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MONTGOMERY WATSON

June 2, 2000 (Via: FedEx)

New Mexico Environmental Department (NMED)
Hazardous and Radioactive Materials Bureau
2044 Galisteo
P.O. Box 26110
Sante Fe, New Mexico 87502

JUN 2000
RECEIVED

Attn: Mr. Steve Pullen

Re: Revised Final of Section 3
Triassic Park Waste Disposal Facility
Gandy Marley, Inc.

Dear Mr. Pullen:

On behalf of Gandy Marley Incorporated (GMI), Montgomery Watson (MW) is pleased to submit three (3) copies of the above referenced document. This version of Section 3 of the Permit Application includes the following revisions:

- Response to General Comments # from the NEMD Comments on the Vadose Zone Monitoring System Work Plan, dated March 2000;
- Update of the geologic and hydrologic information to ensure that is comprehensive and includes any new data presented in the two documents: (1) Final Report for 1999 Stratigraphic and Groundwater Characterization Program (September 10, 1999, Montgomery Watson); and (2) Groundwater Monitoring Final Waiver Request (January 24, 2000, Montgomery Watson);
- A copy of the map Structure Contour – Top of Lower Dockum.

If you have any questions concerning this report, please contact us.

Sincerely,

Montgomery Watson

Patrick G. Corser, P.E. for
Principal

Enclosure

cc: Dale Gandy (1)
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Trey Greenwood (1)
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TABLE OF CONTENTS

Section No. Page No.

TABLE OF CONTENTS

Section No. **Page No.**

LIST OF FIGURES

3.0 GROUNDWATER PROTECTION

Section 3.0 presents historical and 1994 field data, which demonstrate that the proposed landfill at the Facility will not impact groundwater resources. The EPA's RCRA Groundwater Monitoring Technical Enforcement Guidance Document was used in the preparation of this material.

The proposed Facility is located in a remote portion of eastern Chaves County, New Mexico, 36 miles from the city of Tatum (see Figure 3-1). Section 3.1, Geographical Setting and Topography, describes the favorable physical attributes of the proposed site location.

Climatic conditions, which are favorable for the efficient and environmentally safe operations of the proposed landfill and the ability to provide long-term isolation of hazardous waste, are described in Section 3.2. Data in this section were obtained from the National Oceanic and Atmospheric Administration's (NOAA's) recording station at Roswell, New Mexico.

Section 3.3, Soils and Land Use, describes soils, ranching, and other land uses in the area surrounding the proposed site. This section shows that the proposed hazardous waste disposal activities should have no impact on the existing occupational or recreational use of the surrounding land.

The regional and local geologic setting of the proposed landfill site is detailed in Section 3.4. Sediments of the Dockum Group of Triassic age are proposed as host rocks for this Facility. These unsaturated and low permeability sediments represent a stable geologic barrier to potential migration of contaminants from the proposed site.

Section 3.5, Surface Water and Water Balance, describes surface waters and meteorological conditions used to estimate groundwater recharge at the proposed site. Results from this section show that the proposed site's low groundwater recharge rate significantly reduces the potential for migration of contaminants to groundwater.

Regional and local aquifers are described in Section 3.6. This section documents the lack of groundwater present in the proposed Triassic host rocks and presents contaminant transport modeling results that demonstrate that the proposed landfill design, in conjunction with the site's geologic setting, will meet or surpass all RCRA minimum technology requirements.

Section 3.7, Groundwater Protection Requirements, presents the design of the groundwater monitoring network for the proposed Facility.

Section 3.8, Summary and Conclusions, summarizes the detailed technical data, which demonstrate that the proposed Facility is situated in a hydrologic setting that will assure long-term isolation of hazardous wastes from the environment. Technical data to support this conclusion are contained in the appendices included with this application in Volume II.

3.1 GEOGRAPHICAL SETTING AND TOPOGRAPHY

The proposed site is located in a remote portion of eastern Chaves County in New Mexico. The proposed Facility area is located in the eastern half of Section 18 and western half of Section 17, T11S, R31E, encompassing 480 acres.

This site is approximately 4 miles south of U.S. Highway 380, which provides the main access to the property. Roswell, New Mexico is approximately 43 miles west of the proposed site, and Tatum, New Mexico is approximately 36 miles to the east. Other New Mexico communities in the region include Lovington (42 miles to the southeast) and Artesia (50 miles to the southwest).

3.1.1 Physiographic Setting

The proposed site lies within a region of transition between the northern extension of the Chihuahuan Desert and the Southern High Plains. The Caprock escarpment, located approximately 2 miles east of the proposed site, delineates the western boundary of the Southern High Plains province, which, in west Texas and eastern New Mexico, is known as the Llano Estacado. The Llano Estacado is a flat-lying elevated plain, whose grass-covered surface is remarkably different from the wind-blown, sandy desert environment to the west.

3.1.2 Topography

The proposed site is located on the far eastern flank of the Pecos River Basin. The land surface gently slopes to the west at approximately 40 to 50 feet per mile toward the river. This sloping plain is characterized by low-relief hummocky wind-blown deposits, sand ridges, and dunes. The average elevation above sea level of the proposed site is 4,150 feet.

The Caprock escarpment (or Mescalero Rim) is one of the most prominent topographic features in southeastern New Mexico. East of the proposed site, the escarpment has approximately 200 feet of relief. On top of the Caprock, the land surface consists of low-relief undulating plains.

Figure 3-2 contains a portion of the USGS topographic map coverage of the proposed site. The Caprock escarpment is well illustrated in the southeastern corner of the mapped area. The proposed site and surrounding area are covered by two USGS 7½° quadrangle maps: Mescalero Point and Mescalero Point NE.

3.2 CLIMATE

The information used to evaluate the climate of the project area was obtained from climatological data summaries from the Class A recording station in Roswell, New Mexico. This recording station is part of the National Climatic Center of NOAA. The local climatological data summaries provided extreme and normal values of the meteorological parameters (for the period of record at the Roswell Municipal Airport and more recent data from the Roswell Industrial Air Center) that were used to characterize the area's climate.

The climate of the region is semiarid, with generally mild temperatures, low precipitation and humidity, and a high evaporation rate. Winds are most commonly from the south and moderate. During the winter, 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.

3.2.1 Temperatures

Moderate temperatures are typical throughout the year, although seasonal changes are distinct. Mean annual temperatures in southeastern New Mexico are near 60°F (Eagleman, 1976). Temperatures in December through February show a large diurnal variation, averaging 36°F at Roswell. On approximately 75 percent of winter mornings, temperatures are below freezing, and afternoon maximum temperatures average in the high fifties. Afternoon winter temperatures of 70°F or more are not uncommon. Nighttime lows average near 23°F, occasionally dipping as low as 14°F. Generally, there are only two or three winter days when the temperature fails to rise above freezing.

Table 3-1 shows the average monthly and average daily maximum/minimum temperatures recorded for Roswell for a typical year.

3.2.2 Precipitation

Precipitation is light and unevenly distributed throughout the year and averages 10 to 13 inches. Winter is the season of least precipitation, averaging less than 0.6 inch of rainfall per month. Snow averages about 5 inches per year at the site and seldom remains on the ground for more than a day because of the typically above-freezing temperatures in the afternoon. Approximately half the annual precipitation comes from frequent thunderstorms in June through September. Rains are usually brief but occasionally intense when moisture from the Gulf of Mexico spreads over the region.

Precipitation for the project area varies greatly from year to year. For example, Roswell's record low annual precipitation is 4.35 inches. The maximum 24-hour rainfall was 5.65 inches in October 1901. The record annual high is 32.92 inches. Most years are either "wet" or "dry"; few are "average." An average precipitation rate for Roswell, for a 107-year period from 1878 to 1982, is 10.61 inches per year. Table 3-2 shows monthly precipitation rates for the Roswell area for a five-year period and compares annual rates to the average precipitation.

3.2.3 Wind

Prevailing winds are from the south, with a normal mean wind speed at Roswell of 9.6 mph. An annual wind rose for a four-year period is shown in Figure 3-3. This wind rose shows the predominant southerly winds occurring 14 percent of the time.

3.3 SOILS AND LAND USE

The proposed site is located in a rural portion of Chaves County, New Mexico. This section describes soil profiles of the land surface in this area, existing vegetation, and the current land usage.

3.3.1 Soil Profiles

Information on soil profiles at the proposed site has been obtained from the National Cooperative Soil Survey. This survey covers Chaves County and was made cooperatively by the Soil Conservation Service, the BLM, and the New Mexico Agricultural Experiment Station.

There are two types of soils present on the proposed site. The Roswell-Faskin-Jalmar Association is present on the sandy slopes throughout the property. The Alama Series is restricted to topographically lower drainage areas and is associated with flood plain deposits.

3.3.1.1 Roswell-Faskin-Jalmar Association

This association consists of excessively drained and well-drained soils with slopes of 0 to 15%. The association is about 40% Roswell soils, 25% Faskin soils, 15% Jalmar soils, and the remainder being a mixture of various soil types. The soils of this association are used for grazing and wildlife habitat. Vegetation is mainly sand dropseed, little bluestem, sand bluestem, sandbur, three-awn, shinnery oak, yucca, and sand sagebrush. Elevation ranges from 3,500 to 4,100 feet. The frost-free season ranges from 190-205 days per year.

Roswell soils are deep, gently undulating to rolling, and rapidly permeable. They are found in hummocky or billowy areas of deep sands. They consist of a surface layer of light brown fine sand. The underlying material is pink fine sand.

Faskin soils are deep, level to nearly level, and moderately permeable. They are intermingled with Roswell soils in depressions. They have a surface layer of brown and strong brown fine sand and loamy fine sand. The subsoil is yellowish red sandy clay loam and reddish brown clay loam.

Jalmar soils are deep, evenly deposited, and moderately permeable. They are intermingled with Roswell soils in depressions. They consist of a surface layer of brown, reddish yellow, and yellowish red fine sand and loamy fine sand. The subsoil is light reddish brown, heavy loamy fine sand, and sandy clay loam.

3.3.1.2 Alama Series

The Alama Series consists of deep, well-drained soils formed in alluvium on flood plains. Slopes are 1% to 3%. Elevation is 3,400 to 3,600 feet. These soils are used for grazing, watershed, and wildlife habitat. Vegetation is mainly tobosa, buffalo grass, vine-mesquite, mesquite, and cactus. The frost-free season ranges from 200-215 days per year.

In a representative profile, the surface layer of these soils is brown loam about 3 inches thick. The subsoil is reddish brown clay loam and silty clay loam about 16 inches thick. The substratum is stratified reddish brown and light reddish brown sandy clay loam, silty clay loam, and loam to a depth of 69 inches or more. The soil profile is strongly calcareous and moderately alkaline throughout.

Permeability is moderately slow, and available water capacity is 11 to 12 inches. Effective rooting depth is 69 inches or more.

3.3.2 Land Ownership and Use

The property for the proposed site is owned by Marley Ranches, Ltd. Adjacent lands are both federally and privately owned. Generally, lands to the west are owned by the BLM, and lands to the east are privately owned.

The predominant land use in this area is grazing. With existing vegetation, approximately one section of land is required to sustain five animal units year-long. Intermittently, the land is the site of exploratory drilling for gas and oil wells, but there are no abandoned well sites within the proposed Facility boundary, and the nearest production well is approximately 3 miles from the proposed site.

The BLM has developed a recreation area known as Mescalero Sands approximately 2 miles northwest of the proposed site. The recreation area allows hikers and recreational vehicles in the sand dunes.

3.4 GEOLOGY

This section describes the regional and geologic setting of the proposed landfill.

3.4.1 Regional Geology

The geologic formations present within the region range in age from Quaternary through Triassic. Those include Quaternary alluvium, Tertiary Ogallala Formation, and the Triassic Dockum Group. Permian sediments do not outcrop in this region but, because they underlie the proposed host sediments, they are also discussed in this section.

3.4.1.1 Regional Stratigraphy

The stratigraphic relationship of the formations discussed in this section is illustrated in Figure 3-4. Information concerning formation tops and thicknesses was obtained from well logs from the New Mexico OCD office in Hobbs, New Mexico. Appendix B presented in Volume II contains a representative oil well log.

