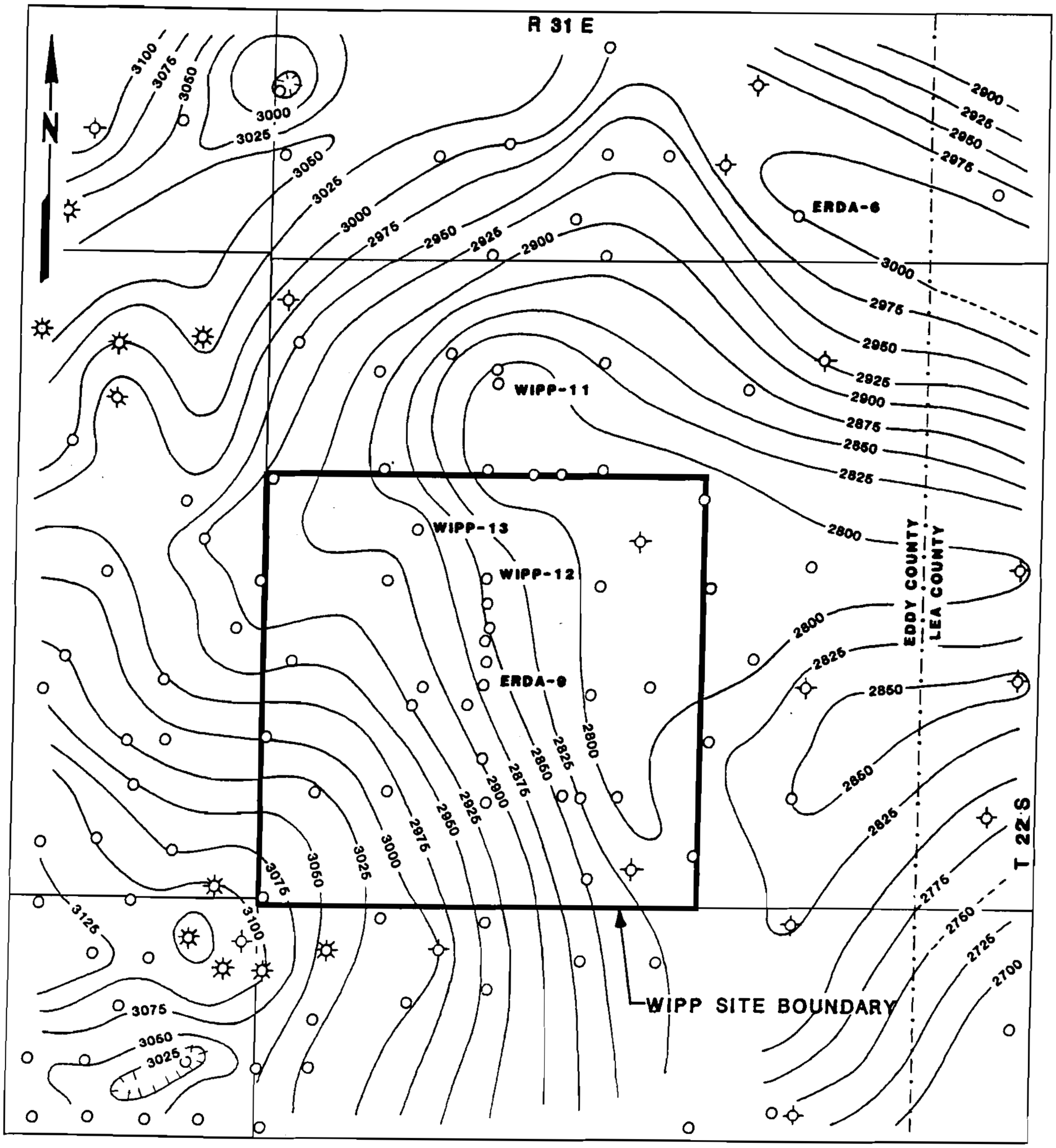
- DRILL HOLE ○
- DRY HOLE
- PRODUCING GAS WELL

(Contour Interval, 100 ft.)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-16

FIGURE 2.7-36
Isopach Map, Base of Cowden Anhydrite Member to Top of Castile Formation



LEGEND

DRILL HOLE

DRY HOLE

PRODUCING GAS WELL

(Contour Interval, 25 ft. Hachures Indicate Closed Low)

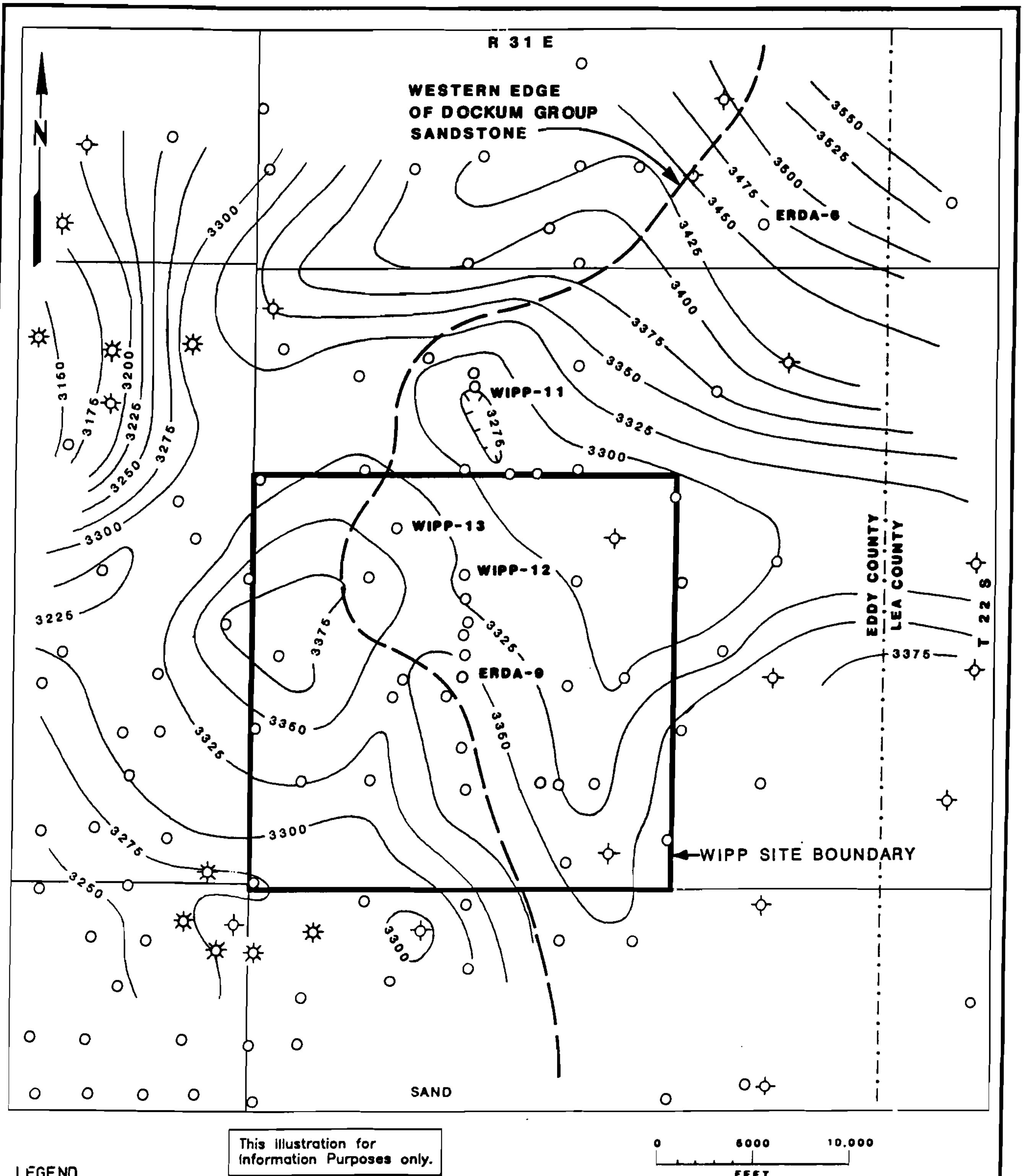
REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-24

This Illustration for Information Purposes only.

