RCRA PERMIT APPLICATION FOR A HAZARDOUS WASTE STORAGE, TREATMENT AND DISPOSAL FACILITY ANDREWS COUNTY, TEXAS

SECTION VI. GEOLOGY REPORT

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Table of Contents

List of Tables iii
List of Figures iv
List of Plates vi

VI. Introduction .... VI. - 1

VI.A. Geology and Topography .... VI.A. - 1
- A.1. Active Geologic Processes .... VI.A. - 1
  - A.1.1. Identification of Faults .... VI.A. - 1
  - A.1.2. Land Surface Subsidence .... VI.A. - 6
  - A.1.3. Potential for Erosion (AME Report) .... VI.A. - 7
- A.2. Physiography and Topography .... VI.A. - 7
  - A.2.1. Physiographic Setting and Climate .... VI.A. - 7
  - A.2.2. Topographic Features, Soil and Land Use .... VI.A. - 8
- A.3. Regional Geology .... VI.A. - 11
  - A.3.1. Regional Surface Sediments .... VI.A. - 11
  - A.3.2. Regional Stratigraphy .... VI.A. - 14
- A.4. Site Subsurface Soils Investigation .... VI.A. - 20
  - A.4.1. Investigation Procedures (JHA Report) .... VI.A. - 20
  - A.4.2. Subsurface Structure .... VI.A. - 20
  - A.4.3. Subsurface Stratigraphic Complexity .... VI.A. - 25
  - A.4.4. Hydrogeologic Framework .... VI.A. - 32
  - A.4.5. Geotechnical Properties of the Subsurface Soils (JHA Report) .... VI.A. - 33

VI.B. Facility Groundwater .... VI.B. - 1
- B.1. Regional Aquifers .... VI.B. - 1
  - B.1.1. Ogallala Aquifer .... VI.B. - 1
  - B.1.2. Cretaceous Aquifer .... VI.B. - 3
  - B.1.3. Dockum Group Aquifer .... VI.B. - 3
- B.2. Local Groundwater Conditions .... VI.B. - 5
  - B.2.1. Uppermost Aquifer .... VI.B. - 5
  - B.2.2. Aquiclude .... VI.B. - 8
  - B.2.3. Underground Sources of Drinking Water (USDW) .... VI.B. - 8
- B.3. Detection Monitoring System (AME Report) .... VI.B. - 9
  - B.3.1. Proposed Well System (AME Report) .... VI.B. - 9
  - B.3.2. Sampling Parameters (AME Report) .... VI.B. - 9

Table of Contents (Continued)

VI.C. Exemption from Groundwater Monitoring .... VI.C. - 1

VI.D. Unsaturated Zone Monitoring .... VI.D. - 1

VI.E. References .... VI.E. - 1

Appendix A Records of Water Wells and Oil and Gas Wells in the Area
Appendix B Soil Boring and Well Completion Logs
Appendix C Shallow Geophysical Logs

List of Tables

Table	Title
VI.A.1	Historical Seismic Activity Within 250-km (155-mile) Radius of the Proposed Landfill Site
VI.A.2	Source of Identification of Oil and Gas Artificial Penetrations
VI.A.3	Summary of Oil and Gas Artificial Penetrations Within a 1-Mile Radius of the Landfill Site
VI.A.4	Soil Boring, Well Completion and Geologic Data Summary, Andrews County Landfill Site
VI.B.1.a	Tabulation of Water Wells Within 2-Mile Radius of the Landfill Site
VI.B.1.b	Summary of Groundwater Quality Characteristics in Western Andrews County, Texas and Eastern Lea County, New Mexico
VI.B.2	Water Level Data Summary, Andrews County Landfill Site

List of Figures

Figure	Title
VI.A.1	Site Location Map
VI.A.2	Major Structural Provinces of West Texas and Southeastern New Mexico
VI.A.3	Regional Structure Contour Map of the Precambrian Basement
VI.A.4	Major Tectonic Features of the Permian Basin - Late Mississippian to Permian
VI.A.5	Regional East-West Structural Cross Section, Central Basin Platform
VI.A.6	Regional North-South Structural Cross Section, Matador Arch to Val Verde Basin
VI.A.7	Regional Structure Contour Map of the Woodford Formation
VI.A.8	Regional Structure Contour Map of the Upper Guadalupe (Whitehorse Group)
VI.A.9	Historic Seismic Events Within 250 Km of the Landfill Site
VI.A.10	Seismic Risk Map of the United States
VI.A.11	Regional Surface Lineation Map
VI.A.12	Color-Infrared Aerial Photograph Showing the Landfill Site and Surface Lineations
VI.A.13	Physiographic Units of the Texas Panhandle and Eastern New Mexico
VI.A.14	Mean Annual Precipitation Texas Panhandle and Eastern New Mexico
VI.A.15	Stratigraphic Column Central Basin Platform
VI.A.16	Location of Oil and Gas Artificial Penetrations
VI.A.17	Location of Stratigraphic Cross Sections
VI.A.18	Inferred Paleogeography of Dockum Sedimentation
VI.A.19	Isopach Map of the Upper Dockum Group
VI.A.20	Map of Cretaceous Subcrops
VI.A.21	Structure Contour Map of the Base of the Ogallala Formation
VI.A.22	Ogallala Depositional Facies Map
VI.A.23	Location of Site Investigation Cross Sections
VI.A.24	Cross-Section A - A'
VI.A.25	Cross-Section B - B'
VI.A.26	Cross-Section C - C'
VI.A.27	Cross-Section D - D'
VI.A.28	Cross-Section E - E'
VI.A.29	Cross-Section F - F'
VI.A.30	Cross-Section G - G'
VI.A.31	Cross-Section H - H'
VI.A.32	Cross-Section I - I'
VI.A.33	Cross-Section J - J'

List of Figures (Continued)

Figure	Title
VI.A.34	Structure on top of the Dockum Group
VI.A.35	Dockum Group Orthographic Projection Looking Northwest
VI.A.36	Dockum Group Orthographic Projection Looking Northwest and Southeast
VI.A.37	Depth to top of the Dockum Group
VI.A.38	Dockum Group Percent Sandstone and Siltstone
VI.A.39	Percent Sand Map of Lower Dockum Group
VI.B.1	Regional Potentiometric Surface of the Ogallala Aquifer
VI.B.2	Regional Potentiometric Surface of Water in Cretaceous Aquifers
VI.B.3	Hypothetical Regional Flow Paths of Groundwater in the Ogallala Formation and Dockum Group
VI.B.4	Regional Potentiometric Surface of the Lower Dockum Aquifer
VI.B.5	Potentiometric Head-Difference Map Between the Ogallala Aquifer and Underlying Aquifers
VI.B.6	Potentiometric Surface Map of the Local Dockum Aquifer

List of Plates

Plate	Title
VI.A.1	Regional Topographic Map and Water Well Locations
VI.A.2	Geologic Atlas of Texas, Hobbs Sheet
VI.A.3	Site Topographic Map
VI.A.4	Dip-Oriented Stratigraphic Cross-Section A-A'
VI.A.5	Strike-Oriented Stratigraphic Cross-Section B-B'

VI. Introduction

Waste Control Specialists, Inc. (WCS) proposes to permit a Class I hazardous waste landfill pursuant to 40 CFR Part 270, 31 TAC Chapter 305 (C) and (D) and 31 TAC Chapter 335. This report, which addresses the geologic aspects of the Resource Conservation and Recovery Act (RCRA) Part B Permit Application, has two companion reports which focus on the various engineering and geotechnical considerations of the Part B Permit Application. These two companion reports, provided under separate cover, were prepared by AM Environmental, Inc. (AME) of Austin, Texas (engineering design) and Jack H. Holt and Associates, Inc. (JHA) also of Austin, Texas (geotechnical evaluation). Where engineering design and/or geotechnical aspects of the geologic report are addressed by one of the other two reports, this fact is noted in the geologic report table of contents as well as noted within the geologic report text.