Quaternary

The surface throughout the project area is covered by alluvial deposits of Quaternary age. These deposits are comprised of fine-grained, red-brown sands, interbedded with red-brown silts and clays. A major source of these sediments was the topographically higher Ogallala Formation, as evidenced by the abundant granitic cobbles, chert pebbles, and fragments of petrified wood found throughout this unit. The thickness of these alluvial deposits along the eastern flank of the Pecos River Basin in Chaves County varies from a few feet to as much as 50 feet.

Tertiary

The "Caprock," which is the surface expression of the Tertiary Ogallala Formation, unconformably overlies Triassic sediments in southeastern New Mexico. This flat-lying sandstone and conglomeritic unit is approximately 300 to 400 feet thick. It consists of fluviatile sand, silt, clay, and gravel capped by caliche. The sand deposits of the Ogallala Formation consist of fine- to medium-grained quartz grains, which are silty and calcareous. Bedding features range from indistinctly bedded to massive to crossbedded. The formation varies from unconsolidated to weakly cohesive and contains local quartzite lenses. The sand intervals of the Ogallala Formation occur in various shades of gray and red.

Ogallala Formation silt and clay deposits are reddish brown, dusky red, and pink and contain caliche nodules. Gravels occur as basal conglomerates in intra-formational channel deposits and consist primarily of quartz, quartzite, sandstone, limestone, chert, igneous rock, and metamorphic rock. There are abundant petrified wood fragments throughout this unit.

Triassic

Triassic sediments are the potential host rocks for the proposed Facility and, as such, are described in more detail than the other formations. The Depositional Framework of the Lower Dockum Group (Triassic), Texas Bureau of Economic Geology, No. 97, 1979, by McGowen was used as a major reference for gathering information on the characteristics of Triassic sediments.

Triassic sediments unconformably overlie Permian sequences in Texas and New Mexico and have been classified as the Triassic Dockum Group. The Dockum Group is comprised of a complexly interrelated series of fluvial and lacustrine mudstone, siltstone, sandstone, and silty dolomite deposits that can be as much as 2,000 feet thick in this part of the Permian Basin. These sediments accumulated in a variety of continental depositional settings, including braided and meandering streams, alluvial fan deltas, lacustrine deltas, lacustrine systems, and mud flats.

The Triassic Dockum Group is divided into an Upper and Lower Unit. The Upper Dockum Unit is very near the surface within the project boundary, covered only by a thin veneer of Quaternary sediments. The character of this unit, also know as the Chinle Formation, is a series of fluvial sediments. These sediments conformably overlie the Lower Dockum Unit and consist of red-green micaceous mudstones, interbedded with thin, discontinuous lenses of siltstone and silty sandstones. A continental fluvial depositional environment predominated during Upper Dockum time, when the Triassic basin was filled with lacustrine sediments. The Chinle Formation is widespread in the southwestern United States.

The Lower Dockum accumulated in a fluvial lacustrine basin defined by the Amarillo Uplift on the north and the Glass Mountains on the south (Figure 3-5). As presented in this basin map, the Lower Dockum represents sediments from a large, regional depositional system. For any given portion of this basin, these sediments tend to be very homogeneous and not subject to abrupt local changes. This basin was peripherally filled, receiving sediment from the east, south, and west. Chief sediment sources were Paleozoic sedimentary rocks. Lowlands to the east and west were traversed chiefly by meandering streams. Higher gradient streams with flashy discharge existed at northern and southern ends of the basin. The large shallow lake (or lakes) was the last portion of the basin to be filled. The lacustrine sediments that accumulated here consist primarily of low-energy mudstone.

The proposed site, situated on the western flank of the Triassic paleobasin, is underlain by thick sequences of Lower Dockum mudstones. In Triassic times this area was dominated by meandering streams. The former tectonic belts were more than 200 miles away, and the regional slopes were relatively low. Surface exposures today in these areas consist of thick sequences of maroon-red-purple variegated mudstones with thin discontinuous layers of siltstones and silty sandstones.

The stratigraphy of Lower Dockum sediments in east-central New Mexico is significantly different from that of the proposed site. Figure 3-6, a subsurface sand percent map of this unit, was compiled from drill hole data from more than 1,500 oil wells throughout the basin. Thick sequences of sandstones at the northern and southern portions of the basin are shown projecting inward toward the center of the basin. In the New Mexico portion of this basin, these sand accumulations are related to the occurrence of the Santa Rosa Sandstones. This medium-to-coarse grained, white to buff sandstone represents the lowermost Triassic depositional unit and is a major aquifer in this portion of New Mexico.

Figure 3-6 illustrates that the great accumulation of Santa Rosa Sands that fills the northern portion of the Triassic paleobasin pinches out before reaching the Facility site. During the Lower Dockum time, the Facility site was part of a low-relief area with little fluvial deposition. The McGowen report specifies sand percentages of the Lower Dockum group in the Facility site area to be in the 10-20% range. This is consistent with data gathered from the two deeper drill holes completed north and south of the site boundary. There is a basal sand unit in the Lower Dockum below the site, but it appears not to be depositionally related to the Santa Rosa Sandstone.

Permian

Permian sediments are important to the geologic setting because they are immediately below the proposed Triassic host rocks. The deeper formations of Permian age were deposited in a restricted-marine environment and thus contain salt deposits, which make the groundwater produced from them too brackish for use.

Permian sediments underlying the Triassic units in the project area are assigned to the Artesia Group. Oil well logs from the New Mexico OCD in Hobbs, New Mexico, have provided sufficient data to identify the Dewey Lake Formation, Rustler Formation, and Yates Formation from the upper portion of this group. Geologic literature describes these Permian sediments to be gently dipping to the east. This fact was confirmed by using oil well log data to construct a graphic 3-point solution, as shown in Figure 3-7. Using the top of the anhydrite (Rustler) as a marker bed, the following simple calculations were made:

Known Point Elevations of Marker Bed

A = Lowest elevation - 2,975 feet
C = Highest elevation - 3,148 feet
B = Middle elevation - 3,091 feet

Strike Determination

Strike is defined as the direction of a horizontal line along the bedding plane and is calculated as follows:

D = point along AC with the same elevation as B (BD is strike)

$$AD = AC \times \frac{\text{difference in elevation between A and B}}{\text{difference in elevation between A and C}}$$

$$AD = 18{,}500 \text{ ft} \times \frac{3091 - 2975}{3148 - 2975} = 12{,}405 \text{ ft}$$

$$CD = 18{,}500 \text{ ft} - 12{,}405 \text{ ft} = 6{,}095 \text{ ft}$$

$$BD = \text{direction of strike} = N6°E$$

Dip Determination

Dip is defined as the angle of the bedding plane measured from a horizontal line perpendicular to the strike and is calculated as follows:

$$E = \text{point along strike, therefore, } E(\text{elevation}) = B(\text{elevation})$$

$$\text{Tangent of dip angle} = \frac{E(\text{elevation}) - A(\text{elevation})}{AE}$$

$$\text{Tangent of dip angle} = \frac{3091 \text{ ft} - 2975 \text{ ft}}{7520 \text{ ft}} = \frac{116 \text{ ft}}{7520 \text{ ft}} = .015$$

$$\text{Dip angle} = \text{Tangent}^{-1}(.015)$$

$$\text{Dip angle} = 0°52'$$

These calculations indicate a north-south strike and a dip of less than 1° to the east. These results are consistent with the reported regional dip for Permian (and Triassic) sediments along the western flank of the Permian Basin.

Dewey Lake Formation— The uppermost Permian sediments underlying the Triassic sequence in the project area correlate to the Dewey Lake Formation. These sediments are predominately red to red-brown mudstones and siltstones and are virtually indistinguishable from the overlying Triassic sediments. Geologic literature reports a conformable relationship between these sediments and the overlying Triassic sediments. There are approximately 240 feet of Permian redbeds in this section.

Rustler Formation— The top of the Rustler Formation was identified on OCD well logs and corresponds to the top of a 40-foot bed of anhydrite. These anhydrites are visible in outcrop on the hills immediately east of the Pecos River drainage east of Roswell, New Mexico. Underlying the anhydrite are approximately 500 feet of halite (salt). The Rustler Formation represents the youngest anhydrite sequence in the Permian Basin.

Yates Formation— Unconformably underlying the Rustler, the Yates Formation is composed primarily of interbedded sandstone with minor dolostone and limestone. The sands are light gray and fine to very fine grained. Limestone is white to very light gray microcrystalline lime mudstone with a chalky texture. Dolostone is pink to light gray and microcrystalline.

3.4.1.2 Regional Structure

The tectonic setting and seismic activity are discussed in this section.

Tectonic Setting

The proposed Facility site is located on the western flank of the Permian Basin of west Texas. Because of the distance from tectonic centers and the minimal seismic activity, this is considered one of the more geologically stable regions within the United States.

The region underwent intense deformation, however, during late Paleozoic times. As shown in Figure 3-5, major uplifting occurred along the Ouachita Tectonic Belt and the Wichita System of Texas and Oklahoma. The Sacramento and Sangre de Cristo uplifts in northeastern New Mexico were also active during late Paleozoic time. The overall structural configuration of the Permian Basin was established at this time.

This period of intense deformation was followed by a long period of gradual subsidence. The sea covered the region, and throughout the remainder of Permian era, the Permian Basin was slowly filled with several thousand feet of evaporites, carbonates, and shales. As discussed in Section 3.4.1.1, non-marine deposition began in Triassic time with the accumulation of lacustrine/fluvial sediments into a large shallow lake.

During the late Cretaceous to early Tertiary Laramide Orogeny, there was renewed uplifting along the Sacramento, Sangre de Cristo, and other ranges within the Rocky Mountains. This orogeny uplifted the region to its present position and supplied sediments for the Tertiary Ogallala Formation.

Seismic Activity

The Permian Basin is an area of moderate to low seismic activity. Data obtained from the National Geophysical Data Center of NOAA indicate a total of 102 observed earthquakes within a 250-km (155-mile) radius of the proposed site. These data reflect observations made from 1930 to 1993.

As shown in Figure 3-8, there were no recorded earthquakes with a magnitude greater than 3.9 within 70 miles of the proposed site and no recorded seismic activity within a radius of 45 miles. The distance from any tectonic centers and the low recorded seismic activity suggest that the proposed site is located in an extremely stable environment where activity is not expected. Consequently, little damage from earthquake activity is anticipated.

3.4.2 Site Geology

Figure 3-9 illustrates the surficial geology on and adjacent to the proposed site. This section will provide detailed descriptions of the proposed Triassic host sediments and the Quaternary alluvium that overlies these sediments only.

3.4.2.1 Site Stratigraphy

Specific data for this section was obtained through drilling activities described in Section 3.4.3. Figure 3-10 is a stratigraphic cross-section based on this drilling, illustrating relationships between the proposed Triassic host sediments and adjacent formations. Other site-specific cross-sections are located in Volume II, Appendix G.

Quaternary

The thickness of Quaternary alluvial deposits at the site varies from less than 10 feet to 35 feet. The upper portion of these sediments consists of fine to very fine, wind-blown yellow-brown sands. Below this sand are varying thicknesses of red-brown to yellow-brown siltstones and silty mudstones.

Scattered throughout these sediments are small chert pebbles and granitic cobbles derived from the Tertiary Ogallala Formation.

A caliche zone (Mescalero Caliche) is present in most of this unit. The caliche is found immediately under the top wind-blown sands and coats and fills fractures within the more consolidated siltstones. Where the Quaternary alluvium is quite thin, this caliche is found coating Triassic sediments.

Triassic

Drilling at the site has delineated 1,175 feet of Dockum sediments. Two distinct units can be identified in these sediments: the Upper Dockum (475 feet thick) and the Lower Dockum (700 feet thick). Within the proposed Facility boundary the thickness of the Upper Dockum unit never exceeds 100 feet. Upper Dockum sediments are in contact with the overlying Quaternary alluvium throughout the project area.

Upper Dockum—This unit consists of variegated (red-brown-green) mudstones interbedded with reddish gray siltstones and reddish-gray-green sandy siltstones. The siltstones are micaceous (predominantly muscovite), indicating they were part of a relatively active fluvial system capable of transporting material into the basin from distant source rocks.

From examination of lithology and down-hole electric logs, it is estimated that 30 percent of the unit is comprised of mudstones. Lithologies of the remainder of the unit are evenly divided between siltstones and sandy siltstones. However, as the geotechnical properties of these two lithologies are very similar, this geologic discussion will simply refer to them both as siltstone. Mudstones were found to have an average permeability of 2.45×10^{-7} cm/s, and the siltstones average 1.22×10^{-5} cm/s.