FIGURE 2.7- 37
Structure Contour Map,
Top of Rustler Formation

GG136..2



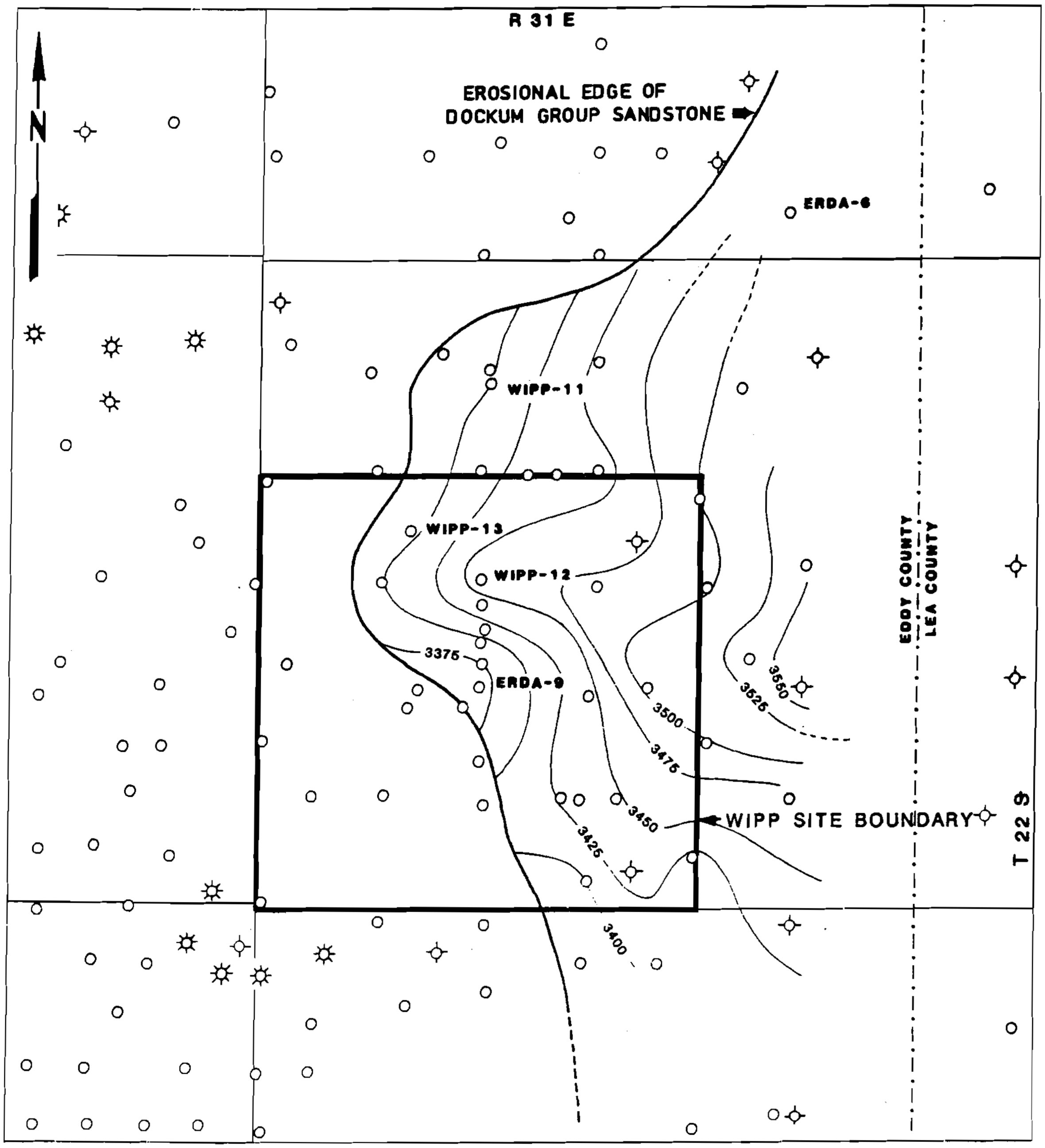
(Contour Interval. 25 ft. Hachures Indicate Closed Low)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-26

FIGURE 2.7-38
Structure Contour Map,
Top of Dewey Lake Redbeds

GG137.2



LEGEND

DRILL HOLE ○

DRY HOLE

PRODUCING GAS WELL

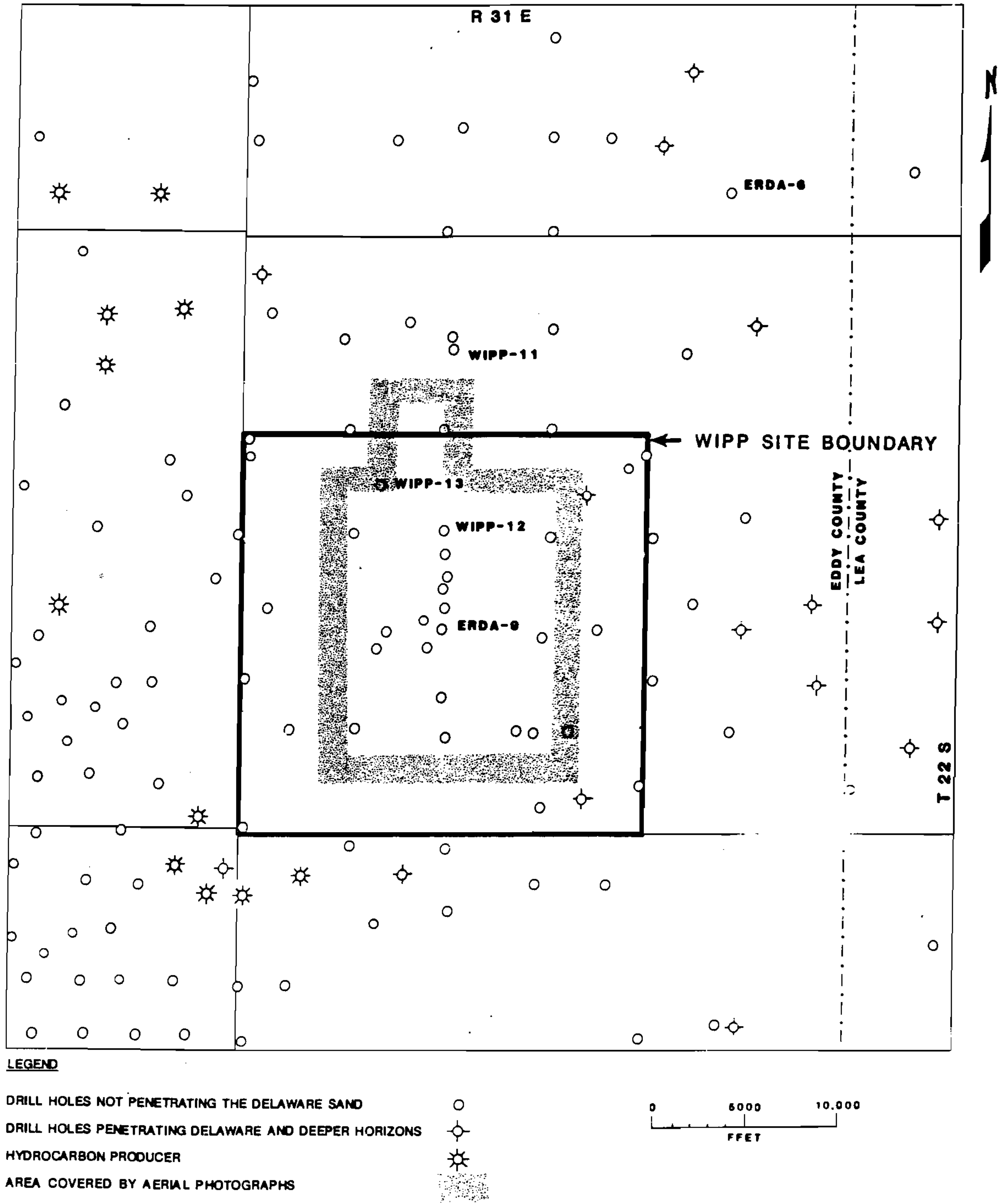
This illustration for information Purposes only.

(Contour Interval, 25 ft.)