The proposed WCS landfill site is located in northwest Andrews County, Texas, approximately 30 miles northwest of the City of Andrews (Figure VI.A.1). This site rests on a gently sloping plain with a natural slope of approximately 0.5 degrees. The site is underlain by Quaternary windblown sands, the Tertiary Ogallala Formation, and the Triassic Dockum Group.

Portions of the Ogallala Formation serve as the regional aquifer for the Southern High Plains. However, the proposed WCS landfill site is located on the western edge of the Caprock Escarpment where the Ogallala Formation has been mostly eroded away and appears to be locally dry.

Regionally, the erosional remnants of the Ogallala Formation are typically cemented with caliche and produce water only in relatively low topographic areas, following wet weather periods. However, the vertical downward migration of groundwater from the Ogallala Formation appears to be locally impeded by many feet of low hydraulic conductivity claystones, siltstones, and interbedded silty sandstones which comprise the upper portion of the Dockum Group.

A summary of the regional and local topography, physiography and geology is presented in Section VI.A. of this report. Section A.1. contains a discussion regarding the active geologic processes, including: fault identification; seismicity; surface lineations; and land surface subsidence. The potential for erosion is discussed in a separate report provided by AME.

A regional and local physiographic and topographic discussion is provided in Section A.2. A discussion regarding the regional geology, including surface geology and stratigraphy, is contained in Section A.3. The regional discussion addresses the conditions that exist in the area of West Texas and Southeast New Mexico.

Results of the site subsurface soils investigation are presented in Section A.4. The subsurface structure, stratigraphic complexity, and the general hydrogeologic framework of the proposed WCS landfill site are discussed in this section. The subsurface investigation procedures and geotechnical properties of the subsurface soils are discussed in a separate report provided by JHA.

Section VI.B. of this report provides a detailed discussion of the regional and local groundwater conditions. This discussion includes a review of regional aquifers (Section B.1.) as well as a presentation of local groundwater conditions and the underground sources of drinking water (USDW) (Section B.2.). The detection monitoring system is discussed in a separate report provided by AME.

Section VI.C. of this report pertains to groundwater monitoring exemption, while Section VI.D. focuses on unsaturated zone monitoring. Records regarding local oil and gas wells are provided in Appendix A. Soil boring and well completion logs are provided in Appendix B. Shallow geophysical logs are provided in Appendix C.

VI.A. Geology and Topography

A.1. Active Geologic Processes

Active geologic processes consist of faulting, seismicity, surface lineations, land surface subsidence and the potential for surface erosion. These processes are discussed in the following section, except the potential for surface erosion. This is discussed in the companion engineering design report prepared by AME.

A.1.1. Identification of Faults

<u>Regional Tectonic Processes</u>
The proposed WCS landfill site is located within the Permian Basin region of West Texas. The Permian Basin derives its name from the fact that it is underlain by extensive deposits of Permian sediments.

The proposed landfill site is situated over the north central portion of a prominent structural feature known as the Central Basin Platform (Figure VI.A.2). The Central Basin Platform is a deep-seated horst-like structure that extends northwest to southeast from Southeast New Mexico to eastern Pecos County, Texas. The Central Basin Platform is flanked by two prominent structural depressions known as the Delaware Basin and the Midland Basin.

From the Cambrian to late Mississippian, West Texas and Southeast New Mexico experienced only mild structural deformation that produced broad regional arches and shallow depressions (Wright, 1979). The Central Basin Platform served intermittently as a slightly positive feature during the early Paleozoic (Galley, 1958). During the Mississippian and Pennsylvanian, the Central Basin Platform uplifted along ancient lines of weakness (Hills, 1985). The Delaware, Midland, and Val Verde Basins began to form out of the previously existing broad limestone shelf and shale basin.

Late Mississippian tectonic events uplifted and folded the platform and were followed by more intense late Pennsylvanian and early Permian deformation that compressed and faulted the area (Hills, 1963). Highly deformed local structures formed ranges of mountains oriented generally parallel to the main axis of the platform (Wright, 1979). The overall structural configuration of the Permian Basin was essentially completed by the end of Wolfcampian time (early Permian) (Stone and Webster, 1983).

This period of intense, late Paleozoic deformation was followed by a long period of gradual subsidence and erosion that stripped the Central Basin Platform and other structures to near base-level (Wright, 1979). The expanding sea gradually encroached over broad eroded surfaces and truncated edges of previously deposited sedimentary strata. These strata included new layers of arkose, sand, chert pebble conglomerate and shale deposits, which accumulated as erosional products along the edges and on the flanks of both regional and local structures. Throughout the remainder of Permian, the Permian Basin slowly filled with several thousand feet of evaporites, carbonates, and shales (Stone and Webster, 1983).

From the end of the Permian until late Cretaceous, there was relatively little tectonic activity except for periods of slight regional uplifting and downwarping (Stone and Webster, 1983). During the early Triassic, the region was slowly uplifted and slightly eroded. These conditions continued until the late Triassic, when gentle downwarping formed a large land-locked basin in which the terrigenous deposits of the Dockum Group accumulated in alluvial flood plains and as deltaic and lacustrine deposits (McGowen, et. al., 1979).

The late Cretaceous to early Tertiary marked the beginning of the Laramide Orogeny, which formed the Cordilleran Range to the west of the Permian Basin. This orogeny uplifted the region to essentially its present position, supplying sediments for the Pliocene Ogallala Formation and initiating the present hydrologic regime (Stone and Webster, 1983). There have been no major tectonic events within the Permian Basin since that time, except for a period of minor volcanism during the late Tertiary in northeastern New Mexico (Stone and Webster, 1983). Slight Tertiary movement along Precambrian lines of weakness may have opened joint channels which allowed the circulation of groundwater into Permian evaporite layers (Hills, 1985). The near-surface regional structure may be locally modified by differential subsidence related to groundwater dissolution of Permian salt deposits (Gustavson et. al., 1980).

Regional Faulting

Two types of faulting were associated with early Permian deformation. Most of the faults were long, high-angle reverse faults with several hundred feet of vertical displacement that often involved the Precambrian basement rocks (Hills, 1985). The traces of these faults are shown on the Precambrian structure map provided in Figure VI.A.3. The second type of faulting is found along the western margin of the platform where long strike-slip faults, with displacements of tens of miles, are found (Harrington, 1963) (Figure VI.A.4).

The large structural features of the Permian basin are reflected only indirectly in the Mesozoic and Cenozoic rocks, as there has been virtually no tectonic movement within the basin since the Permian (Nicholson and Clebsch, 1961). The east-west and north-south regional cross-sections provided in Figures VI.A.5 and VI.A.6 illustrate this relationship. Figure VI.A.5 reveals the draping of the Permian and Triassic sediments over the Central Basin Platform structure, located approximately 7,000 feet beneath the present land surface. The faults that uplifted the platform do not appear to displace the younger Permian sediments. The northernmost fault on Figure VI.A.6, located at the Matador Uplift, terminates in lower Wolfcamp sediments.