These sediments were deposited in a fluvial environment. Mudstone and siltstone bodies are very lenticular and are found to pinch out abruptly. Accordingly, individual lithologies are not correlatable over significant distances (thousands of feet).

Cross-sections prepared from the close-spaced drilling within the proposed Facility boundary establish an understanding of the fluvial nature of this unit (see Appendix G in Volume II). Figure 3-11 shows the locations of drill holes for the close-spaced drilling pattern and provides an index of cross-sections that illustrate the character of the Upper Dockum Unit. Also shown on Figure 3-11 is the location of the "most favorable" area for the construction of the proposed landfill. As shown in the cross-section on Figure 3-10, the lithology of this area (centered on drill hole PB-4) is predominantly mudstone, with thin beds of siltstones. The lenticular nature of the mudstone and siltstone bodies is also shown in these cross-sections. Cross-sections 3-1 and 3-2, in Appendix G (Volume II), show the facies relationships of the "most favorable" area.

The fluvial nature of the Upper Dockum Unit has led to the scouring of channels into the underlying Lower Dockum Unit. This scouring and the pinching-out of fluvial sediments have resulted in the local development of an undulatory surface on top of the Lower Dockum Unit. This phenomenon is well illustrated in Cross-sections 3-3, 3-4, and 3-5, in Appendix G (Volume II).

Lower Dockum — The Lower Dockum Unit, described in Section 3.4.1.1, has a completely different character from the upper unit. The lower unit represents a time of relatively quiet lacustrine deposition, which resulted in the accumulation of thick sequences of predominantly mudstones interbedded with thin siltstones. These sediments are very homogeneous, in contrast with the abrupt facies changes present in the more active Upper Dockum depositional system.

Most of the close-spaced drilling within the proposed Facility boundary "bottomed" in Lower Dockum mudstones. These mudstones were consistently a moderate reddish brown color, which according to McGowen (1979), is associated with low stand lacustrine and mud flat deposition.

The 1995 confirmation drilling provided some important data on this unit. As illustrated in Figure 3-13, all three holes penetrated the clays of the Lower Dockum unit. PB-36 encountered 64 feet of this unit, PB-37 encountered 55 feet, and PB-38 encountered 18 feet. Ten feet of core of Lower Dockum were collected from PB-36 at a depth of 138 to 148 feet and 7 feet of Lower Dockum were collected from PB-37 at a depth of 148 to 155 feet. Four representative samples of this core were sent to AGRA Earth & Environmental laboratories for permeability analyses. The results of these analyses confirm the Lower Dockum to be a very impermeable unit (average permeability of 5.7×10^{-8} cm/s), capable of performing as a geologic barrier to downward migration from the proposed landfill. Following are the results of the core analyses:

Core Interval	Permeability (cm/sec)
PB-36 (144'-145')	$5.2 X 10^{-8}$
PB-36 (147'-148')	$6.8 X 10^{-8}$
PB-37 (150'-151')	$5.8 X 10^{-8}$
PB-37 (154'-155')	$4.9 X 10^{-8}$

3.4.2.2 Site Structure

There are no identified faults within the project area. As previously discussed, the proposed site is located in a geologically stable area. There are no mapped faults on or adjacent to the project area. Color air photos of the area were examined for surface lineations, which can reflect faulting in the subsurface. All surface lineations observed on these photos were attributed to man-made features (i.e., fences, roads, etc.).

Subsurface drilling did not encounter displacement or repeating of geologic sequences that would be indicative of faulting. In the Upper Dockum Unit, there are abrupt changes in lithologies, but these are attributed to depositional processes associated with an active fluvial system. The fluvial nature of the Upper Dockum Unit has led to the scouring of channels into the underlying Lower Dockum Unit. This scouring and the pinching-out of fluvial sediments have resulted in the local development of an undulatory surface on top of the Lower Dockum Unit (Figure 3-14, Structure Contour - Top of Lower Dockum). Figure 3-14 also shows the northeast dip of the Loer Dockum.

3.4.3 Site Investigation Activities

Triassic sediments in eastern Chaves County were initially identified as excellent host rocks for proposed hazardous waste disposal because they (1) contain thick sequences of low permeability clays; (2) occur in remote, unpopulated areas; and (3) produce virtually no groundwater. This section describes the series of exploration activities undertaken to verify and document the suitability of the site for hazardous waste disposal.

As part of this permit application, a total of 41 drill holes were completed. The lithologies of these holes were recorded and a geophysical log was run on each drill hole. Thirty-one of these drill holes were completed within the project boundary (Figure 3-15).

3.4.3.1 Preliminary Evaluation Activities

The first phase in determining an appropriate disposal site was to identify potential sites with exposed or near-surface Triassic sediments. To identify such sites, color aerial photos were obtained of areas underlain by Triassic sediments in eastern Chaves County (Figure 3-16). The areas exhibiting the characteristic coloration associated with the Triassic sediments on the photos were then plotted on topographic maps. The locations with desirable geology were screened for additional factors, including accessibility and land ownership. From this process, a prioritization of sites was developed and a shallow drilling program designed.

In July and September 1993, two shallow drilling programs were conducted to examine Triassic sediments underlying the Quaternary alluvium. Average depth of these holes was 40 to 60 feet, and the drilling was conducted on a spacing of approximately 1,000 feet between holes. As shown in Figure 3-17, three areas encompassing seven sections were examined. The objective of this drilling was to identify an area where the Triassic sediments were unsaturated, were situated close to the surface, and contained low permeability clays. An Ingersol Rand 1500 air rotary drill was used to perform this work. This air rotary technique was used because of the high quality of drill cuttings it produces and because the presence of any subsurface water can be easily detected.

Of all areas investigated, the surface and near-surface geology in the vicinity of Red Tank (the proposed site) was found to be the most favorable. Over most of this area, the thickness of Quaternary alluvium averaged approximately 10 feet, and the shallow drilling indicated the presence of unsaturated mudstones underlying the alluvium. Five shallow core holes were completed, adjacent to rotary air holes, to obtain preliminary geotechnical data on the near-surface Triassic sediments. As a result of the shallow depth of these sediments, many of the clays were very dry and brittle. This presented some difficulty in obtaining "undisturbed" core samples. Despite these difficulties, materials testing results showed low permeabilities for Triassic clays, ranging from $1x10^{-7}$ to $3x10^{-8}$ cm/s. These values, along with the local geologic setting, established the Red Tank area as an area conducive to more detailed site characterization.

Two deep holes (WW-1 and WW-2) were drilled to the base of the Dockum Group in November 1993. These holes encountered an unsaturated thickness of 600 to 650 feet of Lower Dockum mudstones consisting primarily of reddish brown, maroon, and purple mudstones with thin intervals of reddish brown silts.

Lithologic logs developed from cuttings samples and down-hole geophysical logs (gamma and thermal neutron) confirm the homogeneity of this thick mudstone interval. In addition, samples of drill cuttings from one of the deep holes (WW-2) were taken to the University of New Mexico's Diagnoses Laboratory for a grain size analysis. This analysis showed a remarkably constant grain size distribution throughout the sequence, which is consistent with the technical definition of a mudstone. This procedure involved desegregating, centrifuging, drying, wet sieving, and weighing the samples. A complete procedure and the results of this analysis are contained in Volume II, Appendix F.

The 600- to 650-foot mudstone interval rests on a basal sandstone unit that is approximately 50 feet thick. This basal unit is present in oil well logs in the area as a clean to a silty sand. The deep drilling did not retrieve any cuttings from this basal unit. The drilling was performed with air, and the moisture in this unit prevented the return of cuttings to the surface. Casing was placed in these holes, and water levels were taken (Section 3.6.2).

WW-1 and WW-2 were drilled north and south of the project boundary to characterize the nature of the Lower Dockum. Because of the consistent, continuous depositional environment within the lacustrine sediments at the Lower Dockum, it was decided (and approved by the NMED) that is was unnecessary to penetrate the entire Lower Dockum sediments within the site boundary. Such penetration would have certainly violated the integrity of the formation in the area of the planned hazardous waste landfill and in all likelihood would not have provided additional geologic information.

3.4.3.2 1994 Site Characterization Activities

In June 1994, a drilling plan for site characterization activities at the proposed site was prepared and submitted to the Hazardous and Radioactive Materials Bureau of the New Mexico Environment

Department. The plan identified drilling locations, depths and methods, proposed geotechnical tests and methods, and down-hole geophysical logging methods. The 100-foot depth was sufficient to penetrate the base of the Upper Dockum (with the exception of the easternmost portion of the site). The plan was approved as submitted.

Drilling operations commenced on July 17, 1994 and a total of 36 drill holes were completed. There were three distinct phases of this drilling program: (1) close-spaced pattern drilling in the area of the proposed site (to a depth of 100 feet) to obtain detailed lithologic and hydrologic information for the design of a landfill, (2) stratigraphic drilling across the project area (to a depth of 200 feet) to correlate the site geology with the regional setting, and (3) selected core drilling in the proposed site for geotechnical samples. Samples of drill cuttings were collected and logged for each hole (see Volume II, Appendix C). Southwest Geophysical Services, Inc. conducted down-hole geophysical logging of each drill hole. These electrical surveys consisted of thermal neutron and gamma logs. The electric logs provide lithologic information from unsaturated drill holes to supplement and verify the lithologic interpretations based on drill cuttings. Copies of all geophysical logs can be found in Volume II, Appendix D.

A rotary air rig (Ingersol Rand 1500) was used for this work. Drilling with air provides cleaner drill cuttings than drilling with water, and usually a good indication of water saturation. However, in the case of the Upper Dockum sediments on the Facility site, this drilling technique was not always successful in identifying water saturation. This failure was a result of the low to very low permeabilities of the silty sands and the low amount of water saturation. The pressure of the air from the drilling process prevented water from immediately entering the holes. If groundwater was present, it was not always detected until the hole had stabilized and a geophysical log was taken. Geophysical logs on all 31 drill holes within the site boundary encountered no saturated Upper Dockum sediments.

Three core holes were completed and a total of 85 feet of core recovered. A CME-55 hollow-stem auger rig using a continuous sampler was used to collect these samples. The dry, brittle nature of these shallow, unsaturated sediments made the recovery of undisturbed core samples difficult.

Representative core samples of mudstones, siltstones, and sandy siltstones were sent to materials testing laboratories for measurement of geotechnical parameters to be used in the Facility design and contaminant transport modeling. In addition to core samples, 11 backhoe pits were dug adjacent to drill holes for the collection of bulk samples. Proctor tests were performed on these bulk samples to provide information required for design studies. All geotechnical results are contained in Volume II, Appendix E.

3.4.3.3 1995 Confirmation Drilling Program

In order to confirm the unsaturated nature of the Upper Dockum sediments on the eastern boundary of the proposed Facility, a drilling plan was submitted to Mr. Bob Sweeney of NMED on June 26, 1995. This plan was modified and approved in a letter from Mr. Ronald A. Kern, dated July 12, 1995. A three-hole drilling program was conducted on the GMI site on July 24 & 25, 1995. Mr. Bob Sweeney visited the site and observed the drilling operations on Monday, July 24, 1995.

Holes PB-36, PB-37, and PB-38 were completed as an extension to an existing east-west line of drill holes. The westernmost drill hole was located on the eastern boundary of the proposed landfill. The other two holes were drilled 1,000 feet apart and examined the area immediately east of the proposed landfill. All surface locations for these drill holes were surveyed.

No groundwater saturation was encountered. All holes were completed with air so that saturated sediments could have easily been detected. Lithology logs describing drill hole cuttings were prepared in the field and down-hole geophysical logs were run on each hole. The geophysical logs included gamma ray, thermal neutron, and caliper profiles.

3.4.3.4 1999 Drilling Program

In order to further clarify the subsurface stratigraphy and groundwater conditions underlying and adjacent to the proposed site within the upper Dockum and its contact with the Lower Dockum, a drilling program was conducted in August 1999 consisting of 10 drill holes. This drilling program was conducted at the request of NMED and in accordance with the Final Work Plan for Stratigraphic and Groundwater Characterization Program, dated July 28, 1999. The results of this program were documented in Final Report for 1999 Stratigraphic and Groundwater Characterization Program, dated September 10, 1999 (Montgomery Watson).