REFERENCE

Modified from:
R.P. Snyder, "General Site Geology", D.J. Borns, L.J. Barrows, D.W. Powers, and R.P. Snyder, Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, SAND 82-11069 (1983) Fig 2-28

FIGURE 2.7-39
Structure Contour Map,
Top of Dockum Group Sandstone



REFERENCE

Modified from:

Griswold, G.B., Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Las Medaños, Eddy County, N.M., SAND 77-0946 Fig 4

Snyder, R.P., General Site Geology; Borns, D.J., Barrows, L.J., Powers, D.W., Snyder, R.P., Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site SAND 82-1069

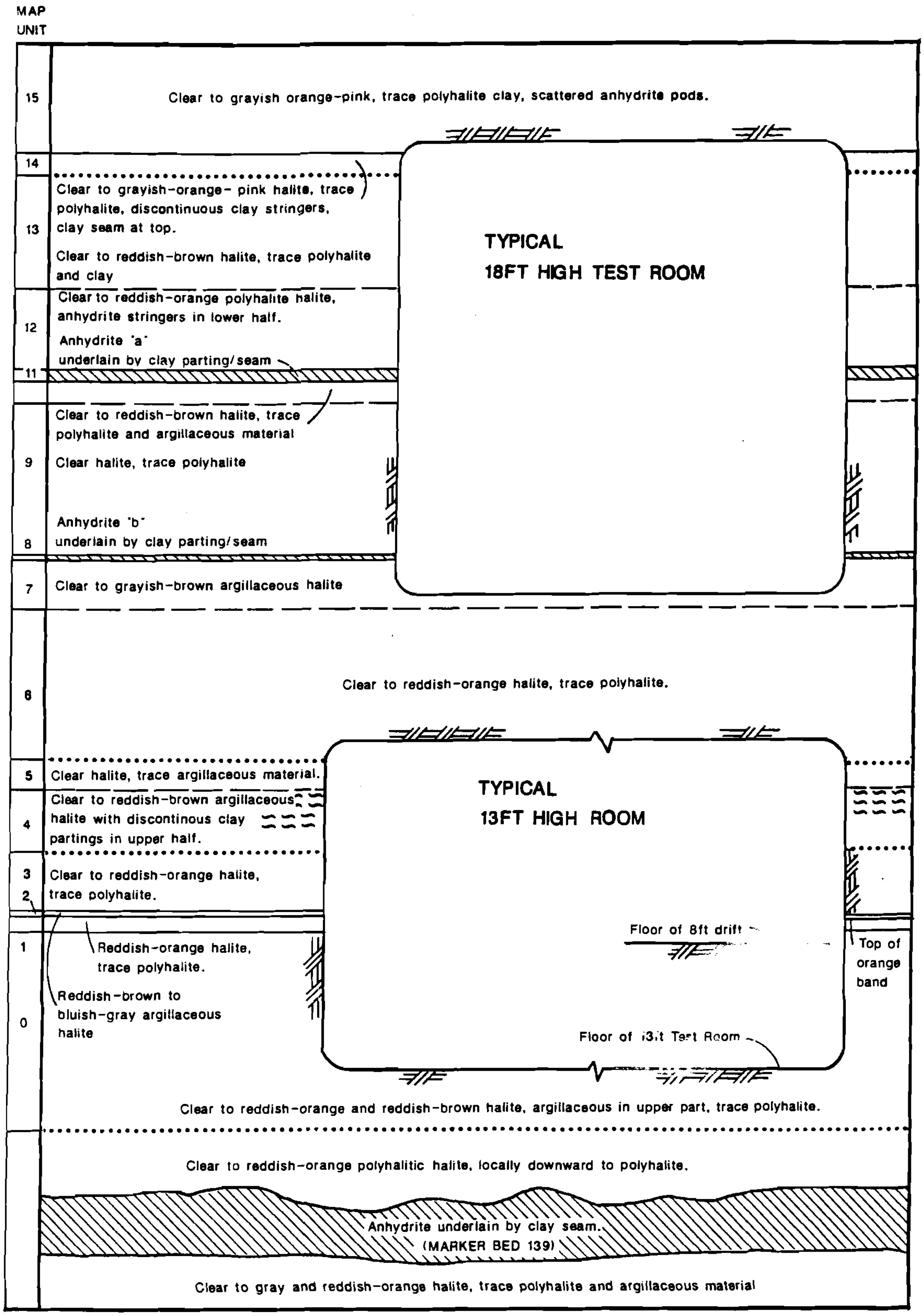
Sandia, personal communication

Note:

1. Additional drill hole data are listed in Table 2.5-2 and 2.5-3.
2. Plant site drill hole locations are shown on Figure 2.5-11.
3. Drill holes H-8, H-9, and H-10 are indicated on Figure 2.5-6.

This Illustration for Information Purposes only.

FIGURE 2.7-40
Drill Hole Locations
Showing Area of Photo Coverage



NOTE: Descriptions are based on geologic mapping of exposures in rooms and drifts throughout the facility, including the waste experimental rooms.

This Illustration for Information Purposes only.

FIGURE 2.7- 41
Generalized Geologic Cross Section of the WIPP Underground Storage and Experimental Area

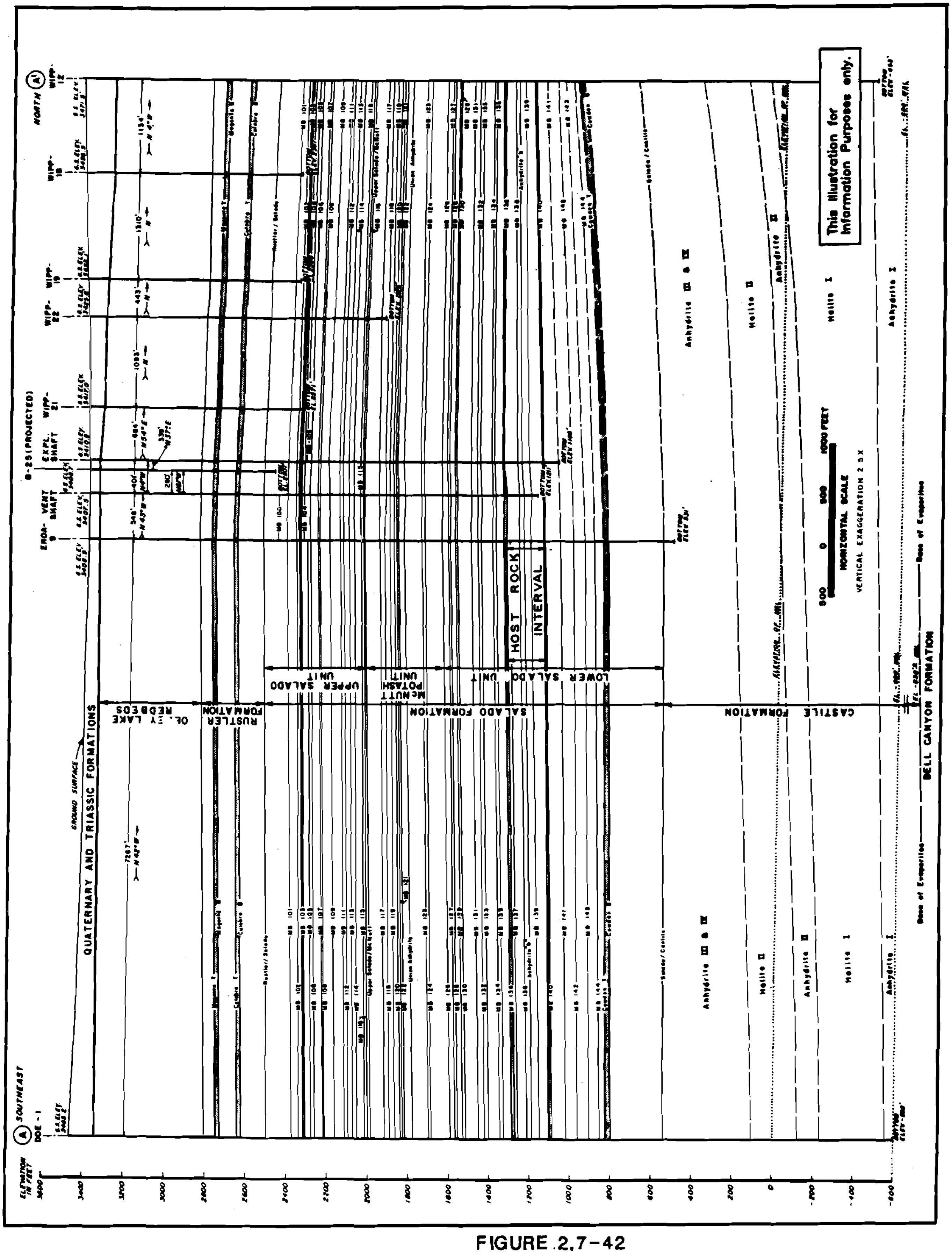
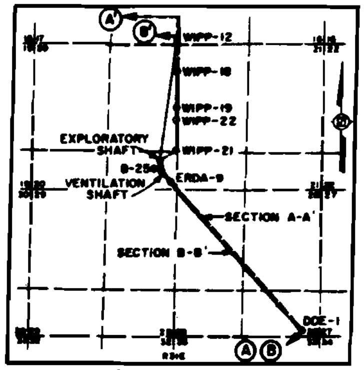