A further comparison of the structure of the Devonian Woodford Formation (Figure VI.A.7) to the structure of the younger Upper Guadalupe Whitehorse Group (Permian) (Figure VI.A.8) indicates that the structure of the younger strata is intimately related to the older structure. However, structural mapping of the younger strata does not indicate the upward continuation of this faulting into the overlying, shallow section. Therefore, the regional information does not indicate the presence of post-Permian faulting within the regional study area. In addition, the local information does not indicate Holocene displacement of faults within 3,000 feet of the proposed WCS landfill site. This local information is discussed fully in Section A.4.2.

Seismicity

The Central Basin Platform is an area of moderate, low intensity seismic activity, based on observational data obtained from the National Geophysical Data Center of the National Oceanic and Atmospheric Administration (NOAA, 1992). A computer search for all recorded seismic activity within a 250 km (155 mile) radius of the proposed WCS landfill site (32.433N, 103.05W) provided a list of 84 seismic events (152 total, 68 suspected duplicates) during the period from 1931 to 1992 (Table VI.A.1, Figure VI.A.9). Seismic activity within the regional area has been reported as recently as 1992 (Table VI.A.1). However, all documented seismic events are located at distances which exceed the required search distance of 3,000 feet from the proposed WCS landfill site.

The proposed WCS landfill site is located within an earthquake risk area zone of (1), which represents an area where only minor damage is expected as a result of earthquake activity (Algermissen, 1969) (Figure VI.A.10). This is due, in part, to the relatively low level of tectonic activity occurring within the regional study area. While data are insufficient to equate any seismic activity with specific tectonic structures or to indicate the tectonic stress levels and direction, the seismic activity that has occurred within the region is postulated to be associated with salt dissolution or movement along faults near oil and gas secondary recovery operations (Davis et. al., 1989). A search of Texas Railroad Commission (TRC) and New Mexico Oil Conservation Commission (OCC) records conducted by Geosource, Inc., Austin, Texas, revealed no secondary recovery operations within a three-mile radius of the proposed WCS landfill site.

<u>Surface Lineations</u>

Surface lineations are straight physiographic features. Surface lineations are typically identified based on a review of surface geologic maps, surface topography maps, LANDSAT images and/or high altitude aerial photographs (Finley and Gustavson, 1981). In the Southern High Plains, surface lineations typically fall into a combination of six categories: 1) linear stream segments; 2) drainage lines along linear valleys; 3) prominent topographic breaks (scarps); 4) alignment of playa lakes; 5) geologic contacts; and 6) anomalous ground surface color tones based on aerial photographic data. More than 4,600 surface lineations have been identified in the area of the Southern High Plains, ranging in length from 1.2 miles up to 40 miles (Finley and Gustavson, 1981).

Surface lineations are often associated with subsurface joint patterns and faults (Finley and Gustavson, 1981). Fractures form in geologic material along planes of weakness where cohesion has been lost (Dennis, 1972). Joints, unlike faults, are defined as fractures along which movement has been negligible or absent (Dennis, 1972). The development of joints is an indication of the brittle behavior of rock, and is most evident in the Triassic and Permian sandstones within the area of the Southern High Plains (Finley and Gustavson, 1981). The poorly consolidated sediments of the Ogallala Formation do not exhibit well-developed jointing patterns. The caliche caprock material often exhibits an irregular, nearly orthogonal jointing pattern. Since few surface faults have been recognized and mapped in the Southern High Plains, it is the jointing of the geologic material that exerts the greatest control over regional surface lineation patterns (Finley and Gustavson, 1981).

Several mechanisms can account for the relationship between surface lineations and subsurface jointing. Joints form preferential planes that can be exploited by surficial and subsurface weathering processes. Consequently, drainage systems in the Southern High Plains are often classified as surface lineations, since their linear orientation is controlled by the joint systems that they exploit (Finley and Gustavson, 1981). In addition, joints can be propagated upward into geologically younger sediments, by the differential compaction and dissolution of underlying materials (Stone and Webster, 1983; Finley and Gustavson, 1981).

In the Southern High Plains, the orientation of subsurface joints and their associated surface lineations is controlled primarily by historical tectonic and structural trends (Finley and Gustavson, 1981). As shown in Figure VI.A.11, the dominant direction of orientation for surface lineations in the Southern High Plains is northwest to southeast, with a secondary orientation direction of northeast to southwest. Figure VI.A.11 shows a surface lineation with a northwest-southeast alignment in the approximate vicinity of Monument Draw. This feature is located in northern Andrews County about 14 miles from the proposed WCS landfill site. This is the closest lineament to the proposed landfill site observed by Finley and Gustavson (1981). Their data do not indicate the presence of surface lineations at the site.

Surface lineations were identified in the vicinity of the proposed WCS landfill site, based on an analysis of NASA color-infrared aerial photographs (Figure VI.A.12).

These lineations, including one that is inferred through the proposed WCS landfill site, correspond to linear drainage features and ground surface color tone anomalies.

The lineation inferred through the proposed WCS landfill site appears as an anomaly in the ground surface color tone on a NASA color-infrared aerial photograph (Figure VI.A.12). This anomaly may be caused by shadows, changes in soil moisture and vegetation etc. (Finley and Gustavson, 1981) and appears to be linked to relatively abrupt topographic variations.

A.1.2. Land Surface Subsidence

Land surface subsidence can be induced by fluid withdrawal or can be naturally occurring. Most commonly, fluid withdrawal is associated with groundwater pumpage and oil and gas production activities.

<u>Subsidence Associated with Fluid Withdrawal</u>
The water-bearing zones of the Ogallala Aquifer consist of poorly consolidated to unconsolidated sands and gravels at a depth greater than 300 feet below the ground surface (Knowles et. al., 1984). The aquifer is typically under water table conditions. Despite the potential withdrawal of groundwater in the general vicinity of the proposed WCS landfill site, pressure declines associated with groundwater pumpage are probably insufficient to induce significant subsidence.

Oil production is occurring in the area from consolidated sediments at depths greater than 3,000 feet. Therefore, no subsidence is expected to occur from the withdrawal of brine or oil and gas. No evidence of subsidence related to fluid withdrawal was found in the reviewed literature (Section VI.E.).

<u>Naturally Occurring Subsidence</u>
Subsidence can also be naturally occurring and result from sediment compaction and/or subsurface dissolution of soluble strata. As discussed previously, joint/lineament systems can be associated with sediment compaction and dissolution (Finley and Gustavson, 1981).

A zone of active salt dissolution and subsidence has been noted by Gustavson et. al. (1980, 1981) in Permian strata of the Northern Texas Panhandle. Collapse features are evidence of such subsidence. However, no salt dissolution collapse features are noted within the study area based on a search of the available literature. Shallow depressions are noted in the study area. However, these depressions can be attributed to eolian deflation, caliche caprock solution and compaction, animal activity, and differential compaction (Collins, 1990).

A.1.3. Potential for Erosion

The potential for erosion is discussed in the companion engineering design report provided by AME.

A.2. Physiography and Topography

A.2.1. Physiographic Setting and Climate

Physiographic Setting

The proposed WCS landfill site is located in West Texas, which lies within the southern portion of the North American Great Plains Physiographic Province (Stone and Webster, 1983). The site is situated in northwest Andrews County, Texas on the southwestern edge of the Southern High Plains (Llano Estacado) (Figure VI.A.13).