The results of this program 1999 demonstrated that the subsurface stratigraphy underlying the proposed site is both continuous with and predictable from previous drilling results. There were no unexplainable features within the depositional environment. In all cases, the depth of the contact between the Upper Dockum and the Lower Dockum sediments was encountered where it was estimated to be. There was no groundwater within these sediments.

The groundwater characterization drilling demonstrated that there is even less groundwater in the vicinity of the site than originally thought. Pooled surface waters have the potential of migrating through the surface alluvial sediments. Limited saturation encountered one-mile northeast of the site in the Upper Dockum appears to have been an isolated occurrence of perched groundwater. Upper Dockum sediments underlying the site and extending ¾ mile downgradient have been examined by over 40 drill holes and found to be unsaturated.

3.5 SURFACE WATER AND WATER BALANCE

This section describes surface waters and meteorological conditions used to estimate groundwater recharge at the proposed site.

3.5.1 Surface Water

There are no perennial stream drainages on or near the proposed site. The nearest surface drainage is the Pecos River, approximately 30 miles to the west.

There is one small stock tank (Red Tank) within the proposed Facility boundary and several additional tanks on adjacent lands. These tanks are approximately 200 feet by 200 feet and contain water for livestock. The tanks are clay-lined and retain water from run-off or receive water from an underground pipeline. Water in the underground pipeline is supplied from three water wells on the Marley Ranch located in Section 10, T11S, R31E. These wells are east of the Mescalero Rim and produce water from the Ogallala Formation. In the past, water from the springs along the Caprock excarpment was used in this pipeline, but now water is pumped from the Ogallala Formation. The pipeline is personally owned and maintained by the Marley Ranch to provide water to cattle operations below the Caprock.

Once the site is designated as a disposal area, cattle operations on this property will cease and the Marley Ranch will stop using Red Tank. They will also re-route their personal pipeline, as appropriate, to avoid landfill operations and continue to supply water to their cattle operations below the Caprock.

3.5.2 Water Balance

The water balance analysis estimated groundwater recharge from direct precipitation, surface water bodies, and irrigation at the proposed landfill site. This information is useful for assessing the potential migration of contaminants released at or near the surface to groundwater. The groundwater recharge rate is directly related to the potential for contaminants spilled or leaked at the surface to reach groundwater. In areas with little or no groundwater recharge, there is less potential for groundwater contamination from releases of hazardous substances than in high recharge areas because the mechanisms to transport potential contamination are limited.

A water balance requires quantification of the hydrologic components, which can result in changes in the amount of water stored in the area of interest. Often, water balances are calculated for an entire watershed to understand the relative importance of the hydrologic components within that area. For this analysis, the water balance was performed to estimate groundwater recharge at the proposed landfill site.

Groundwater recharge at the proposed site can be estimated by summing precipitation, infiltration from surface water bodies, and irrigation at the site and subtracting evapotranspiration and surface run-off. As no natural surface water bodies or irrigation occur at the site, groundwater recharge is estimated as the difference between direct precipitation and evapotranspiration. This assumes no surface run-off at the site.

Precipitation data collected at the Roswell weather station indicate that mean annual precipitation is 10.61 inches (Section 3.2.2). This annual mean is used as the average precipitation at the proposed site.

Evapotranspiration refers to the processes that return water to the atmosphere by a combination of direct evaporation and transpiration by plants and animals. It is the largest item in the water budget because most of the precipitation that falls in the area returns almost immediately to the atmosphere without becoming part of the surface water or groundwater systems. On unirrigated rangeland, much of the precipitation that does not evaporate immediately is taken up fairly rapidly by plants and transpired. In a regional water balance conducted in southeastern New Mexico, it was estimated that approximately 96 percent of total precipitation is lost to evapotranspiration (Hunter, 1985). This number corresponds to data presented for the Rio Grande Basin by Todd (1983), which estimated that 95.4 percent of total precipitation was being lost to evapotranspiration.

Assuming a mean annual precipitation rate of 10.61 inches, of which 96 percent is lost to evapotranspiration, the net recharge to groundwater is estimated as 0.42 inch per year. This low groundwater recharge rate significantly reduces the potential for groundwater contamination from spills or leaks at the proposed Facility.

The purpose of this water balance is to provide a conceptual understanding of the hydrologic components at the site. The amount of groundwater recharge is a reflection of the arid climate of the region. The net recharge estimate of 0.42 inch per year (based on average hydrologic components) represents the expected long term annual conditions at the site. The relatively low recharge rate appears to be reasonable given the unsaturated conditions of the Upper Dockum within the site boundaries. Using the highest recorded annual precipitation value of 32.92 inches yields only a slightly higher recharge rate of 1.32 inches (assuming an evapotranspiration rate of 0.96). This short term (1 year) increase in recharge is unlikely to have a significant impact on the unsaturated flow regime at the proposed site.

3.6 GROUNDWATER

This section describes regional and local aquifers.

3.6.1 Regional Aquifers

In the region surrounding the proposed site, there are two geologic units that have produced groundwater, the Triassic and the Tertiary Ogallala Formation. Very minor amounts of groundwater have been produced from Triassic sediments; but the Tertiary Ogallala Formation is a major aquifer in southeastern New Mexico, west Texas, and several other western states.

A listing of all water wells within a 4-mile radius and 10-mile radius of the proposed site was obtained from the New Mexico State Engineer's office. Water wells within a 10-mile radius are shown in Figure 3-18, while those within a 4-mile radius, along with oil well locations and the locations for all site investigation drilling activities, are shown in Figure 3-19.

Sixteen water wells were reported, fourteen from the Ogallala Formation and two from the Triassic. Of the two Triassic wells, one is now reported to be dry and the other is actually located more than 6 miles west of the proposed site. Six of these wells are shallow completions (100 feet or less) from the 1910's and 1940's and are used with windmills to supply water to livestock and wildlife. The numbers of these wells are RA-8585 through RA-8589 and RA-8363. These are included as wells penetrating Triassic sediments because of their surface locations. However, due to their shallow depths, the source of water could be from surface alluvial sediments.

The four other wells range in depth from 560 to 640 feet and have been completed within the past seven years. These wells would have penetrated the Lower Dockum sediments (including the Santa Rosa Sandstone equivalent). Following is a description of these wells:

- RA-8577 was drilled to a depth of 614 feet in 1992. It's initial production was 4 gallons per minute.

- RA-9320 was drilled in 1996 to a depth of 560. The estimated yield was 6 gallons per minute, however, the water was determined to be not potable. The well was plugged and abandoned on 11/25/96.

- RA-9568 was drilled to a depth of 640 feet in 1998. It was a dry hole and was plugged and abandoned on 08/14/98.

- RA-9670 was drilled in 1998 to a depth of 587. The estimated initial yield was 2 gallons per minute.

3.6.1.1 Ogallala Aquifer

The Ogallala Aquifer is the primary freshwater aquifer within the regional study area and serves as the principal source of groundwater in the Southern High Plains. The saturated thickness of the Ogallala Aquifer ranges from a few feet to approximately 300 feet in the Southern High Plains. Groundwater within the Ogallala Aquifer is typically under water table conditions, with a regional hydraulic gradient toward the southeast ranging from approximately 10 feet/mile to 15 feet/mile. The average hydraulic conductivity of the Ogallala Aquifer ranges from 1 foot/day to 27 feet/day.

The Ogallala Aquifer is recharged primarily through the infiltration of precipitation. The rate of recharge is believed to be less than 1 inch/year. Groundwater discharge from the Ogallala Aquifer occurs naturally through springs, underflow, evaporation, and transpiration, but groundwater is also removed artificially through pumpage and catchment. Currently, the rate of withdrawal exceeds the rate of recharge for much of the Ogallala Aquifer.

3.6.1.2 Triassic

Regionally, the only aquifer within Triassic sediments is the Lower Dockum Aquifer. However, because the Upper Dockum is known to have permeable facies that locally produce low quantities of good to poor quality water, it is included in this section.

Lower Dockum Aquifer

The major aquifer within the Lower Dockum is the Santa Rosa Sandstone. This sandstone is present along the northern and southern flanks of the Permian Basin and is a principal source of groundwater in Roosevelt and Curry Counties, New Mexico. The Santa Rosa Sandstone is not present along the western flank of the Permian Basin, which includes the proposed site.

Where the Santa Rosa Aquifer has been studied, hydrochemical analyses and groundwater oxygen isotopes indicate that it is distinctly different from the Ogallala Aquifer. The thick, impermeable clays within the Triassic section have been sufficiently impermeable to prevent hydraulic communication between these aquifers.

The major aquifer within the Lower Dockum is the Santa Rosa Sandstone. This sandstone is present along the northern and southern flanks of the Permian Basin and is a principal source of groundwater in Roosevelt and Curry Counties, New Mexico. The Santa Rosa Sandstone is not mapped along the western flank of the Permian Basin, which includes the proposed site. Where the Santa Rosa Aquifer has been studied, hydrochemical analyses and groundwater oxygen isotopes indicate that it is distinctly different from the Ogallala Aquifer. The thick, impermeable clays within the Triassic section have been sufficiently impermeable to prevent hydraulic communication between these aquifers.

Upper Dockum Aquifer

There is no regional aquifer developed within Upper Dockum sediments. In local areas, recharge to the Upper Dockum is provided through vertical infiltration from overlying aquifers which are water-bearing units within the Ogallala Formation. This relationship has been illustrated in Figure 3-10.

3.6.2 Site Groundwater

Potential Triassic host sediments within the proposed Facility boundary are unsaturated. Detailed drilling within this boundary has encountered no groundwater. Drilling outside the proposed Facility boundary has identified saturated zones in both the Upper and Lower Dockum Units. The following subsections contain descriptions of these saturated zones.

3.6.2.1 Ogallala Aquifer

The western boundary of the Ogallala Aquifer, represented by the Caprock escarpment, is located topographically/stratigraphically above and 2 miles east of the proposed site. At the base of the escarpment, along the contact of the Ogallala Formation and the underlying Upper Dockum, are numerous springs, which are a result of downward-migrating Ogallala groundwater coming into contact with low permeability zones within the Upper Dockum and being diverted to the surface.

3.6.2.2 Upper Dockum - "Uppermost Aquifer"

For the purpose of this application, the uppermost aquifer is considered to be the Upper Dockum Unit because the Ogallala Aquifer is not present at the site. The EPA has defined the uppermost aquifer as the geologic formation, group of formations, or part of a formation that is the aquifer nearest to the ground surface capable of yielding a significant amount of groundwater to wells or springs. The Upper Dockum Unit certainly does not yield a significant amount of groundwater. However, preliminary drilling in the site area has found portions of this unit to be water-bearing and to possess consistent hydrologic characteristics.

The identification of a confining layer on the lower boundary is an essential factor in the identification of the uppermost aquifer. The thick sequence of mudstones of the Lower Dockum Unit (as discussed in Section 3.4.2.1) represents a high-integrity aquitard, effectively confining the aquifer. Although there is a saturated basal sandstone in this unit, the 600 to 650 feet of mudstones separating the Upper Dockum sediments from this sandstone are of sufficiently low permeability to prevent hydraulic communication between the Upper and Lower Dockum Units.

As previously discussed in Section 3.6.2.1, several springs are present where the Ogallala Formation crops out, two miles east of the Facility site, along the 200-foot high Caprock escarpment. These springs are present where the Ogallala sands unconformably overlie impermeable Dockum mudstones and claystones and the groundwater moves laterally to the surface. Where these water-bearing Ogallala sands are in contact with more permeable units of the Upper Dockum, saturation of these underlying sediments occurs. The result, as illustrated in Figure 3-10, is the formation of a groundwater divide east of the proposed site. The majority of the groundwater entering the Upper Dockum flows to the east, conforming to the regional dip of the unit. There is also a minor flow component which slopes away from the unconformable contact, creating a steep hydraulic gradient towards the west. This gradient does not extend beneath the Facility site. As shown in Figure 3-20, this gradient must lie immediately east of PB-38, which is still unsaturated, whereas holes WW-1, and PB-26 are saturated.