FIGURE 2.7-42
Detailed Cross Section from DOE-1 to WIPP-12



LOCATION KEY

NOTES

1. ONLY BASES SHOWN FOR THIN MARKER BEDS.
2. SELECTED INTERVALS SHADED FOR CLARITY.
3. DASHED LINES INDICATE POSSIBLE CONTACTS.

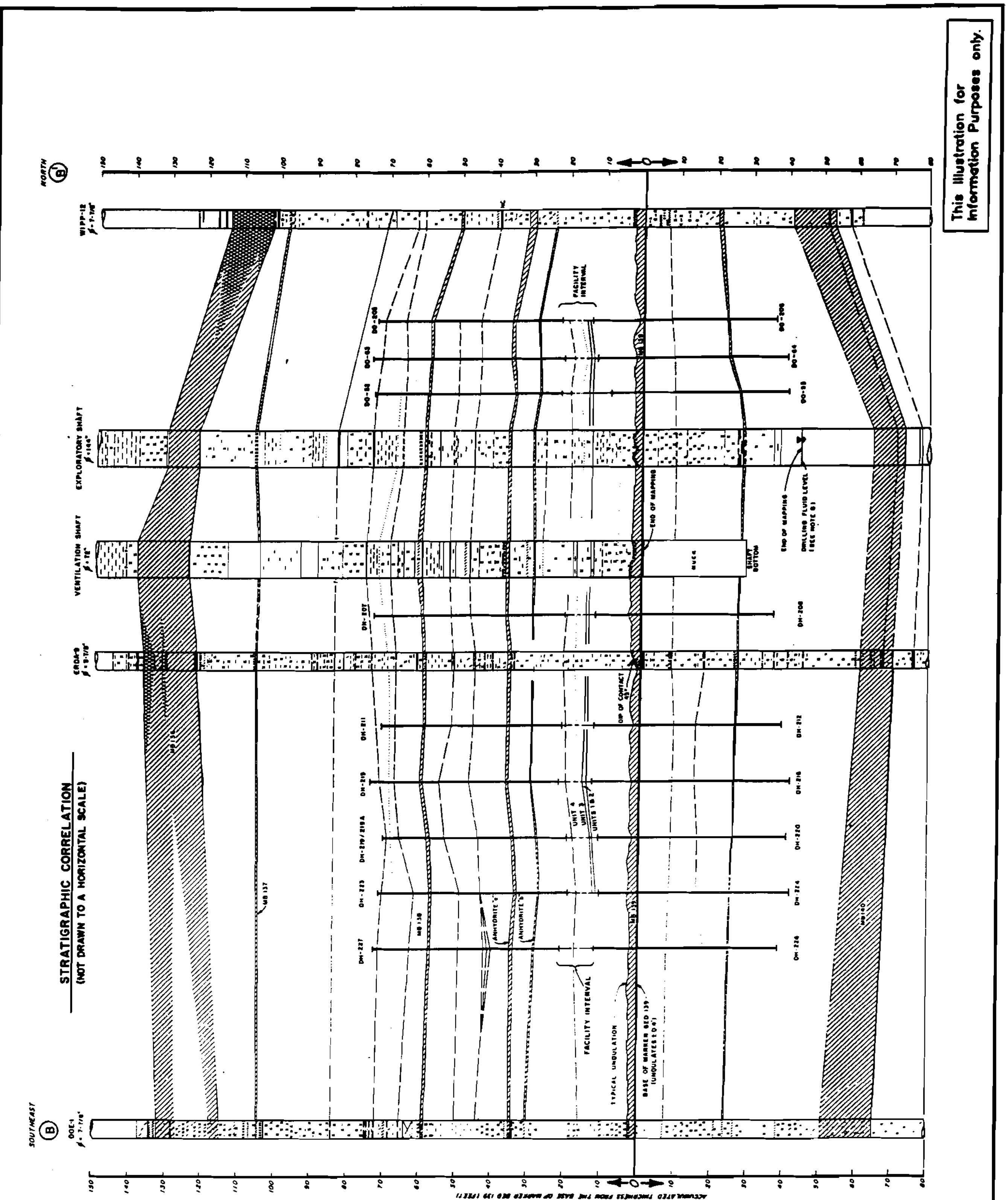
REFERENCE

Modified from:

Jarolimek, et al., Correlation of Drill Holes and Shaft Logs, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, TME 3179, DTD March 1983, Fig 2

This illustration for Information Purposes only.

Explanation to Figure 2.7-42



REFERENCE

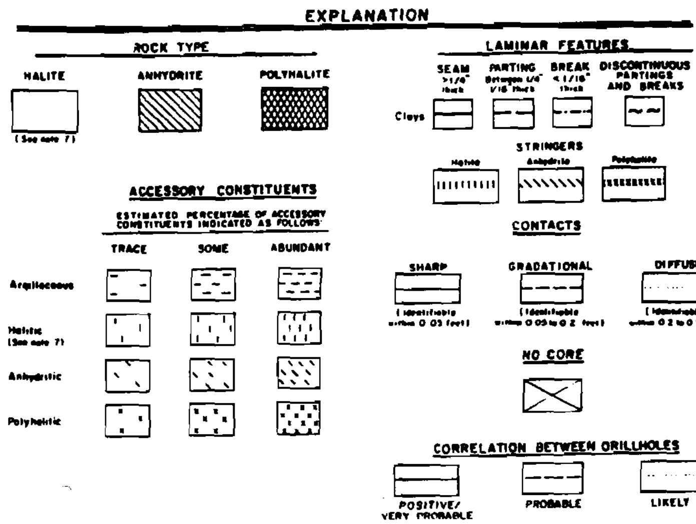
Modified from:

Jarolimek, et al., Correlation of Drill Holes and Shaft Logs, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, TME 3179, DTD March 1983, Fig 4

FIGURE 2.7-43

Detailed Cross Section of WIPP Underground Storage and Experimental Level DOE-1 to WIPP-12

GG146.1



NOTES

1. Stratigraphic section is related to the base of MB 139 which was used as a datum. Connecting lines indicate only changes in thickness of individual intervals (slopes of the lines have no other meaning).

2. Symbols in the geologic log columns graphically represent the written geologic logs.

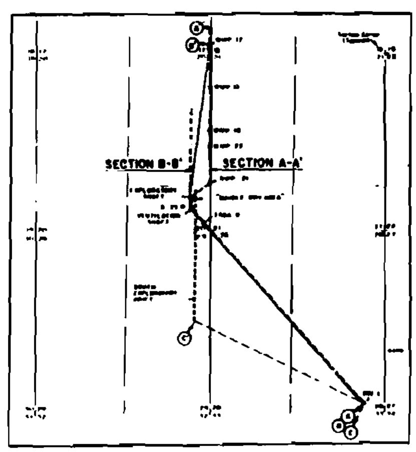
3. Indicated dips of the strata in the geologic section (2.5X vertical exaggeration) represent average apparent dips. Locally, the dips may vary depending on the undulation of individual beds.

4. Standard symbol for halite is not used in order to enhance the clarity of the log column.

REFERENCE

Modified from:

Jarolimek, et al., Correlation of Drill Holes and Shaft Logs, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, TME 3179, DTD March 1983, Fig 4



This Illustration for Information Purposes only.