The Llano Estacado is an elevated area of low relief undulating plains encompassing a large area of West Texas and Eastern New Mexico. It is bounded by the Western Caprock Escarpment along the Pecos River Valley to the west and the Eastern Caprock Escarpment developed by the headward tributaries of the Colorado, Brazos, and Red Rivers to the east (Stone and Webster, 1983) (Figure VI.A.13). The Basin and Range Physiographic Province lies to the west of the Southern High Plains. The Rolling Plains Physiographic Province lies to the east and the Edwards Plateau lies to the south of the Southern High Plains. Cities on the approximate boundary of the Llano Estacado include Amarillo, Texas to the north, Big Spring, Texas to the east, Midland/Odessa, Texas to the south, and Roswell, New Mexico to the west.

Climate

The proposed WCS landfill site lies within an area of temperate, arid climate. The average annual precipitation is approximately 14.5 inches (Figure VI.A.14), with more than 70 percent of the precipitation occurring between early May and late October (TNRIS, 1992). The mean annual maximum temperature is 77.4°F and the mean annual minimum temperature is 49.4°F. The maximum average daily temperature of 95.5°F occurs in July and the minimum average daily temperature of 29.5°F occurs in January. The average annual wind speed is 10.4 miles per hour with the prevailing direction being southwesterly in the winter and south to southeasterly in the summer. The average free water evaporation exceeds precipitation by about 58 inches per year (Conner et. al., 1974).

A.2.2. Topographic Features, Soil and Land Use

Regional Topography

The proposed WCS landfill site is located on a gently sloping plain. The regional slope is toward the southeast at 8 to 10 feet per mile (Reeves, 1966), with the local slope oriented toward the southwest at 25 feet per mile (Plate VI.A.1). Regional topographic features include the Pecos River Plain to the south and west, the Mescalero Ridge to the northwest, Monument Draw and Rattlesnake Ridge to the west, and the Llano Estacado to the north and east (Nicholson and Clebsch, 1961) (Figure VI.A.13 and Plate VI.A.2).

The Southern High Plains can be characterized by relatively flat topography, cut by regional surface drainage features and punctuated by playa lakes (Stone and Webster, 1983). Drainage is not well defined and consists of ephemeral streams that channel runoff into the playas.

The Mescalero Ridge defines the western edge of the Llano Estacado. It is a nearly perpendicular cliff, facing west to southwest. The ridge has a relief of nearly 150 feet in western Lea County, New Mexico, but displays very little relief in eastern Lea County or western Andrews County due to a heavy cover of dune sand. The south to southeast sloping Pecos River Plain, to the west, is covered with dune sand resulting in a low-relief undulating topography.

The only major regional drainage feature is Monument Draw, which is located to the southwest of the site, in Lea County, New Mexico (Plate VI.A.2). Monument Draw runs between the proposed WCS landfill site and Eunice, New Mexico. The draw begins with a southeasterly course to a point north of Eunice where it turns south and becomes a well defined cut approximately 30 feet in depth and 1,800 to 2,000 feet in width. The draw does not have through-going drainage and is partially filled with dune sand and alluvium (note: a second Monument Draw is shown on Plate VI.A.2 in northern Andrews County; this draw is a separate feature not to be confused with the draw in Lea County, New Mexico). East of Monument Draw is a north-south trending topographic high known locally as Rattlesnake Ridge. This poorly defined ridge parallels the Texas - New Mexico State line and crests about 125 feet higher than Monument Draw (Nicholson and Clebsch, 1961).

<u>Large-Scale Local Topography Within the Boundary of the Proposed Landfill Site</u>
The ground surface elevation within the boundary of the proposed WCS landfill site ranges from a high of 3,487.56 feet relative to mean sea level (MSL) in the extreme north central section to a low of 3,422.74 feet MSL in the southwest corner over a linear distance of approximately 4,600 feet (Plate VI.A.3). A relatively abrupt topographic slope break occurs along the central portion of the proposed WCS landfill site, south of a line from surveyed grid locations 10-F, 8-F, 6-D, 4-D and 2-D.

<u>Small-Scale Local Topography Within the Boundary of the Proposed Landfill Site</u>
Small-scale topographic features within the boundary of the proposed WCS landfill site include two highs, five closed depressions (locally referred to as "buffalo wallows") and a subtle surface water drainage feature (Plate VI.A.3).

A total of three of the local topographic depressions are located in close proximity to each along the southwestern margin of the proposed WCS landfill cell (Plate VI.A.3). The largest of these depressions (located at grid location 8-E) is about 400 feet by 300 feet with approximately one to two feet of vertical relief. The next largest of the three depressions (located near grid location 8-F) is nearly circular with a diameter of 300 feet and approximately three to four feet of vertical relief. The smallest of the three depressions (located between grid location 7-D and 7-E) is about 300 feet by 200 feet in size with approximately one to two feet of vertical relief.

A subtle surface water drainage feature is headed in the area immediately to the west of the three topographic depressions discussed above. This drainage feature accounts for approximately 12 feet of topographic incising over a run of approximately 500 feet. Field observations of this surface water feature indicate channel flow in the upper reach, with a rapid transition to sheet flow at its terminal end to the south.

A fourth topographic depression is located near grid location 2-D, along the eastern boundary of the proposed WCS landfill cell. This depression has dimensions of 200 feet by 100 feet and approximately four feet of topographic relief.

A fifth topographic depression is located near grid location 10-A, along the northwest corner of the proposed WCS landfill site. This depression has dimensions of around 125 feet by 200 feet and approximately one to two feet of topographic relief.

Local topographic highs are located along the southwest margin of the proposed WCS landfill cell. The largest high (located between grid 10-E and 10-F) is crescent-shaped with the long axis measuring approximately 600 feet and the short axis measuring about 300 feet. This topographic high has a vertical relief of one to two feet. The other topographic high (located between grid 8-E and 9-E) measures about 100 feet by 200 feet with less than two feet of vertical relief.

<u>Local Topography Outside the Boundary of the Proposed Landfill Site</u>

Local topographic features outside the boundary of the proposed WCS landfill site include three depressions to the west, a spring to the west and three highs to the north (Plate VI.A.3). Baker Spring is located 1,925 feet west and 360 feet south of the northwest corner of the proposed WCS landfill site, in Lea County, New Mexico. The water surface elevation at Baker Spring was surveyed at 3,440.82 feet MSL on February 2, 1993. Reports by local residents indicate that this spring is no longer active, and that the loss of spring activity may be linked to blasting activities at a nearby rock quarry (Vance, 1993). Site observations suggest that the historical source of Baker Spring may be attributed to seasonal seepage from the base of a surface outcropping of Ogallala Formation sediments. Field observations regarding the topography surrounding Baker Spring indicate evidence of historical quarrying activity.

Area Soils

The soils at the proposed WCS landfill site consist of dune sand mixed with organic material overlying weakly to strongly cemented caliche (Conner et. al., 1974; Turner et. al., 1974). The top soil depth ranges from 2 to 24 inches. The shallow caliche consists primarily of cemented dune sand and cemented Ogallala Formation sediments.