Where groundwater has been observed in the Upper Dockum, not all lithologies within the unit are saturated. Air drilling through these sediments found the mudstones to be unsaturated. The more permeable sandy siltstone facies were water-bearing below depths of 135 to 150 feet. These saturated lithologies were encountered approximately 2,500 feet east (downdip) of the proposed landfill site, beyond the proposed Facility boundary (Figure 3-20). It is extremely significant that this saturation does not extend beneath the Facility site. All 31 drill holes within the site boundary, as shown on Figure 3-19, were unsaturated. For this reason, there were no groundwater production tests conducted.

Exploratory drilling west of the proposed Facility boundary (updip), near the outcrop of the Upper Dockum Unit, the small sandy hills located along the section line between Section 18, T11S, R31E and Section 13, T11S, R30E, encountered an isolated occurrence of groundwater (Figure 3-18). In a single drill hole (PB-14), at a depth of 42 feet, a small accumulation of groundwater was found in a depression developed on the surface of the underlying Lower Dockum mudstones. This depression is consistent with the "scouring" of the Upper Dockum fluvial sediments into the Lower Dockum mudstones (Section 3.4.3.2). Closer spaced drilling in the vicinity of this occurrence encountered no other such accumulations. This isolated "pooling" is most likely a result of surface run-off entering the subsurface from the nearby outcrop and being caught in a small "stratigraphic trap."

Because of the identification of groundwater in borehole 14, an offset (borehole 14o) was completed 400 feet to the east (down-gradient). This borehole location was in addition to those pre-approved by the NMED, but determining the potential extent of groundwater saturation was important. Borehole 14o was drilled to a depth of 100 feet.

There was no saturation observed while drilling this offset, but the geophysical log indicated the presence of fluid at the bottom of this borehole. The top of the fluid was observed to be at a depth of 92.0 feet, indicating a maximum apparent concentration of 3.5 feet. This is an apparent concentration because a 2.25 inch probe will displace approximately one-half of the volume of the hole. Regardless of all of these factors, there was approximately one gallon of fluid in the bottom of this borehole introduced by a heavy rainfall that occurred after the hole was drilled and before it could be logged. Due to the impermeable nature of the Lower Dockum mudstones, the water did not infiltrate into the formation and was trapped in the bottom of the hole.

The hole was cased with 3-inch plastic tubing and monitored for several weeks. No additional water entered the hole, and, in fact, the gallon of water eventually dispersed into the Lower Dockum. An examination of the log for PB-14o shows the bottom of the sandy silt unit (Upper Dockum) to be a depth of 36 feet. If the Upper Dockum was the source of the water, the hole would have equilibrated or filled to a depth of at least 36 feet. The fluid did not migrate upward through several hundred feet of Lower Dockum mudstones; therefore, there is no apparent subsurface source for the small quantity of water shown in the log for this hole.

Water Level Measurements— After the stratigraphically trapped water (Cross-section 3-3, Appendix G, Volume II) was encountered, temporary casing was placed in the drill hole (PB-14) so that piezometric water levels could be measured. For the first six weeks after casing the drill hole, the water was pumped from the hole weekly. After each pumping event, the water returned to a static level of 42 feet. Subsequent water level measurements have confirmed a static water level in this drill hole.

In addition to casing drill hole PB-14, nine other drill holes, located downdip, were also cased. Although the Upper Dockum is unstaturated in these other drillholes, the holes were examined weekly for six weeks. No water was observed except for that previously described in PB-14o. The drill holes that were cased with 3-inch plastic casing and the perforated intervals for these holes are as follows:

Hole No.	Perforated Zone	Base of Upper Dockum
PB-14	30-80	42'
PB-14o	20-40	36'
PB-33	20-55	52'
PB-18	60-80	78'
PB-16	60-80	79'
PB-15	30-65	62'
PB-13	30-50	48'
Hole No.	**Perforated Zone**	**Base of Upper Dockum**
PB-9	40-80	72'
PB-7	20-40	38'
PB-17	60-85	80'

The intent of installing casing in these 10 holes was to allow any groundwater in the vicinity of these drill holes to collect for detection purposes. The depths of the cased intervals varied because there is an approximate 1° regional dip to the east. All cased intervals extend down to the bottom of the Upper Dockum sand. Slits were cut in the PVC casing every foot throughout the perforated zones.

Water Quality— Preliminary water quality data were obtained from limited chemical analyses on a sample of the stratigraphically trapped groundwater from drill hole PB-14. These results include the following measurements:

Total Dissolved Solids	4,920 mg/L
Alkalinity	396 mg/L
Sodium	1,640 mg/L
Magnesium	103 mg/L

These preliminary data indicate that water from the Upper Dockum is of poor quality. The most significant parameter is total dissolved solids (TDS); water with TDS values of greater than 5,000 mg/L is considered to be unfit for human consumption.

3.6.2.3 Lower Dockum Aquifer

The basal sandstone of the Lower Dockum Unit is the water-bearing portion of this unit. As shown in Figure 3-10, this unit is overlain by a thick sequence (600 to 650 feet) of low permeability mudstones that act as an aquitard. The recharge area for the Lower Dockum Aquifer is the Pecos River drainage to the west. Groundwater flow direction is easterly, along the regional dip of this unit.

Most of the shallow drilling in the site area has "bottomed" in the upper portion of the aquitard. Two holes (WW-1 and WW-2) were drilled to approximately the base of the Triassic section and encountered water from the Lower Dockum Aquifer (Figure 3-18). Hole WW-1 also penetrated a saturated zone in the Upper Dockum Unit, resulting in a mixing of these groundwaters in this drill hole.

Both holes were drilled with an air rotary rig and drill cutting samples were collected. WW-1 was completed to a depth of 820 feet and, at the time of drilling, no water saturation was apparent in the drill cuttings. WW-2 was completed to a depth of 710 feet; however, circulation was lost at a depth of 645 feet. Loss of circulation commonly occurs when drill cuttings are too wet for the air pressure of the rig to remove the cuttings from the hole. It is likely that the basal sandstone of the Lower Dockum Unit was penetrated at this depth.

Water Level Measurements— Temporary plastic casing was placed in each of the two holes immediately after completion. In July 1994, geophysical logs were run for each hole, and water levels were identified. WW-1 had a water level of 155 feet. This level is 20 feet above the Upper/Lower Dockum contact, and it is likely that groundwaters from both units are present in this drill hole. A water level of 467 feet was observed for WW-2. This finding indicates that there is a hydrostatic head pressure within the Lower Dockum Aquifer of 178 feet.

Both of these cased holes were pumped and allowed to recover. After a sufficient recovery period, a static water level (155 feet for WW-1 and 467 feet for WW-2) was maintained.

Water Quality— Preliminary water quality data are presented only for WW-2. This drill hole encountered groundwater from the Lower Dockum. Because groundwater from the Upper Dockum and Lower Dockum was mixed in drill hole WW-1, preliminary water quality data from WW-1 do not accurately characterize either aquifer and are not presented. The results from WW-2 include the following:

Total Dissolved Solids	18,800 mg/L
Alkalinity	83 mg/L
Sodium	7,030 mg/L
Magnesium	87 mg/L

These preliminary data indicate that the water quality of the Lower Dockum is very low. The extremely high TDS values are indicative of long formation retention times, which reflects low groundwater flow and low permeability conditions within the Lower Dockum aquifer.

3.6.3 Contaminant Transport Modeling

For the purpose of this application, two types of groundwater modeling were performed to estimate contaminant transport times. One approach is extremely conservative and presents a "worst case" scenario. One of the many conservative assumptions used in these calculations, despite field evidence, is that contaminant transport will take place under saturated conditions. A second, more realistic approach, assumes unsaturated flow conditions.

3.6.3.1 Saturated Flow Modeling

Saturated flow modeling was used to simulate potential leakage or infiltration from the Facility landfill. The objective of contaminant transport modeling was to calculate the time necessary for a hypothetical leak from the landfill to reach the uppermost aquifer. Travel time was calculated using a steady-state groundwater flow model. The model was based on results of the site investigation and geologic characterization, which indicated that perched groundwater exists upgradient and downgradient of the site (Section 3.6.2.2).

Perched groundwater located approximately 2,500 feet downgradient of the proposed landfill is the uppermost aquifer that could be affected by a contaminant. For the purpose of calculating travel time to the uppermost aquifer, contaminants were assumed to travel from the location of the Upper Dockum/Lower Dockum interface at borehole PB-3 to the perched groundwater downgradient of the site (Figure 3-18). This location was chosen for contaminant transport modeling because it represents the shortest distance from the proposed landfill to downgradient groundwater. The Lower Dockum unit will act as a barrier limiting the vertical migration of contaminants because of its lower permeability and contaminated groundwater will preferentially migrate along the Upper Dockum/Lower Dockum contact until reaching the uppermost aquifer, located 2,500 feet downgradient of the site.

The following assumptions were made during modeling groundwater flow and contaminant transport to the uppermost aquifer. All of these assumptions are believed to be conservative in that they result in shorter travel times to the uppermost aquifer:

- It was assumed that contaminants would migrate completely through siltstones, along the Upper Dockum/Lower Dockum contact. A saturated hydraulic conductivity value of the siltstone unit (1.22×10^{-5} cm/s) was used for calculating travel time. In reality, both higher permeability siltstones and lower permeability mudstones (2.45×10^{-7} cm/s) will exist along the migration pathway. As contaminant velocity is directly proportional to the permeability value that is used in the calculation, using a value approximately two orders of magnitude greater than the lower permeability unit results in an extremely conservative estimate of travel time to the uppermost aquifer.

- It is reasonable to assume that any lateral migration of contaminants from the proposed landfill will occur in the most permeable units (siltstones/sandstones) within the Upper Dockum unit. However, the fluvial depositional environment of the Upper Dockum resulted in the formation of discontinuous lenses of various lithologies. This discontinuous deposition pattern (facies changes) is well illustrated in cross-sections shown in Figure 3-13. Using these cross-sections as a specific example, any lateral migration within the siltstones/sandstones at the base of the Upper Dockum unit will encounter a lower permeability mudstones facies approximately 1,000 feet downgradient from the eastern edge of the proposed landfill. This permeability barrier will severely retard continued migration. In the contaminant modeling for this section, these lithologic changes were not credited. Instead, it was assumed that there was a continuous siltstone/sandstone migration pathway from the proposed landfill to the uppermost aquifer. This assumption, based on the discontinuous, fluvial deposition environment within the Upper Dockum, is considered to be conservative;

- To provide an additional degree of conservatism for the travel time calculations, a non-reactive contaminant was assumed to be transported in the groundwater at the interstitial water velocity. Most contaminants are reactive, which results in longer travel times. The ratio of the reactive transport time to non-reactive travel time is given by the retardation coefficient. The retardation coefficient can be calculated, for organic contaminants, by using Equation 1:

Equation 1

$$R = 1 + \frac{(\rho_b * F_{OC} * K_{OC})}{\phi}$$

where:

R = retardation coefficient
ρ_b = bulk density
K_{oc} = organic carbon partition coefficient
F_{oc} = fraction of organic carbon
ϕ = porosity

- For a typical reactive compound such as trichloroethylene (TCE), a retardation coefficient of 4.89 is calculated using measured values of 0.0089 for the fraction of organic carbon, 1.96 g/cm^3 for bulk density, and 0.48 for the porosity of the siltstone; and a handbook value of 107.15 cm^3/g for the organic carbon partition coefficient (Knox et al., 1993). This means that TCE would require 489 percent more time to reach the uppermost aquifer than a non-reactive contaminant;

- The Upper Dockum sediments in the area of the proposed landfill and extending approximately 2,500 feet downgradient from the landfill are unsaturated. For the purpose of this contaminant transport modeling, it was assumed that these sediments were saturated and that lateral migration occurred under steady-state conditions. Due to our understanding of the subsurface conditions of the Upper Dockum unit at the proposed site, this assumption is also considered to be conservative. Assuming saturated conditions results in a conservative estimate of travel time to the uppermost aquifer because unsaturated hydraulic conductivities are orders of magnitude less than saturated values, especially at low water contents (Fetter, 1988). Assuming saturated conditions may result in slightly underestimating hydraulic gradients, especially at short distances; however, at longer distances hydraulic gradients will approach saturated values. Most importantly, while hydraulic gradients vary only by a factor of two or three, this variation is more than offset by the use of values for hydraulic conductivity. The hydraulic conductivity values are orders of magnitude greater during saturated conditions.