Explanation to Figure 2.7-43

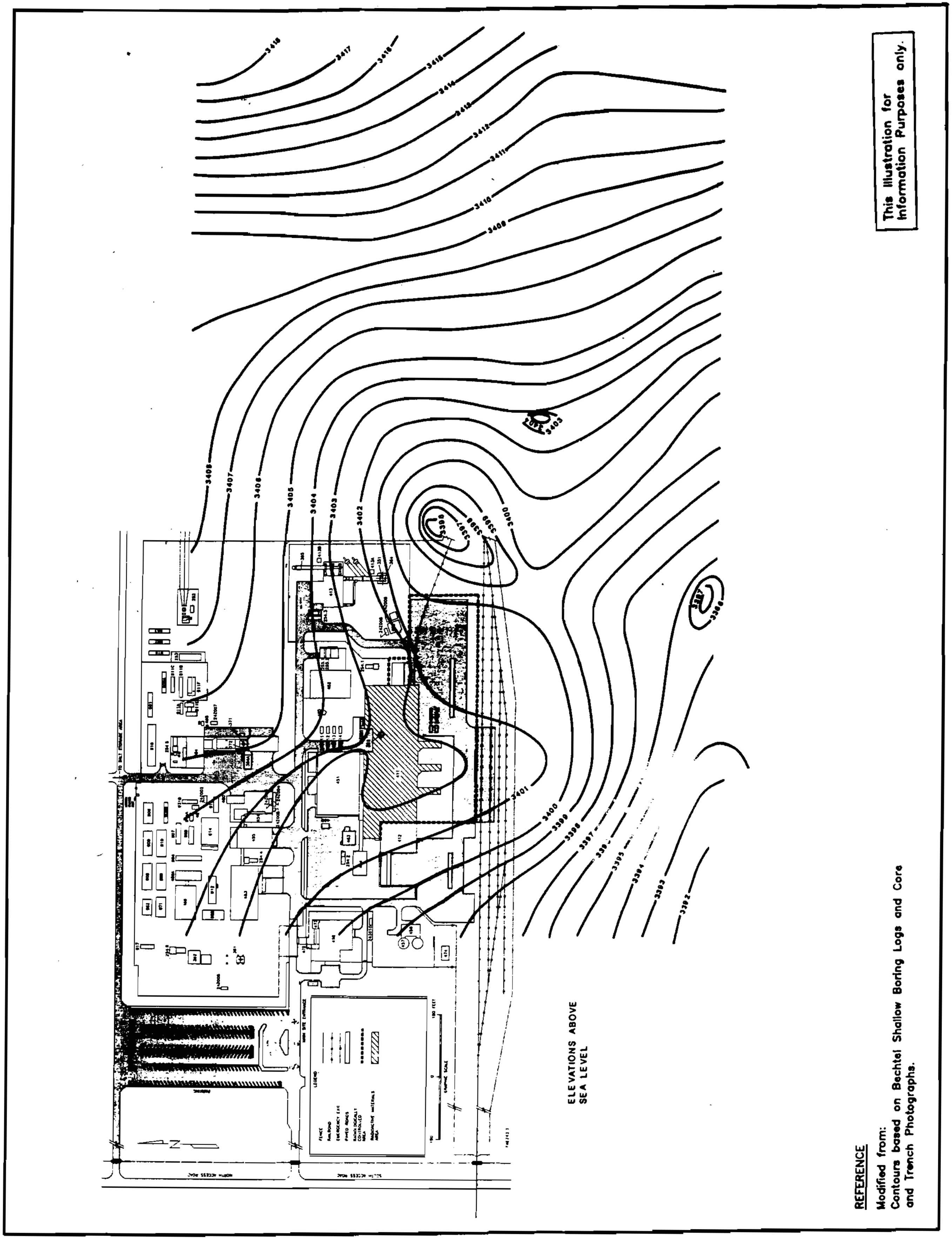
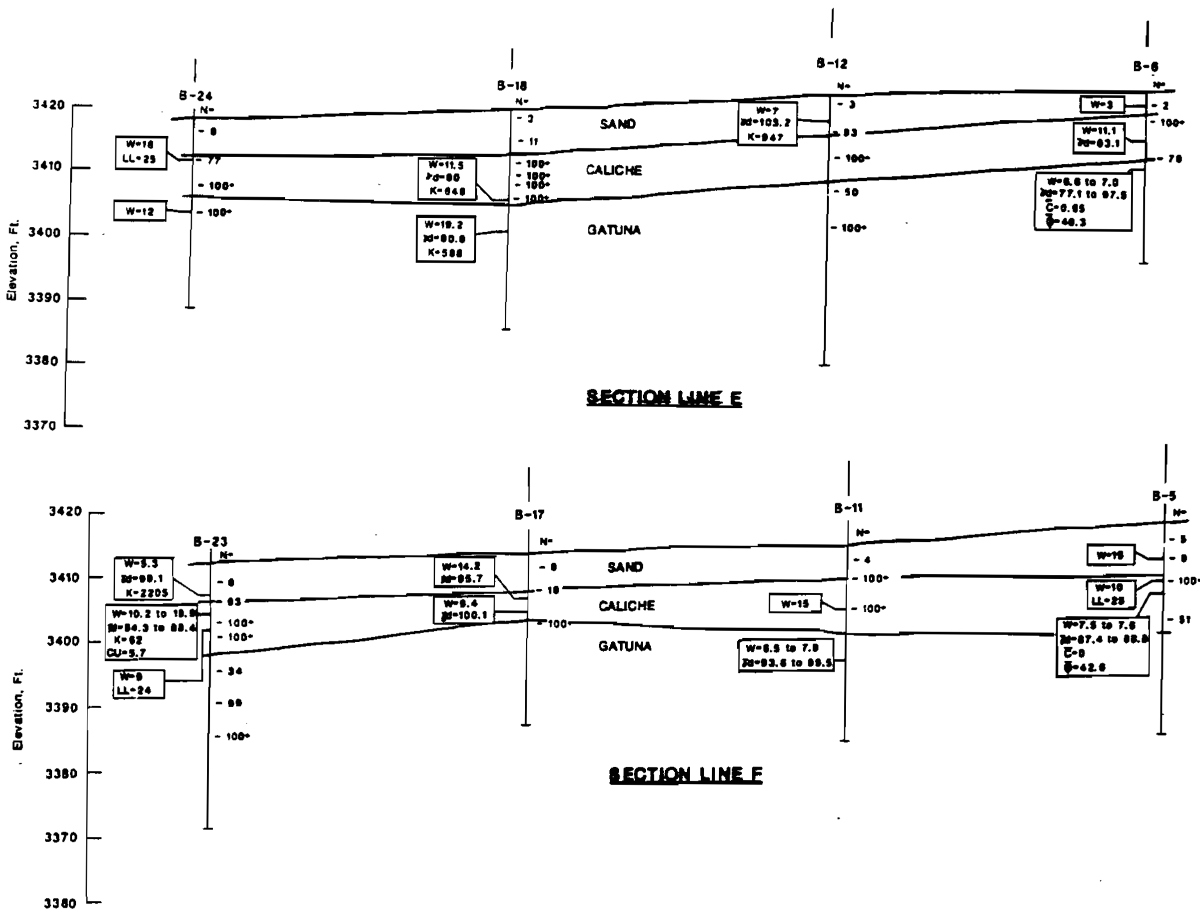
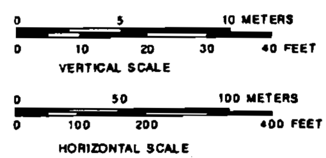


FIGURE 2.7-44
Contours on Top of Mescalero Caliche



LEGEND

- N — Standard penetration resistance in blows/ft.
- W — Natural moisture content in percent
- δd — Dry density in pounds/cu.ft.
- LL — Liquid limit
- PI — Plasticity index
- $\overline{C}$ — Cohesion in kips/sq.ft.
- $\overline{\Phi}$ — Effective angle of friction in degrees
- CU — Undrained shear strength in kips/sq.ft. (natural moisture content)
- K — Laboratory permeability in ft/yr.