Area Land Use

The proposed WCS landfill site is located on land owned by the Flying "W" Diamond Ranch. This property, and the property immediately surrounding the proposed WCS landfill site is presently used as rangeland for cattle, requiring approximately 60 acres to sustain each head (Vance, 1993)

Other uses of land within the vicinity of the proposed WCS landfill site include: drill sites for oil and gas wells (a producing oil well is located near the southwest corner of the property); quarrying operations; and the surface recovery of oil field wastes. Surface quarrying of sand and gravel is conducted approximately one mile to the west of the proposed WCS landfill site, in New Mexico. The oil field waste recovery facility is adjacent to this rock quarry.

A.3. Regional Geology

A.3.1 Regional Surface Sediments

The geologic formations that outcrop within the region range from Quaternary through Triassic in age and include: Quaternary Alluvium (Holocene), Windblown cover sand (Pleistocene), and the Tahoka Formation (Pleistocene); the Tertiary Ogallala Formation (Pliocene); the Cretaceous Fort Terrett Formation; and the Triassic Dockum Group (Chinle Formation). The Hobbs Sheet of the Geologic Atlas of Texas showing the area surrounding the proposed WCS landfill site is provided on Plate VI.A.2.

Alluvium, Windblown Cover Sand, and Tahoka Formation

Floodplain deposits of fluvial origin outcrop at the surface to the west and southwest of the proposed WCS landfill site. These sediments are Holocene and possibly Pleistocene in age and were deposited along the course of Monument Draw in New Mexico (Plate VI.A.2).

Windblown cover sand of Pleistocene age is found immediately north of the proposed WCS landfill site, to the east along Highway 176, and at numerous other locations in Andrews, Gaines and other counties in Texas shown on Plate VI.A.2. This windblown cover sand ranges up to 10 feet in thickness and is calcareous, grayish red, fine to medium-grained quartz with silt and caliche nodules common (Barnes, 1976).

The Tahoka Formation is of Pleistocene age and consists of lacustrine clay, silt, sand, and gravel (Barnes, 1976). The clay and silt is sandy, indistinctly bedded to massive, and consists of various shades of light gray and bluish gray. The sand is gray, fine to coarse-grained quartz, friable, and grades to gravel at the margins of the deposits. These sediments occur approximately four miles east of the proposed WCS landfill site, near a topographic depression located north of Highway 176. The Tahoka Formation also outcrops at Whalen Lake and Shafter Lake in Andrews County, at San Simon Sink in New Mexico, and at a few other locations as shown on the Plate VI.A.2.

Ogallala Formation

The Pliocene Ogallala Formation consists of fluviatile sand, silt, clay, and gravel capped by caliche (Barnes, 1976). The sand deposits of the Ogallala Formation consist of fine to medium-grained quartz grains, which are silty and calcareous. Bed forms range from indistinctly bedded to massive, crossbedded, unconsolidated to weakly cohesive with 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. The capping caliche is hard, sandy, pisolitic at the top, and produces caprock along Mescalero Ridge. Development of the local caliche horizon probably occurred relatively recently, after the deposition of the Pliocene Ogallala Formation.

Within the southern region of the Llano Estacado, the Ogallala Formation lies unconformably above either Triassic or Cretaceous rocks, and occurs as an apron of coalescing alluvial fan lobes which extend eastward from the Rocky Mountains. This alluvial outwash plain was dominated by braided streams and extends from South Dakota to the Texas Panhandle (Seni, 1980).

The headward erosion of the major rivers, such as the Pecos River in New Mexico and the Canadian, Colorado, and Brazos Rivers in Texas, and their various tributaries has regionally modified the surface expression of the Ogallala Formation (Figure VI.A.13). Consequently, portions of the Ogallala Formation have been erosionally removed, exposing deeper, older stratigraphic units. In addition, winds and streams have locally eroded the Ogallala Formation, exposing Cretaceous rocks around some saline lakes in the southern part of the Southern High Plains (Plate VI.A.2). The Ogallala Formation, in the regional area shown on Plate VI.A.2, ranges from 0 to 100 feet in thickness (Barnes, 1976).

<u>Fort Terrett Formation</u>

A very isolated occurrence of the Fort Terrett Formation is exposed in a rock quarry approximately one mile west of the proposed WCS landfill site (Plate VI.A.2). This formation consists of limestone and shale deposited in a marine environment. Fort Terrett limestones are light gray to grayish yellow in color and are mostly fine grained, argillaceous, thin to thick bedded and massive. The shales are calcareous and thinly laminated and occur in shades of dusky yellow, yellowish gray, light olive-gray, and dark gray (Barnes, 1976).

The possibility exists that the Fort Terrett Formation sediments mapped at the rock quarry east of the proposed WCS landfill site (Plate VI.A.2) may actually be caliche. This is based on the fact that no Fort Terrett Formation sediments were observed (during on-site field activities) at an outcrop at Baker Spring, which is immediately east of the quarry. An exposure of highly cemented, concretionary and pisolitic caliche was observed at Baker Spring, which could be confused as a Cretaceous marine limestone.

However, the silt, sand and gravel content of the limestone material at Baker Spring indicates that it is caliche, and it is suggested that this caliche material may be the same material that was mapped by Barnes (1976) as the Fort Terrett Formation at the adjacent rock quarry.

Dockum Group - Chinle Formation

The Chinle Formation is the uppermost unit of the Triassic Dockum Group in eastern New Mexico and western Texas (Nicholson and Clebsch, 1961). The Chinle Formation consists of red and greenish micaceous claystone, thinly interbedded with fine-grained sandstone (Barnes, 1976). The Chinle Formation is exposed in a rock quarry in New Mexico approximately one mile west of the site (Plate VI.A.2).

In Texas, the Dockum Group consists of shale, sandstone, siltstone, limestone, and gravel. These shale sediments are typically micaceous, thinly bedded, and variegated. The Dockum Group lies immediately beneath the Ogallala Formation at the proposed WCS landfill site and ranges up to 1,400 feet in thickness within the region.

A.3.2 Regional Stratigraphy

Groundwater resources are commonly referred to as underground sources of drinking water (USDWs). The base of the Dockum Group (Santa Rosa Formation) is considered to be the base of the lowermost aquifer capable of providing usable groundwater to the land surface in the regional study area (Nicholson and Clebsch, 1961). This formation lies unconformably on top of the Permian Dewey Lake Formation, with the base of the Dockum Group at a depth of approximately 1,400 feet beneath the proposed WCS landfill site.

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. The stratigraphic column for the Central Basin Platform area is shown in Figure VI.A.15. Included on the column are all stratigraphic units from the Precambrian to Recent time. However, for the purpose of this regional discussion, only the Permian Ochoan units through the Recent units will be reviewed.

To better understand how the local geology relates to the regional stratigraphy, information was obtained from oil and gas operations in Andrews County, Texas and Lea County, New Mexico. A search of the oil and gas well records within a one-mile radius of the proposed WCS landfill site was conducted by Geosource, Inc., Austin, Texas, in November 1992.

Geosource, Inc. utilized public and private sources of data to identify producing and abandoned oil and gas wells or well tests located in the area. Table VI.A.2 lists the sources of information reviewed and briefly describes the information which can be obtained from each source. There are 12 operating or plugged wells located within a one-mile radius of the site. A map showing the location of oil and gas artificial penetrations within the area is included as Figure VI.A.16. A tabulation of the oil and gas wells is included as Table VI.A.3. Records of these wells are provided in Appendix A.