- Saturated hydraulic conductivity and porosity values for the Upper Dockum siltstone used during modeling were based on laboratory tests of cores collected during the drilling program. Average saturated hydraulic conductivity and porosity values for the siltstone were 1.22 x 10^{-5} cm/s and 0.48, respectively.

- Travel time was calculated using a steady-state model represented by Darcy's Law as shown in Equation 2 (Fetter, 1988).

Equation 2

$$q = K_{sat} \frac{dh}{dl}$$

where:

q = darcy flux

K_{sat} = saturated hydraulic conductivity
h = hydraulic head
l = length

- The hydraulic gradient used in the model was calculated by dividing the elevation difference between the location of the hypothetical leak and the perched downgradient water (4055-4025) by the distance between these sites (2,500 feet). This calculation results in a hydraulic gradient of 0.012 and a darcy flux of 1.46 x 10^{-7} cm/s.

- Interstitial water velocity was calculated using Equation 3. Water content was assumed to be 0.48 based on the assumption of saturated flow.

Equation 3

$$v = \frac{q}{\theta}$$

where:

v = interstitial water velocity
q = darcy flux
θ = water content

The results of the modeling indicate that a solute would travel at an interstitial velocity of 3.05 x 10^{-7} cm/s and would require 7,920 years to reach the uppermost aquifer. This estimate of travel time is extremely conservative for the following reasons: (1) the saturated hydraulic conductivity of the siltstone used in the calculations is two orders of magnitude greater than the hydraulic conductivity of the mudstone; (2) non-reactive chemical transport was assumed; and (3) saturated hydraulic conductivity values used in the model are orders of magnitude greater than unsaturated values.

To confirm this travel time, similar calculations were conducted using the results of the 1995 confirmation drilling program. A hydraulic gradient of 0.0135 was calculated between drill holes PB-36 and PB-38. The same modeling parameters and equations were applied to this gradient. It was estimated that the time required for contaminants to migrate 2500 feet from the eastern boundary of the proposed landfill to the uppermost aquifer will be 7,042 years.

3.6.3.2 Unsaturated Flow Modeling

Unsaturated flow modeling was performed to simulate potential leakage or infiltration from the proposed hazardous waste landfill. Site characterization data indicate unsaturated conditions in the strata surrounding the proposed landfill. The unsaturated flow model developed by Mckee and Bumb (1988) predicts the extent of wetting fronts emanating from leakage sources on the base and side slopes of the landfill. Leakage rates were based on preliminary HELP (Hydrologic Evaluation of

Landfill Performance) modeling results presented in Tables 3-3 and 3-4. The modeling results help illustrate how the natural hydrological conditions at the site inhibit subsurface fluid flow. [Note: These HELP modeling results should not be confused with those presented in the engineering report in Volumes III and VI, which support the current landfill design.] Three separate simulations were performed to account for the heterogeneities at the site. The first simulation predicts the soil moisture distribution in the Lower Dockum from leakage sources at the base of the landfill. The second simulation predicts the lateral movement of the wetting front into the Upper Dockum from leakage sources on the side slopes of the landfill. The third simulation predicts fluid movement through the clay berm and adjacent Quaternary alluvium along the perimeter of the landfill. The predicted wetting fronts led to the estimation of unsaturated hydraulic conductivities, darcy flux rates, interstitial water velocities and approximate contaminant travel times to the nearest aquifers. The primary modeling objectives include the following:

- prediction of the effective saturation distribution (wetting front) emanating from the landfill source;
- determination of the unsaturated hydraulic conductivity and advective transport rates; and,
- breakthrough time of the wetting front at the edge of the clay berm.

Modeling Methodology

Unsaturated flow modeling was performed using the exact steady state solution developed by Mckee and Bumb (1988) and Bump and Mckee et al. (1988). The steady state solution derived from the Richards equation (1931) of unsaturated flow provides more conservative results in lieu of transient based solutions. The Mckee and Bumb (1988) and Bumb and Mckee et al. (1988) steady state solution for a continuous point source in an infinite isotropic medium is governed by the following equation:

$$\Delta\eta_{\infty} = \frac{Q^{\exp\left[\frac{\alpha}{2}\left(z-z'-\sqrt{r^2+(z-z')^2}\right)\right]}}{4\pi\sqrt{r^2+(z-z')^2}}$$

where

$$r = \sqrt{(x-x')-(y-y')^2}$$

$$\Delta\eta = \text{hydraulic potential}$$

$$S = S_r + (S_m - S_r)(\alpha\eta / K_o)^{1/n}$$

or

$$S_e = (a\eta / K_o)^{1/n}$$

At the Facility site, the evapotranspiration rate is high with respect to precipitation (Stoller, 1994). According to Mckee and Bumb (1988), the soils in semi-arid regions of the western United States are at or below residual saturation (Sr). Therefore, the observed initial moisture contents are probably at or near the residual moisture content. Generally fluid flow is inhibited at soil moisture contents at or below the residual moisture content. The amount of saturation above the residual moisture content is referred to as the effective saturation. Unsaturated hydraulic conductivity is a function of the effective saturation and is expressed in the following equation (Mckee and Bumb, 1988; Bumb and Mckee et al., 1988):

$$K(\theta) = K_0 S_e^n$$

Brooks and Corey (1964) correlated the n exponent with the pore size distribution index α. Mckee and Bumb (1988) by confirmation of theoretical derivations by Irmay (1954) suggest an optimal value of 3 for η.

Under steady state conditions flow is driven by the force of gravity as the matric potential approaches unity (Hillel, 1980). Therefore, under steady state conditions the unsaturated hydraulic conductivity ($K(\theta)$) is equal to the darcy flux ($q(\theta)$), which in turn is multiplied by the unit area to obtain a leakage or discharge rate (Q). The following equations express these relationships:

$$q(\theta) = K(\theta);$$

$$Q = \frac{q(\theta)}{A}$$

The average interstitial water velocity (v) was used to estimate advective transport rates of non-reactive conservative solutes. Approximate travel times to the nearest aquifers can be estimated from the interstitial water velocity using the following expression:

$$v = q / \theta$$

In summary, modeling assumptions include steady state unsaturated flow in an infinite domain, a continuous leakage source, flow through porous medium, complete saturation of the soil beneath the source, and initial uniform saturation of the medium. The modeling does not account for secondary permeability features such as faults, fractures and macropores.

Input Parameters

Input parameters and initial boundary conditions were based on observed field conditions, landfill design specification, and preliminary HELP modeling results [Note: These preliminary HELP modeling results were based on a landfill liner design which did not incorporate a double liner system on the side slope areas. These results should not be confused with the HELP modeling results presented in the engineering report in Volume III and VI. The results presented in the engineering report support the currently proposed landfill design which incorporates a double liner in all areas and does not indicate any leakage from the landfill.] Average hydraulic parameters for the Lower and Upper Dockum and landfill design specifications are presented in this section. Input parameters used for the unsaturated flow modeling are presented in Table 3-5.

The source term geometry was based on the east-west geologic cross-section (Figure 3-13)(Stoller, 1994). Modeled source coordinates correspond to the basal and eastern slope dimensions of the proposed landfill. Conservative average leakage rates from the preliminary HELP modeling were used as source terms along the base (8.58 gpad) and eastern side slope (40.86 gpad) of the landfill to provide conservative "worst case" estimate of unsaturated flow. The leakage rate for the floor of the landfill was based on HELP modeling simulations between 70 and 200 years. The initial leakage rates for the first 50 years of HELP modeling were excluded from the average because these rates were extremely low and probably not representative of steady state conditions. These simulated leakage rates are based on extreme conditions such as waste moisture content conditions which exceed the field capacity of the waste and a termination of leachate pumping following the 30-year post-closure period.

Average site-specific saturated hydraulic conductivity values for the Upper Dockum siltstone (1.22 x 10^{-5} cm/s) and Lower Dockum (5.68 x 10^{-8} cm/s) were used as initial conditions for the first two modeling simulations. The design specifications of the clay berm require material with a permeability on the order of 10^{-7} cm/s. The saturated hydraulic conductivity of the Quaternary alluvium was assumed to be three orders of magnitude less than that of the clay berm. The effective saturation values for the Upper and Lower Dockum simulations were based on site-specific average initial moisture contents (Stoller, 1994). The bubbling pressures for the Upper and Lower Dockum, clay berm, and Quaternary alluvium simulations were based on average values of similar types of geologic materials reported by Bumb and Mckee et al. (1988).

Initial boundary conditions are presented in Figure 3-21, which shows a schematic of the proposed landfill and surrounding hydrostratigraphy. As displayed in Figure 3-21, the Lower Dockum Aquifer is approximately 600 feet (200 meters) below the site. The perched aquifer in the Upper Dockum is located approximately 2,500 feet (755 meters) to the east. The clay berm surrounding the proposed landfill is approximately 20 feet (6 meters) thick and rests on top of the Upper Dockum. The initial soil moisture contents of the surrounding clay berm and strata are assumed to be uniform and at residual saturation.

Modeling Results

The steady state unsaturated flow modeling results are presented in Figures 3-22 through 3-26. The Upper Dockum and clay berm results are presented as a function of lateral distance from the landfill source. The Lower Dockum results are presented as a function of depth from the source. The results of the modeling simulations are in reference to the landfill source.

Figure 3-22 displays the effective saturation at various distances from the source. As the wetting front disperses from the landfill source the chart shows abrupt decreases in saturation. The clay berm/Quaternary alluvium and Upper Dockum simulations show the sharpest decrease in saturation with Se values decreasing by nearly an order of magnitude at less than 100 meters from the source. Although the effective saturation dissipates less rapidly in the Lower Dockum, moisture contents decrease by nearly on order of magnitude at approximately 200 meters from the landfill source. The modeling results indicate that the Lower Dockum maintains greater saturation than the Upper Dockum, clay berm and Quaternary alluvium because fluid movement is driven primarily by gravitational forces; therefore fluid migration is greatest in the vertical direction.

Figures 3-23 and 3-24 display the unsaturated hydraulic conductivity and interstitial water velocity results, respectively. Comparison of these data to the effective saturation distributions (Figure 3-20) show the high degree of correlation between unsaturated flow and soil moisture content. Figures 3-23 and 3-24 show abrupt decreases in unsaturated hydraulic conductivity and interstitial water velocity, respectively, at relatively short distances from the source. Although Figure 3-24 shows that the interstitial water velocities decrease exponentially over distance, gross travel times may be estimated. The simulated interstitial water velocities were used to compute the following contaminant travel times of non-reactive solutes:

- contaminant travel time from the base of the landfill to the Lower Dockum Aquifer, located approximately 200 meters (600 feet) below the site, is estimated at 4,084,674 years;

- contaminant travel time from the eastern slope of the landfill to the perched groundwater in the Upper Dockum at a lateral distance of 755 meters (2,500 feet) was estimated at 3.4 billion years;

- breakthrough time of the wetting front at the edge of the clay berm (a travel distance of 6 meters or (20 feet) was estimated at 866 years; and,

- contaminant travel time through the clay berm and Quaternary alluvium to a point above the perched groundwater (a distance of 755 meters) was estimated at 574,507,913 years.

Figures 3-25 and 3-26 display the steady state leakage per unit area as a function of distance from the source. Figure 3-26 also shows that the leakage rate at the edge of the clay berm (6 meters from the source) is approximately 10 gpad but quickly dissipates in the Quaternary alluvium. Despite the high leakage rate (10-11 gpad), calculations indicate that it would take a wetting front approximately 866 years to reach the outer edge of the berm.

Explanation of equation parameters:

A = area [L^2]
k = hydraulic conductivity [L/T]
K_o = hydraulic conductivity at maximum saturation [L/T]
n = power in the power-law relationship for K as a function of soil saturation
Q = flow rate or strength of point source [L^3/T]
R = distance from point source [L]
S = saturation of the soil
S_e = effective saturation
S_m = maximum saturation
S_r = irreducible or residual saturation
v = velocity of particles
x,y,z = Cartesian coordinates, z defined positive downward [L]
x',y',z' = location of point source [L]
α = constant defined by n/β [1/L]
β = bubbling pressure [L]
θ = volumetric moisture content
$\varnothing$ = porosity
$\Delta\eta$ = hydraulic potential

3.7 GROUNDWATER PROTECTION REQUIREMENTS

The following sections present general monitoring requirements and detection monitoring requirements, respectively.