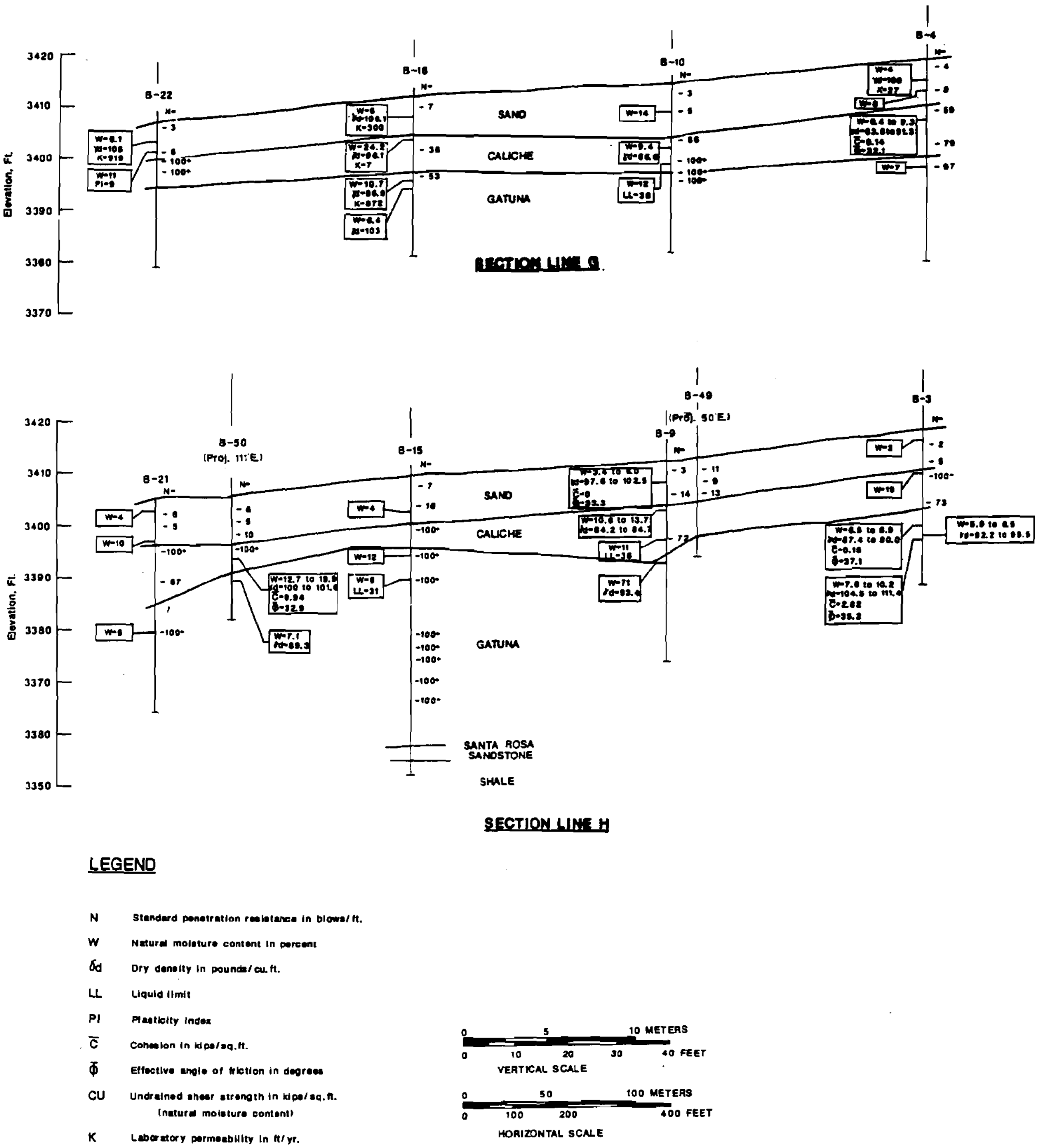
REFERENCE

Modified from:

Based on Bechtel Shallow Boring Logs and Core and Trench Photographs.

This illustration for Information Purposes only.

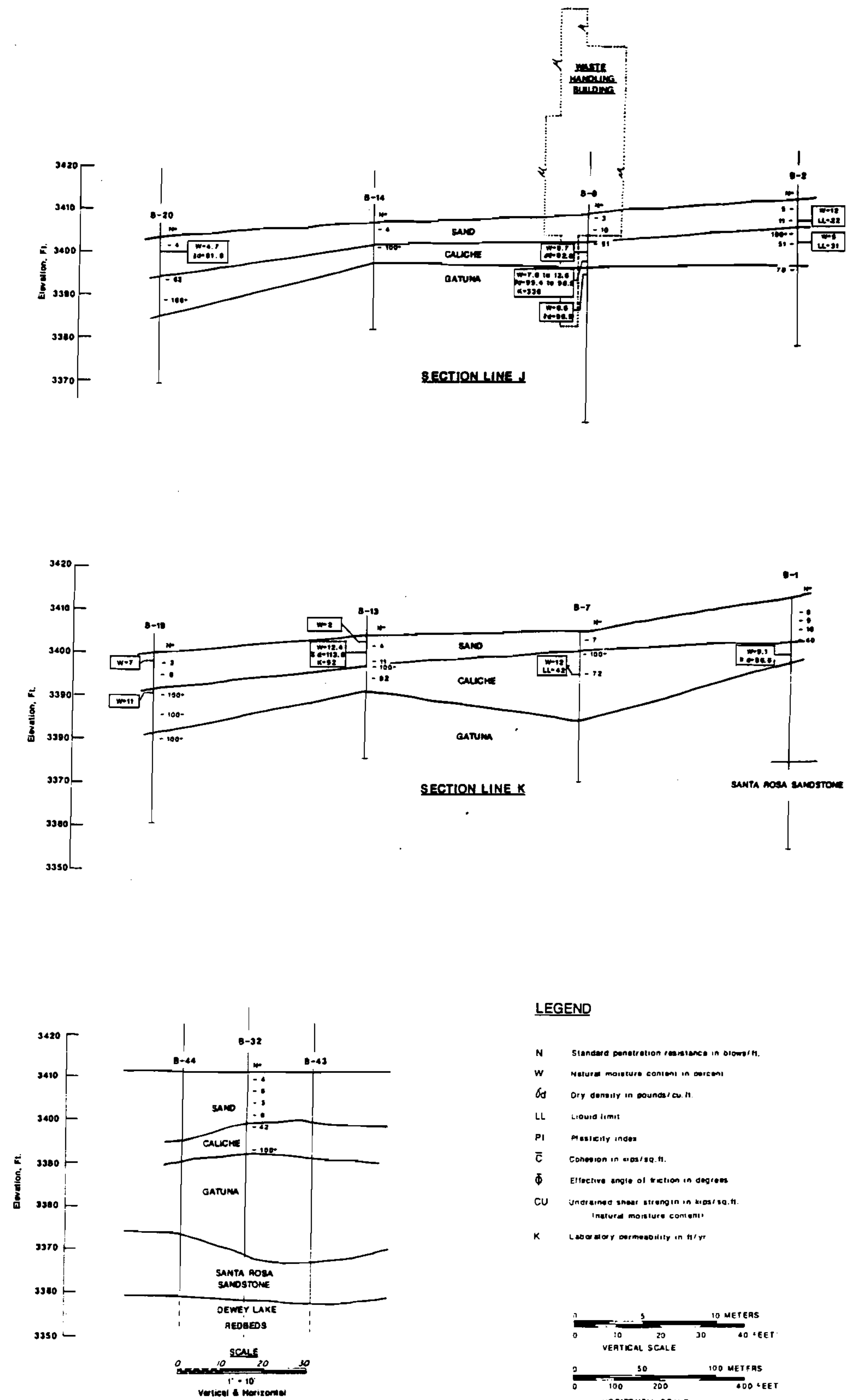
FIGURE 2.7-45a
Near Surface Soil Profiles
North - South
Page 1 of 3



Modified from:
Based on Bechtel Shallow Boring Logs and Core and Trench Photographs.

This illustration for Information Purposes only.

FIGURE 2.7-45b
Near Surface Soil Profiles
North - South
Page 2 of 3



REFERENCE

Modified from:
Based on Bechtel Shallow Boring Logs and Core and Trench Photographs.

This illustration for Information Purposes only.