A detailed analysis of the regional and local subsurface stratigraphy was conducted based on a review of the drilling records and/or electric, nuclear, and lithologic logs from 17 individual locations. The data set consists of all available log data for the area on file with Petroleum Information (PI) within the boundaries of Figure VI.A.17. A total of two regional stratigraphic cross-sections were constructed using these data and are shown as Plates VI.A.4 and VI.A.5. These cross-sections depict the major stratigraphic units that occur within 2,000 feet below ground level (BGL) in the vicinity of the site. Review of these cross-sections does not indicate the presence of local faulting. The locations of the cross-sections are shown in Figure VI.A.17. The individual well logs used to prepare the cross-sections have been named and numbered for cross-referencing purposes.

<u>Permian Units</u>

The Permian sediments consist of the Wolfcamp, Leonard, Guadalupe, and Ochoa Series (Figure VI.A.15). The Ochoan sediments are important to this discussion because they are immediately below the USDW. In addition, the Ochoan stratigraphy provides information pertaining to the deeper structure beneath the site.

The Ochoa Series section represents the top of the Permian strata, and in the Central Basin Platform area consists primarily of the: Salado Formation; the Rustler Formation; and the Dewey Lake Formation (WTGS, 1976). The Salado Formation, which rests unconformably on the Tansill Formation, consists of a thick, regionally extensive evaporite unit composed dominantly of salt and lesser amounts of anhydrite and minor amounts of mudstone (McGillis and Presley, 1981). The Salado Formation ranges in thickness from approximately 750 feet in the area of the Central Basin Platform to over 2,000 feet in the Delaware Basin.

The Rustler Formation consists of a maximum of 375 feet of dolomite and anhydrite with an irregular basal zone of red sand, conglomerate, and variegated shale (Jones, 1953). The Rustler Formation represents the youngest anhydrite in the Permian Basin.

The Dewey Lake Formation lies conformably on the Rustler Formation and consists mainly of fine-grained red sandstone and siltstone with some anhydrite, but no salt. It ranges in thickness from 250 to 300 feet in Andrews County (WTGS, 1961). Although there is an unconformity found at the top of the Dewey Lake Formation, which separates it from Triassic deposits, in many places the nature of this contact is not clear (Stone and Webster, 1983). The Ochoan units have a combined thickness of over 3,000 feet and indicate a similar structural trend as the lower Permian units.

A portion of the Ochoan stratigraphic sequence (i.e., Salado Formation, Rustler Formation, and Dewey Lake Formation) is shown on Cross-sections A-A' and B-B' (Plates VI.A.4 and VI.A.5). The upper contact of the Salado Formation, in the area of the proposed WCS landfill site, is at a depth of approximately 1,595 feet BGL at location #13 and 1,828 feet BGL at location #15.

The Rustler Formation top occurs at a depth of approximately 1,356 feet BGL at location #13 and 1,615 feet BGL at location #15. The total thickness of the Rustler Formation ranges from 210 feet at location #4 to 237 feet thick at location #12.

The erosional surface of the Dewey Lake Formation slopes regionally to the southeast (Nativ, 1988). The upper contact of the Dewey Lake Formation in the area of the proposed WCS landfill site is at a depth of approximately 1,217 feet BGL at location #13 and 1,382 feet BGL at location #9.

Triassic Units

The Triassic Dockum Group disconformably overlies the Permian stratigraphic sequence within the regional study area (Figure VI.A.15). The Dockum Group is comprised of a series of fluvial and lacustrine mudstone, siltstone, sandstone, and silty dolomite deposits (McGowen et. al., 1979) which range up to approximately 1,400 feet thick in the area of the Central Basin Platform. 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 (McGowen et. al., 1979).

Figure VI.A.18 shows the inferred paleogeographic setting that existed during the deposition of the Dockum Group. The terrigenous clastics deposited in the Permian Basin area were mainly derived from older sedimentary rocks that accumulated in Texas and New Mexico. The maximum preserved thickness of Triassic rocks (2,000 feet) occurs in the Midland Basin (Nativ, 1988).

The Tecovas Formation represents the lowermost lithologic cycle of the Triassic System. It consists primarily of claystone and siltstone. However, the Tecovas Formation is absent throughout portions of the Central Basin Platform.

The Trujillo Formation (i.e., Santa Rosa Formation of New Mexico) represents the middle lithologic cycle of Dockum Group deposition. The Trujillo (Santa Rosa) Formation is characterized by a sandy lower interval that becomes increasingly muddy in the upper section. The upper lithologic cycle of the Triassic System, or Chinle Formation, exhibits similar overall upward fining, except in the area of the northwestern Midland Basin, where sand from an eastern source was deposited during the upper Triassic cycle (McGowen et. al., 1979). Figure VI.A.19 presents an isopach (i.e., thickness) map of the upper Dockum Group.

The stratigraphic sequence of the Triassic Dockum Group (i.e., Santa Rosa Formation and Chinle Formation) is shown on Cross-sections A-A' and B-B' (Plates VI.A.4 and

VI.A.5). The upper contact of the Santa Rosa Formation in the area of the proposed WCS landfill site is at a depth of approximately 965 feet BGL at location #13 and 1,202 feet BGL at location #14. The geophysical log characteristic shows the Santa Rosa Formation to be a massive sandstone body. The total thickness of the Santa Rosa ranges from 230 feet at locations #15 and #17 to 305 feet thick at location #12.

The upper Dockum Group (Chinle Formation) top occurs at a depth of approximately 48 feet BGL at location #9 (immediately south of the proposed landfill site) and 93 feet BGL at location #14. The total thickness of the upper Dockum Group ranges from 955 feet at location #13 to 1,125 feet thick at location #4. The cross-sections show the fluvial nature of the upper Dockum Group with interbedded sandstone, siltstone, and clay lenses. The erosional surface of the Triassic Dockum Group is also quite evident. The Dockum Group is overlain in some areas of the Southern High Plains by Cretaceous rocks and in other areas by the Ogallala Formation.

Cretaceous Units

The Jurassic stratigraphic sequence is not found in the Permian Basin (Figure VI.A.15). Therefore, the Cretaceous (Comanchean Series) sediments rest disconformably upon the Triassic Dockum Group. These sediments are found in southeast-dipping isolated erosional remnants (Figure VI.A.20) as much as 100 feet thick (Cronin and Wells, 1963). Note that the subcrop map shows that Cretaceous rocks have been eroded away beneath the proposed WCS landfill site. Therefore, while Cretaceous rocks are found in the region, no Cretaceous units are shown on the accompanying stratigraphic cross-sections (Plates VI.A.4 and VI.A.5).

Cretaceous rocks were deposited in an epineritic and littoral environment on a slowly subsiding shelf (Nativ, 1988). The base of the Cretaceous System in the Southern High Plains is composed of basal sands of the Trinity Group. These light gray to reddish gray sediments consist of nearly pure quartz sands with scattered lenses of gravel (Stone and Webster, 1983). They are poorly consolidated and form a blanket-like deposit that is 10 to 25 feet thick in the southeastern High Plains area.

The sediments of the Fredericksburg Group rest unconformably on top of the Trinity Group deposits and consist predominately of calcareous rocks. These strata consist of light-gray argillaceous limestone interbedded with shale at the base, becoming more massive marly limestone near the middle and grading into interbedded dolomite, shale, and sandstone at the top (Stone and Webster, 1983).