3.7.1 General Monitoring Requirements

The selection of a monitoring program to identify contaminant releases from the proposed Facility was based on results of the geologic characterization and RCRA guidance. For the purposes of designing a monitoring program for the site, the Upper Dockum Unit was considered the uppermost aquifer (Section 3.6.2.2). This unit is not saturated within the Facility boundaries.

Two major geologic factors influence the design of a program to monitor potential contaminant releases from the site. These factors are the intermittent nature of saturation in the Upper Dockum downgradient of the Facility and the presence of a low permeability layer (the Lower Dockum) that significantly limits the potential for vertical migration of contaminants. These two factors influence potential groundwater transport pathways for contaminants released from the Facility and, therefore, affect the placement of monitoring devises.

There is no regional aquifer developed within the Upper Dockum; however, adjacent to the project boundary, permeable zones have been observed to be saturated. Exploratory drilling upgradient and downgradient of the site has identified isolated pockets of groundwater in permeable facies of the Upper Dockum (Section 3.6.2.2). Downgradient of the site, perched groundwater was detected above the Upper Dockum/Lower Dockum contact, approximately 2,500 feet east of the proposed landfill. Upgradient of the site, an isolated pocket of groundwater was detected at Borehole 14. The low permeability of the underlying Lower Dockum will prevent significant vertical migration of groundwater and will direct flow downdip along the Upper Dockum/Lower Dockum contact in the direction of perched groundwater east of the site. Therefore, potential contaminant releases from the proposed Facility will preferentially migrate downdip along the Upper Dockum/Lower Dockum contact.

Given the geologic and hydrologic features controlling the movement of groundwater at the site, monitoring the Upper Dockum is the most effective manner in which to immediately detect potential releases from the Facility. However, the placement of monitoring wells in the Upper Dockum is limited due to the fact that this unit is unsaturated within the site boundary. The utility of placing groundwater monitoring wells 2,500 downgradient of the landfill is questionable. The most effective monitoring program will involve vadose zone monitoring. A request to utilize the vadose zone system for groundwater monitoring is being submitted under separate cover.

3.7.2 Vadose Zone Monitoring Requirements

The proposed design for the Facility includes a vadose zone monitoring system in the sump of each cell. The intent of the sump vadose monitoring system is to provide an immediate indication if there is any leakage from the double composite liner system. Leakage from the secondary liner will be intercepted by the vadose zone monitoring system, which will be checked daily for the presence of liquids.

The design of the vadose zone monitoring system is shown in the design Drawings 15 through 19 in Volume III. It includes a 60 mil HDPE liner system below the bottom of the secondary liner system in the area of the sump. The vadose zone liner system is limited to an area directly beneath the sump, as this is the area expected to have the most liquids ponded for the longest period of time. Above the HDPE liner in the vadose zone sump, a drainage gravel surrounds a side slope riser pipe that extends into the sump. The side slope riser pipe allows a pump to be installed in the sump to remove accumulated liquids.

The vadose zone monitoring system, shown in the design drawings (Volume III) and described above, is expected to be a much more immediate indicator of leakage from the landfill than any other type of groundwater monitoring system or even a vadose zone monitoring system installed around the perimeter of the landfill. Given the geologic and hydraulic conditions at the base of the landfill (unsaturated Upper Dockum siltstones and claystones), any fluids leaking from the landfill will migrate vertically with limited lateral dispersion and will be very difficult to intercept and detect. Since each cell is graded so that leachate will collect in the sump, liquids will be present in this area for the longest period of time, resulting in the sump area having the highest hydraulic head on the liner system. A vadose liner below the sump areas will indicate quickly if liquids are escaping from the liner system. The vadose zone sump will not only provide an indication that the LDRS sump is leaking, but will also provide access to remove the leakage and minimize head buildup in the sumps and in liners above until the source of the leakage is found. The vadose sumps for the landfill and evaporation ponds will be monitored for the presence of liquids whenever the primary or secondary sumps are monitored. As described in Section 5.2.2, these systems will be checked daily during active operations and closure.

It is expected that liquids in the vadose sump could occur from two sources. The first is consolidation of the overlying clay liner draining into the sump. This water is expected to be uncontaminated. The second source is leakage from the landfill. This liquid is expected to be similar to the leachate that is collected from the primary sumps. After the start of operations of the landfill, the leachate that is collected and removed from the primary sump will be analyzed to determine its constituents. Based on this analysis a select series of parameters will be identified that can be used to identify leachate from consolidation water. Thereafter, whenever liquids are detected in the vadose sump, they will be removed and sampled. Samples will be analyzed for leachate characteristics. If any of the leachate parameters are identified, the samples will be tested for the complete EPA Appendix IX parameters. If leachate is confirmed to be present in the vadose zone sump, then corrective action measures will be implemented.

3.8 SUMMARY AND CONCLUSIONS

The proposed location of the Facility landfill in eastern Chaves County, New Mexico is ideal. It is located in an unpopulated portion of the county, on privately owned land, and more than 36 miles from the nearest community. The semiarid climate of this region with its high evaporation rate and lack of surface water, will play an important role in the proposed site's ability to confine and control material placed in the landfill.

Large-scale ranching is the primary land use for this portion of Chaves County. However, setting aside the 480 acres proposed for the Facility will have no impact on the ranching industry in the region, as these acres support fewer than five animal units year-long. Since the economic stimulation provided by landfill-related jobs will greatly offset the minimal economic impact of the loss of grazing land, the project has the support of the surrounding community.

A geologic setting for the Facility was selected that will enable the proposed landfill to be developed in an environment that will protect groundwater resources and ensure long-term isolation of wastes. The host rocks for this Facility are the sediments of the Dockum Group of Triassic age. Because these sediments are unsaturated and of low permeability, they represent a stable geologic barrier to the potential migration of contaminants from the proposed landfill.

The proposed landfill will be developed within sediments of the Upper Dockum unit. These sediments, consisting of fluvial, interbedded mudstones (30 percent) and siltstones (70 percent), are unsaturated beneath the proposed site. The nearest groundwater production comes from the Tertiary Ogallala Aquifer. The western boundary of this aquifer forms a topographic feature called the Caprock, which is approximately two miles east and several hundred feet higher than the proposed site.

While the Upper Dockum unit is unsaturated beneath the site, it is partially saturated 2,500 feet east of the proposed landfill (downdip). The source of this groundwater is infiltration from the overlying Ogallala Aquifer. Due to this perched groundwater, the Upper Dockum unit is designated as the uppermost aquifer for the purposes of this permit application.

The hydrologic setting of the Facility is extremely protective of groundwater resources. To demonstrate the integrity of the natural barriers present at this site, conservative contaminant transport modeling was performed, in which the most conservative parameters were consistently input into the modeling process. Acceptable conclusions were obtained even though "worst case" assumptions were used. The site's actual values will obviously provide an even larger margin of safety than the conclusions indicate.

For example, conservative transport modeling calculated that it will take 7000 - 8000 years for potential contaminates to migrate laterally through the sediments on the flanks of the proposed landfill to the nearest perched groundwater-bearing intervals within the uppermost aquifer. To emphasize the conservative nature of these calculations, saturated conditions were assumed for this modeling even though the Upper Dockum sediments at the proposed site are unsaturated. The migration pathway was assumed to be entirely through highly permeable siltstones, although close-spaced drilling indicated that 30 percent of this pathway would be comprised of low permeability mudstones. A non-reactive contaminant was also assumed, even though in reality a contaminant would react with the sediments through which it was traveling, adding considerably to the overall travel time.

To illustrate the conservative nature of this 7000 - 8000 year travel time, a second, unsaturated flow modeling approach was applied to the lateral contaminant migration scenario. This more realistic calculation resulted in an estimated travel time of 3.4 billion years.

The character of the Lower Dockum sediments is much different from that of the overlying Upper Dockum unit. The Lower Dockum consists of a 600-foot thickness of homogeneous, lacustrine mudstones overlying a thin basal sandstone. This thick sequence of unsaturated, low permeability mudstones represents a geologic barrier to the potential downward migration of contaminants from the proposed landfill. Unsaturated flow modeling estimated that 4 million years would be required for contaminants to migrate downward through these Lower Dockum mudstones and reach a Lower Dockum aquifer.

The description of the proposed Facility, as presented in this permit application is a result of three years of investigation to identify an environmentally sound site in southeastern New Mexico where hazardous wastes could be safely disposed. The location, geology and hydrology of the proposed site present a unique setting, where natural geologic barriers, combined with a well-conceived landfill design, will ensure long-term isolation of hazardous wastes from the environment.

TABLE 3-1
TEMPERATURES AT ROSWELL, 1977 TO 1978

Month	Monthly Average (°F)	Average Daily Maximum (°F)	Average Daily Minimum (°F)
January	38.1	55.4	20.8
February	42.9	60.9	24.8
March	49.3	57.7	30.9
April	59.7	78.2	41.2
May	68.5	86.4	50.5
June	77.0	94.2	59.8
July	79.2	94.7	63.7
August	77.9	93.4	62.3
September	70.4	86.5	54.3
October	59.6	77.0	42.2
November	46.9	64.8	29.0
December	39.3	56.8	21.8
Annual	**59.1**	**76.3**	**41.8**

TABLE 3-2
MONTHLY AND ANNUAL PRECIPITATION SUMMARY FOR ROSWELL (INCHES)
1977 THROUGH 1982

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1977	0.07	0.36	0.27	1.25	2.43	0.25	0.46	4.45	0.29	0.62	0.48	0.02	10.95
1978	0.50	0.48	0.39	0.02	1.81	4.31	0.52	3.49	3.58	1.47	1.25	0.43	18.25
1979	0.41	0.44	0.13	0.32	1.25	1.56	1.44	2.28	0.15	0.18	T	0.37	8.53
1980	0.85	0.19	0.00	1.06	0.85	0.29	0.01	2.45	6.58	T	0.77	0.15	13.20
1981	0.27	0.17	0.10	0.79	3.35	4.55	6.27	4.73	2.70	1.02	0.25	0.13	24.33
1982	0.66	0.20	0.12	0.41	0.20	0.76	1.03	0.93	2.00	0.20	0.92	1.62	9.05

Normal = 10.61
T = trace

TABLE 3-3
TRIASSIC PARK HELP MODEL RESULT SUMMARY FOR CELL FLOOR

Time (years)	LCRS Operational Beyond 30 Years Post Closure			LCRS Not Operational Beyond 30 Years Post Closure		
	Liner Leakage (gal/acre/day)	Cap Leakage (gal/acre/day)	Final Waste Moisture Content (vol/vol)	Liner Leakage (gal/acre/day)	Cap Leakage (gal/acre/day)	Final Waste Moisture Content (vol/vol)
0	1.3781	NA	0.1410	1.3781	NA	0.1410
20	0.9400	0.0454	0.1222	.9400	0.0454	0.1222
30	0.2735	0.0430	0.1181	0.2735	0.0430	0.1181
50	0.1927	0.0450	0.1125	3.4579	0.0450	0.1125
70	0.1329	0.0450	0.1087	8.0071	0.0450	0.1098
90	0.1007	0.0439	0.1059	9.1465	0.0439	0.1083
100	0.0775	0.0442	0.1049	8.5811	0.0442	0.1076
120	0.0744	0.0453	0.1029	8.8612	0.0453	0.1062
140	0.0629	0.0461	0.1013	8.6989	0.0461	0.1048
160	0.0547	0.0442	0.0999	8.5494	0.0442	0.1034
180	0.0482	0.0442	0.0987	8.4178	0.0442	0.1021
200	0.0431	0.0431	0.0976	8.2818	0.0442	0.1008

NA - Not Applicable

TABLE 3-4
TRIASSIC PARK HELP MODEL RESULT SUMMARY FOR CELL SLOPE[1]