FIGURE 2.7-45c
Near Surface Soil Profiles
North - South
Page 3 of 3

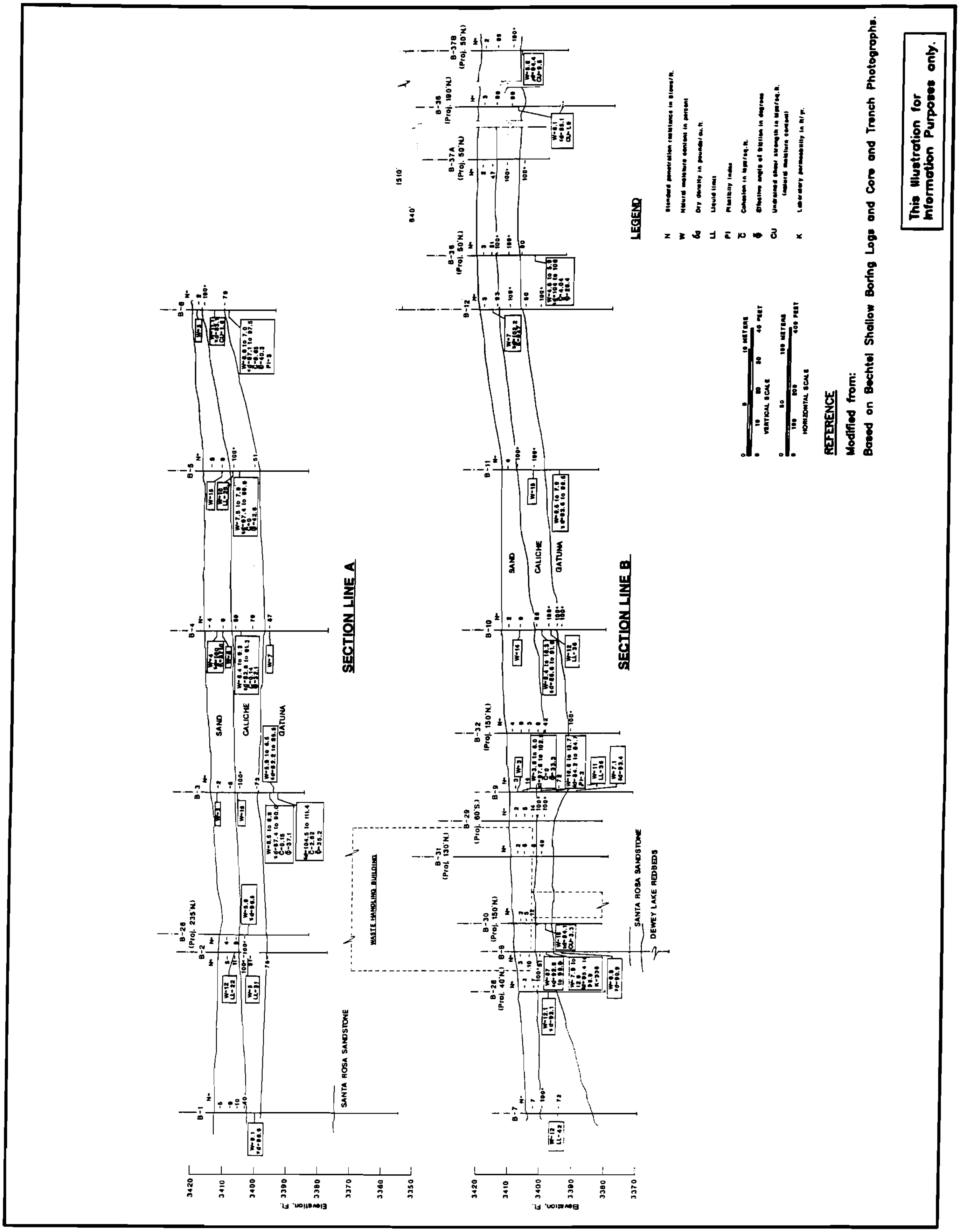


FIGURE 2.7-46a
Near Surface Soil Profiles
West-East
Page 1 of 2

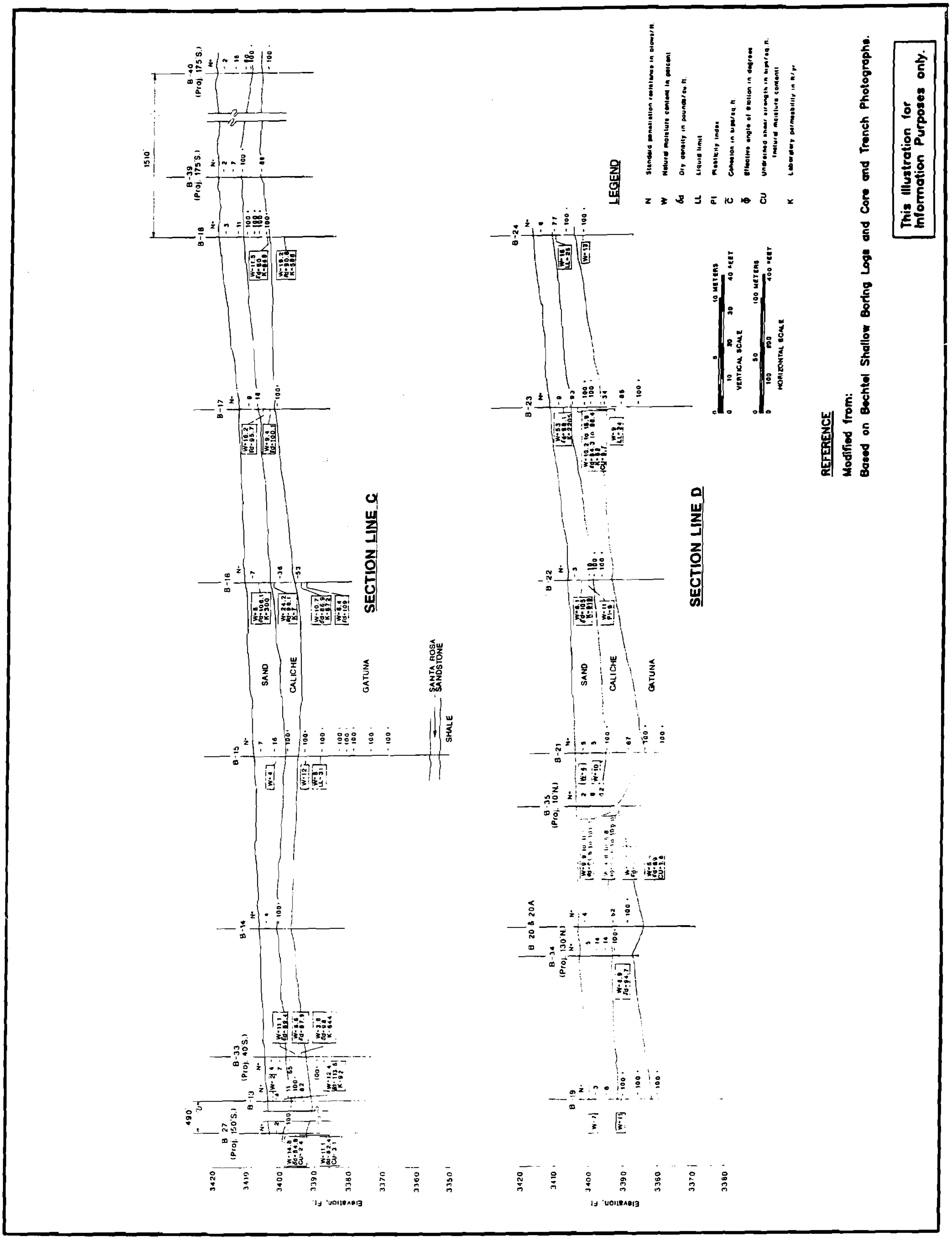
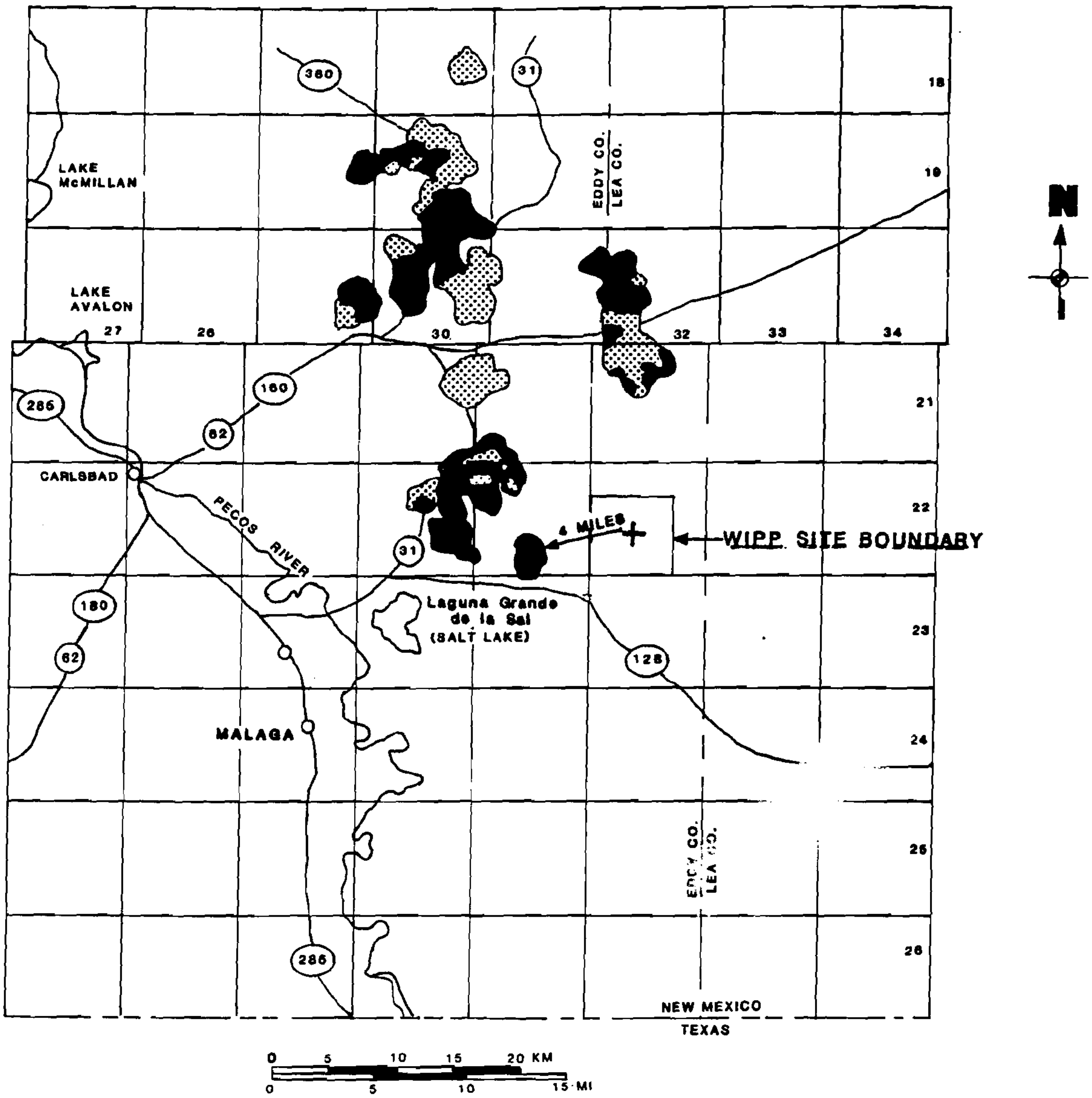