Tertiary Units

Within the regional study area, the Ogallala Formation (Pliocene) rests disconformably upon either the Triassic Dockum Group or the Cretaceous sediments. Figure VI.A.21 presents the structure of the base of the Ogallala Formation, which corresponds to the erosional surface of the underlying Cretaceous and Triassic units. The Ogallala Formation contains both coarse fluvial conglomerate and sandstone and fine-grained eolian siltstone and clay (Nativ, 1988).

Seni (1980) believed that the depositional environment of the Ogallala Formation and the overlying Quaternary deposits produced a series of overlapping, humid-type alluvial fans. Three fan lobes were identified (Figure VI.A.22) whose grain size varies as a function of the distance from the major channel system. After further investigation, it was noted that the grain size of the Ogallala Formation clastics is controlled by the topography of the underlying mid-Tertiary erosional surface (Gustavson and Winkler, 1988). Coarse fluvial clastics were deposited in paleovalleys, while finer eolian sediments covered upland areas (Nativ, 1988). Eolian clastics also overlie the fluvial sediments in the paleovalleys as sand and silt sheets. The Ogallala Formation typically ranges from 0 to 200 feet thick in the south portion of the Southern High Plains. The thickness of the Ogallala Formation reflects the underlying paleotopography.

A resistant calcite layer called the caprock caliche lies at or near the top of the Ogallala Formation (Nativ, 1988). Caliche develops as an authigenic accumulation of calcium carbonate that results from soil-forming processes, precipitation from groundwater, or some combination of both (Stone, 1985). The processes governing the development of caliche are discussed fully in Section A.4.3.

The Ogallala Formation and Dockum Group are easily discernible on electric logs from nearby oil and gas wells and are shown on Plates VI.A.4 and VI.A.5. Because the top of the Dockum Group is an erosional surface, the elevation of the contact between these two formations varies significantly over relatively short distances. The thickness of the

Ogallala Formation in the area shown by the cross-sections ranges from 48 feet at location #9 (immediately south of the proposed landfill site) to 93 feet at location #14 (approximately three miles north of the site). This thickness determination assumes that all material overlying the Dockum Group consists of Ogallala Formation sediments. This is based on geophysical log signature, and includes some amount of surficial deposits and caliche cemented surficial deposits.

A.4. Site Subsurface Soils Investigation

A.4.1. Investigation Procedures

Site operations were conducted from November, 1992 through February, 1993. These operations included: the drilling of continuous cores and soil borings; geophysical logging; and the installation of piezometers and monitoring wells. All soil borings were described using the Unified Soil Classification System (USCS). A summary of soil boring, well completion and selected geologic data is provided in Table VI.A.4. Soil boring and well completion logs are provided in Appendix B. Geophysical logs are provided in Appendix C. A detailed discussion of the site subsurface investigation procedures is provided in the companion geotechnical report provided by JHA.

A.4.2. Subsurface Structure

A discussion of the regional subsurface structure is provided in Section A.1 and A.3. This analysis of faulting, seismicity and the overall regional subsurface structure is based on a review of the available published literature, and is based on the construction of two deep geologic cross-sections (Plate VI.A.4 and V.I.A.5). These two cross-sections were developed from available oil and gas industry data.

The site subsurface structural analysis is based on data resulting from the site investigation: 55 continuous cores; eight geophysical logs; and four shallow exploration borings (Table VI.A.4). The structural interpretation derived from this information is summarized in ten shallow geologic cross-sections A-A' through J-J'. A cross-section location map is provided as Figure VI.A.23. The 10 shallow cross-sections are provided as Figure VI.A.24 through VI.A.33. A structure map on top of the Dockum Group is provided as Figure VI.A.34. In addition, two orthographic projections of the Dockum Group surface are provided as Figure VI.A.35 and VI.A.36, and a depth to the top of the Dockum Group map is provided as Figure VI.A.37.

The regional subsurface structural data indicates no evidence of post-Permian faulting or warping within the local study area. The site subsurface data supports this regional analysis. The local geologic cross-sections (Figure VI.A.24 through VI.A.33) indicate horizontally configured intervals of primarily silty claystone, siltstone and sandstone within the shallow Dockum Group (Chinle Formation) sediments. While individual lithologic intervals range from isolated to laterally extensive, the local depositional framework within the Dockum Group indicates no evidence of faulting or warping.

Paleotopographic Surface of the Dockum Group

The buried surface of the local Dockum Group indicates a paleotopographic expression, which is consistent with published information (Reeves, 1966; McGowen et. al., 1979; Dutton and Simpkins, 1986). As shown in Figures VI.A.34, VI.A.35 and VI.A.36, an apparent ridge runs in a roughly northwest/southeast direction through the middle of the local study area. The "D" survey line, or local cross-section G-G' (Figure VI.A.30) runs along the approximate axis of this structural feature.

This ridge has the general appearance of a east/southeast plunging anticline when viewed from above (Figure VI.A.34). However, local cross-sections A-A', B-B', C-C' and D-D' (Figure VI.A.24, VI.A.25, VI.A.26 and VI.A.27, respectively), which cut profile views across this apparent structural ridge, do not indicate a similar anticlinal warping of the underlying stratigraphic intervals. Rather, these cross-sections indicate a generally horizontal configuration of shallow Dockum Group sediments.

The Dockum Group sediments are locally overlain by nine to 54 feet of top soil, windblown silt and sand, caliche, and the gravel, sand, silt and clay deposits of the Pliocene Ogallala Formation. A disconformable contact exists between the underlying Dockum Group and the overlying Ogallala Formation (Gawloski, 1983). The depositional record of most of the Tertiary System (Miocene through Paleocene), as well as the entire Cretaceous and Jurassic Systems, is not present in the local study area. This represents a missing time-rock interval of approximately 169 million years. Erosion of this time-rock interval, including a portion of the Triassic Dockum Group, occurred prior to the deposition of Ogallala Formation sediments (Gawloski, 1983; McGowen et. al., 1979; Dutton and Simpkins, 1986). It is this erosional activity, combined with some amount of scouring associated with the transportation of Ogallala Formation sediments which has locally shaped the surface of the Dockum Group, giving it the paleotopographic appearance indicated in Figures VI.A.34, VI.A.35 and VI.A.36.

General Relationship Between Local Surface Topography and Dockum Structure

The local surface topography is partially dependant on the structure of the underlying Dockum Group. The surface of the Dockum Group slopes rapidly to the south and north, off of the axis of the Dockum Group ridge (Figure VI.A.34). The local ground surface topography slopes rapidly to the south off of the axis of the underlying Dockum Group ridge and flattens along the southern margin of the study area (Plate VI.A.3). This is in strong similarity to the underlying Dockum Group structure. However, the ground surface topography continues to gently climb toward the north of the underlying Dockum Group ridge, despite the fact that the Dockum Group structure drops off toward the north.

The thickness of sediment overlying the Dockum Group is related to Dockum Group structure and ground surface topography. The difference between ground surface elevation and underlying Dockum Group structure elevation can be expressed in the form of the depth (below ground level) to the top of the Dockum Group, which is referred to here as overburden thickness. As shown in Figure VI.A.37, the overburden sequence within the local study area is thinnest along an arcuate band extending approximately from location 9-H to location 1-E. A comparison of the overburden thickness trend (Figure VI.A.37) to the Dockum Group structure (Figure VI.A.34) and local topography (Plate VI.A.3) shows that this band of thinnest overburden corresponds to the area where the local topography rapidly drops-off, in effect coming closest to reaching the surface of the underlying Dockum Group. However, south of this band of thinnest overburden, the ground surface topography flattens-out to a slope of approximately 0.5 degrees, while the underlying Dockum Group structure continues to drop-off toward the south at a slope of approximately three degrees (six times greater than topography). As a result, the overburden thickness increases along the southern portion of the study area.