	LCRS Operational Beyond 30 Years Post Closure			LCRS Not Operational Beyond 30 Years Post Closure		
Time (years)	Liner Leakage (gal/acre/day)	Cap Leakage (gal/acre/day)	Final Waste Moisture Content (vol/vol)	Liner Leakage (gal/acre/day)	Cap Leakage (gal/acre/day)	Final Waste Moisture Content (vol/vol)
0	173.0000	NA	0.1410	173.0000	NA	0.1414
20	123.0000	0.0453	0.1221	123.0000	0.0453	0.1223
30	53.5373	0.0442	0.1182	53.5373	0.0442	0.1182
50	37.0011	0.0453	0.1152	37.0282	0.0453	0.1152
70	24.5001	0.0461	0.1087	24.5114	0.0452	0.1087
90	18.0529	0.0442	0.1059	18.0583	0.0449	0.1059
100	13.6143	0.0425	0.1049	13.6174	0.0430	0.1049
120	12.9000	0.0443	0.1029	12.9032	0.0450	0.1029
140	10.7627	0.0439	0.1013	10.7642	0.0450	0.1013
160	9.2002	0.0457	0.0999	9.2030	0.0439	0.0999
180	8.0161	0.0462	0.0987	8.0178	0.0457	0.0987
200	7.0994	0.0461	0.0976	7.1002	0.0462	0.0976

Note:[1] Initial HELP Modeling Results were based on landfill liner system without double liner system on side slopes. These should not be confused with HELP results presented in the Engineering Report.
NA - Not Applicable

TABLE 3-5
INPUT PARAMETERS FOR UNSATURATED FLOW MODELING

	β	Ko			Q		α	Source Coordinates (m)		
Unit	**(m)**	**(m/day)**	**Sr**	**Sm**	**(m^3/day)**	**n**	**1/m**	**x[1]**	**y[1]**	**z[1]**
Lower Dockum	0.373	4.90E-05	0.279	1	8.00E-05	3	8.042	0, 33, 66, 99, 132, 165, 193, 231, 264, 297, 330, 363, 396, 429, 462	0	0
Upper Dockum	0.2076	1.05E-02	0.161	1	3.80E-05	3	14.45	5.5, 11, 16.5, 22, 27.5, 33, 38.5, 44, 49.5, 55, 60.5, 66, 71.5, 77	0	24.5, 22.6, 20.72, 18.84, 16.96, 15.07, 13.19, 11.31, 9.42, 7.[illegible] 5.65, 3.77, 1.88, 0
Clay Berm	0.37	8.64E-05	0.126[a]	1	3.80E-05	3	8.108	0, 5.5, 11	0	3.77, 1.88, 0
Quaternary Alluvium	0.0726[a]	8.64E-02	0.0458[a]	1	3.80E-05	3	41.32	0, 5.5, 11	0	3.77, 1.88, 0

Key:

β = bubbling pressure; typical values reported by Bumb and Mckee et al. (1988)
Ko = saturated hydraulic conductivity; site-specific means values
Sm = maximum saturation; assumed
Sr = residual saturation; site-specific mean values
Q = leakage rate; based on HELP modeling results
n = curve fitting parameter based on pre size index (Mckee and Bumb, 1988)
α = n/β
1 = Typical values reported by Bumb and Mckee et al (1988)
a = typical values reported by Bumb and Mckee et al. (1988)
b = assumed values

Insert Figure 3-1, Index Map Proposed Site

Insert Figure 3-2, Topography South East New Mexico

Insert Figure 3-3, Wind Rose South East New Mexico

Insert Figure 3-4, Stratigraphic Column

Insert Figure 3-5, Basin Map for Triassic Period

Insert Figure 3-6, Triassic Period Sand Accumulation in Paleobasin

Insert Figure 3-7, Plan View, 3-Point for the Bedding Strike and Dip Angle

Insert Figure 3-8, Seismic Activity - South East New Mexico

Insert Figure 3-9, Surface Geology - Project Area

Insert Figure 3-10, Stratigraphic Cross-Section

Insert Figure 3-11, Close-Spaced Drilling Pattern

Insert Figure 3-12, Proposed Disposal Site

Insert Figure 3-13, Cross Section 1995 Drill Holes

Insert Figure 3-14, Structure Contour Top of Lower Dockum

Insert Figre 3-15, Total Drill Holes

Insert Figure 3-16, Air Photo - South East New Mexico

Insert Figure 3-17, Project Area

Insert Figure 3-18, Water Wells – 10-Mile radius

Insert Figure 3-19, Drill Hole Locations

Insert Figure 3-20, Upper Dockum Perched Water

Insert Figure 3-21, Landfill Profile

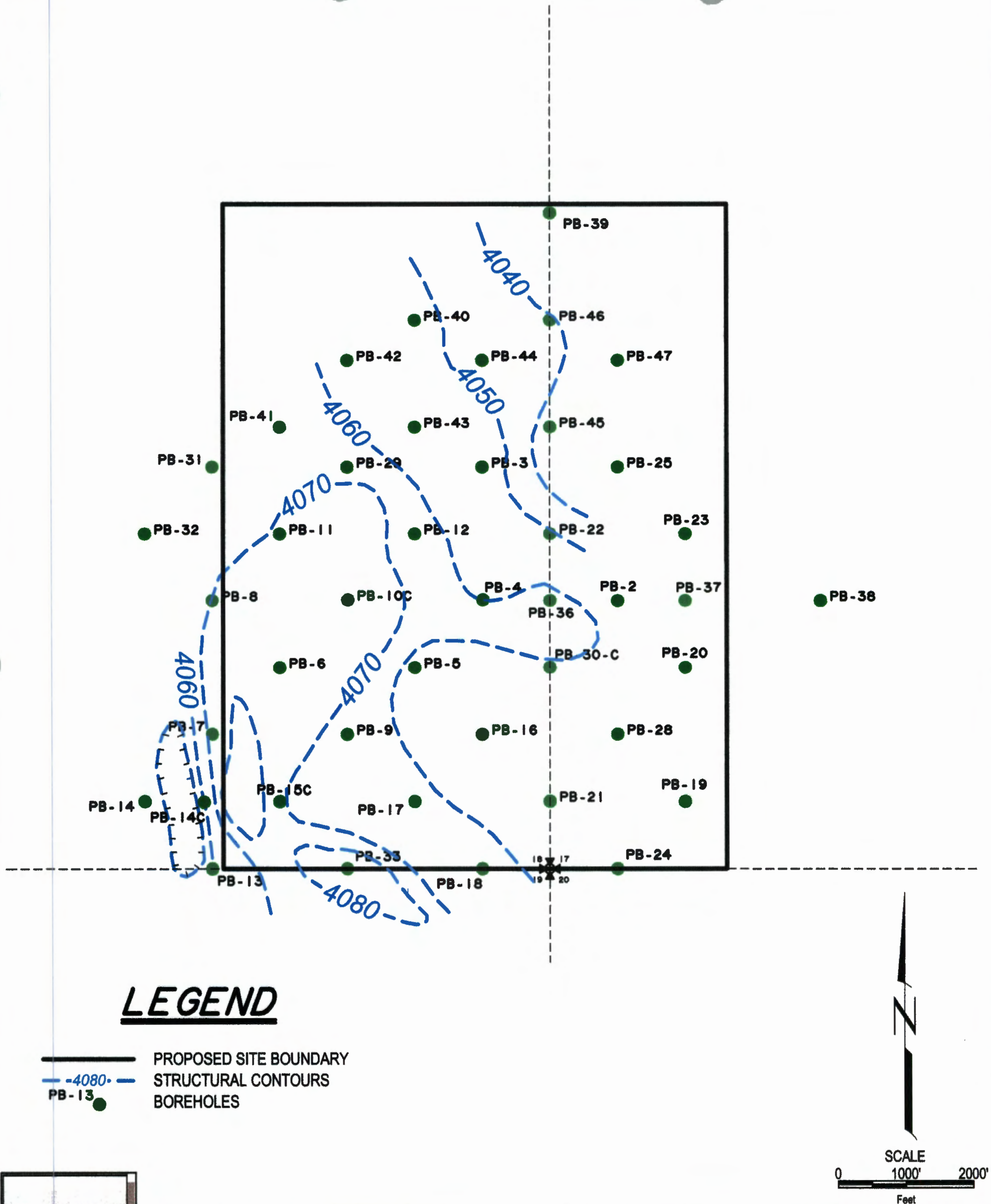
Insert Figure 3-22, Steady State Effect Saturation vs. Distance

Insert Figure 3-23, Steady State Effect Conductivity vs. Distance

Insert Figure 3-24, Steady State Effect Velocity vs. Distance

Insert Figure 3-25, Steady State Effect Leakage vs. Distance

Insert Figure 3-26, Steady State Effect Leakage vs. Lateral

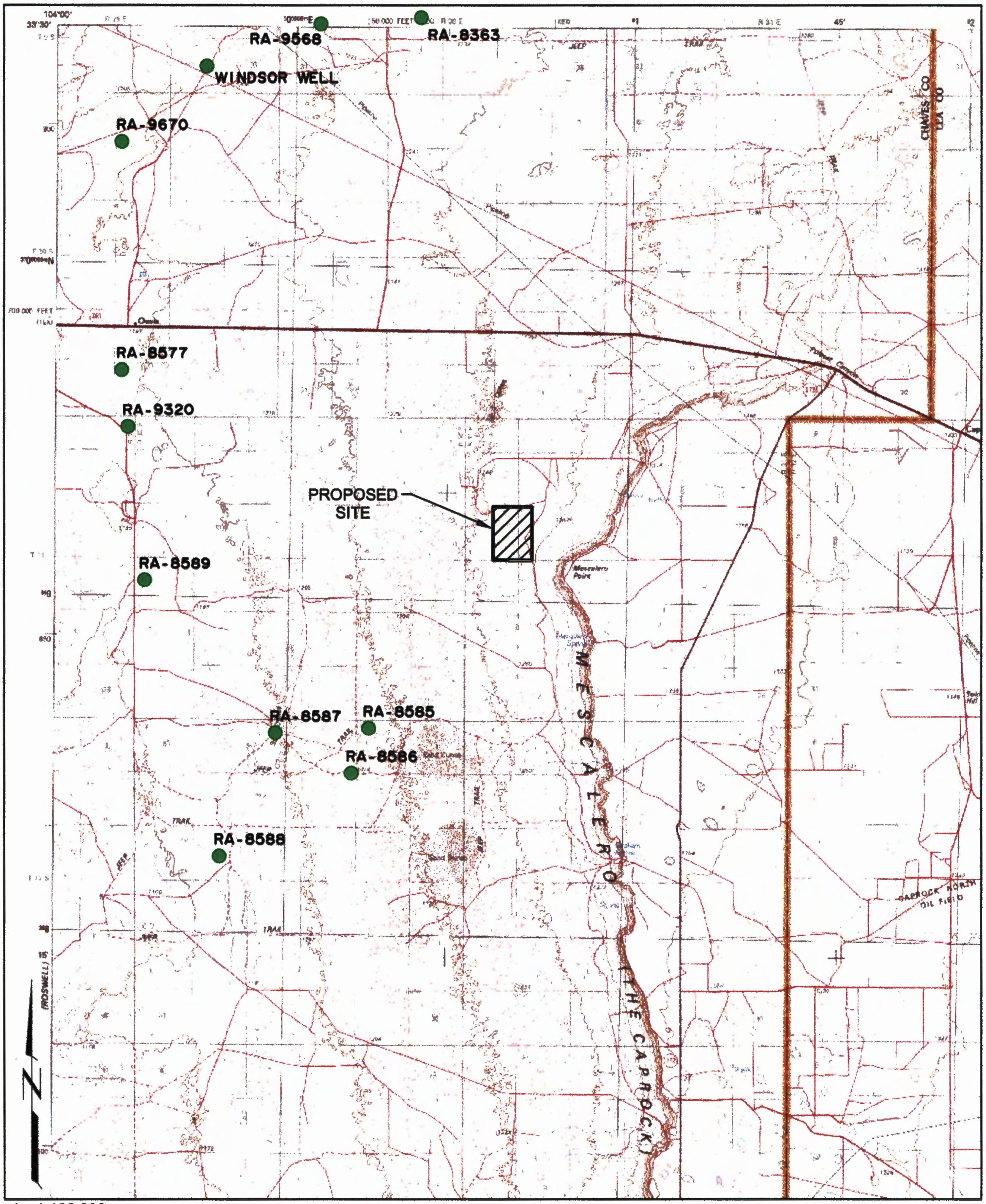


STRUCTURE CONTOUR TOP OF LOWER DOCKUM

TRIASSIC PARK WASTE DISPOSAL FACILITY

Figure 3-14

AutoCAD FILE: GAND-3-6.DWG



Scale: 1:100,000

WATER WELLS - 10 MILE RADIUS

TRIASSIC PARK WASTE DISPOSAL FACILITY

Figure 3-18

AutoCAD FILE: 10-MIWELLS.DWG