FIGURE 2.7-46b
Near Surface Soil Profiles
West-East
Page 2 of 2



LEGEND

Areas where mine subsidence effects are likely to have occurred ■

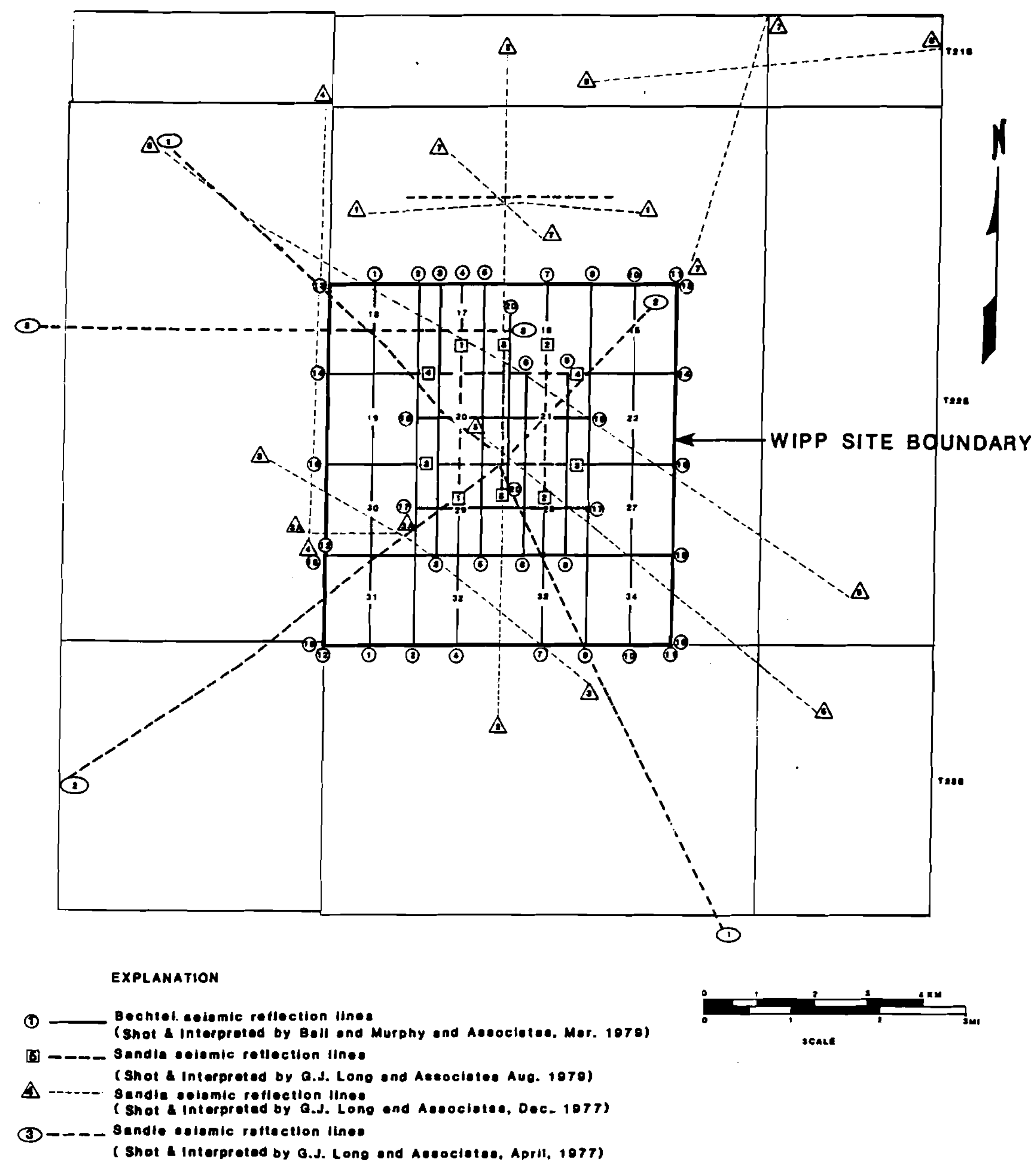
Areas where mine subsidence can be expected to occur in the future ▒

REFERENCE

Modified from:
Generalized map of the Carlsbad mining district showing likely subsidence areas and expected future subsidence areas.
WIPP Final Environmental Impact Statement, 1980 DOE-EIS-0026, Fig 7-20, Pg 7-47

This illustration for Information Purposes only.

FIGURE 2.7-47
Areas of Potential Mine Subsidence



REFERENCE

Modified from:
L.J. Barrows, S.E. Shaffer, W.B. Miller, and J.D. Fett, Waste Isolation Pilot Plant (WIPP) Site Gravity Survey and Interpretations, SAND 82-2922 (1983) Fig 1.2.2-1

This illustration for Information Purposes only.

FIGURE 2.7-48
Seismic Reflection Lines