To the north of the band of thinnest overburden, the topography rises at a gentle rate while the structure of the underlying Dockum Group begins to drop-off on the northern flank of the local Dockum Group ridge. Consequently, the overburden thickness increases in the northern portion of the local study area.

<u>Small-Scale Dockum Group Structural Features and Buffalo Wallow Development</u>

Localized drainage depressions such as playa lakes and buffalo wallows characterize much of the topographic surface of the High Plains, and are attributed to a variety of causes, including: differential compaction; eolian deflation; the transportation of sediment by animal activity (thus the name buffalo wallow); the dissolution and subsidence of the underlying caliche cap; as well as the dissolution and subsidence of underlying Cretaceous limestone and Permian evaporite sediments (Nicholson and Clebsch, 1961; Reeves, 1966; Gustavson and Finley, 1985; Collins, 1990). Within the local study area, a relationship may exist between the formation of buffalo wallows and the existence of underlying structural depressions in the surface of the Dockum Group.

Small-scale features are apparent on the surface of the local Dockum Group. Figures VI.A.34, VI.A.35 and VI.A.36 show that the Dockum Group ridge, which extends through the center of the local study area, is pock-marked with low-relief (i.e., approximately four to nine feet deep) structural depressions. One such depression was explored by a series of four shallow borings (less than 31 feet deep) and one deeper continuous core (depth of 100 feet) near location 2-D. At this location, a bowl shaped structural depression in the surface of the Dockum Group corresponds to an overlying topographic depression, locally referred to as a buffalo wallow.

Both the depression in the surface of the Dockum Group, and the overlying buffalo wallow, have a relief of approximately four feet. However, cross-section D-D' (Figure VI.A.27), which passes beneath this topographic depression, does not indicate a similar down-warping of sedimentary intervals beneath the depression. Instead, cross-section D-D' indicates horizontally configured stratigraphic intervals beneath location 2-D. Therefore, it is unlikely that the structural depression beneath 2-D is due to the dissolution and slumping of underlying Dockum Group or deeper Permian evaporite layers. The structural depression in the surface of the Dockum Group is probably a reflection of a small-scale paleotopographic depression scoured into the surface of the Dockum Group prior to the local deposition of Ogallala Formation sediments.

The results of the coring and soil boring activity at location 2-D suggest that partial dissolution of the shallow caliche cap may have contributed to the development of the buffalo wallow. The continuous core drilled within the buffalo wallow (location 2-D) encountered only six feet of caliche cap, consisting primarily of calcium carbonate cemented silt and sand. However, four exploration soil borings drilled along the outer rim of the buffalo wallow (location 2-D(A), 2-D(B), 2-D(C) and 2-D(D)) encountered a thickness of caliche cap ranging from 5.7 feet to 15.6 feet, with an average thickness of approximately 10.2 feet. This suggests that a portion of the caliche cap material may have been dissolved at the surface or beneath the buffalo wallow at 2-D. Surficial dissolution of caliche cementation and subsequent removal by deflation may explain the development of buffalo wallows (Nicholson and Clebesch, 1961). In addition, dissolution of the deeper portion of the caliche, and subsequent slumping of the overlying caliche cap, may have initiated the topographic expression of the buffalo wallow or simply propagated a pre-existing topographic surface depression.

The drilling results at location 2-D indicate sediment depletion within the buffalo wallow. The depth from ground surface to the top of the Dockum Group is given in Figure VI.A.37. The thickness of material overlying the Dockum Group locally thins in the vicinity of 2-D. This can be explained by the removal of surficial material near location 2-D by eolian deflation or by the transportation of soil from the depression by animal activity. The buffalo wallow is presently covered with a thick carpet of vegetation, which would be expected to greatly diminish the effect of eolian deflation. However, this buffalo wallow presently appears to be frequented by livestock, resulting in possible sediment removal on their hooves and fur. This pattern of current livestock activity at the buffalo wallow may be indicative of the historic use of the site by North American Bison (i.e., buffalo).

The topographic and structural depression at location 2-D may establish a surface water and ground water relationship which has been integral in the development of the buffalo wallow. The buffalo wallow probably serves as a seasonal collection point for surface water. The coring and soil boring process at location 2-D indicated that the buffalo wallow contains approximately two feet of organic-rich soil, compared to less than 0.4 feet of soil along the rim of the buffalo wallow. In addition, the significantly increased density and length of grass and shrub growth within the buffalo wallow suggests increased available moisture.

This potential surface water and groundwater relationship is supported by the fact that the coring activity within the buffalo wallow encountered saturated conditions within the shallow sand and gravel immediately overlying the Dockum Group. However, cores and soil borings surrounding location 2-D did not produce water. This suggests that ponded surface water within the buffalo wallow is able to infiltrate into the subsurface, but is forced to pond beneath the buffalo wallow, possibly due to the structural depression in the underlying Dockum Group. This infiltrating surface water may increase the rate of caliche dissolution beneath the buffalo wallow and, therefore, may help to propagate the growth of the 2-D buffalo wallow. A complete discussion of the site groundwater conditions is provided in Section B.2.

If a local relationship exists between buffalo wallow formation and Dockum Group structure, then it is likely that buffalo wallows would be more abundant overlying Dockum Group structural highs. It is here where structural depressions are most likely to be closed (i.e., bowl-shaped) and, therefore, capable of ponding shallow groundwater. Such a relationship may be suggested by the abundance of buffalo wallows within the local area roughly bounded by survey locations 7-D and 7-E through 11-D and 10-F (Plate VI.A.3). This area directly overlies a broad structural high in the surface of the Dockum Group (Figure VI.A.34).

A.4.3. Subsurface Stratigraphic Complexity

The local subsurface stratigraphic framework is presented in ten shallow geologic cross-sections (Figures VI.A.24 through VI.A.33). These cross-sections are based on the results of the site coring, soil boring and geophysical logging program. A total of 59 soil boring logs are presented in Appendix B. A total of eight geophysical logs are provided in Appendix C. A percent siltstone and sandstone isopach map, which delineates the local sediment distribution pattern in the shallow Dockum Group, is provided as Figure VI.A.38. A stratigraphic column is provided as Figure VI.A.15.

Surficial Materials

The site is overlain by a thin veneer of two feet or less of organic-rich top soil. The top soil consists of moist, brown silty sand which contains abundant vegetation debris and roots. The top soil commonly contains well rounded, white, black, red, pink and opaque quartzitic gravel and gravel fragments, as well as caliche fragments. These gravel and caliche fragments appear to have weathered out of underlying caliche-cemented Ogallala Formation sediments.

Caliche

Within the local study area, the top soil horizon is underlain by a variable sequence of calcium carbonate cemented, calcrete duracrust capping material (i.e., caliche). Caliche is common throughout the Southern High Plains or Llano Estacado, and forms the resistant beds of the Caprock Escarpment along the western and eastern margins of the Southern High Plains (Gustavson and Finley, 1985). Caliche typically forms in arid to semi-arid climates, where seasonal precipitation dissolves and vertically transports low magnesium calcite from the surface soils into the deeper soil, where it is precipitated in the vadose zone of the C soil horizon (Leeder, 1982), or at the vadose zone/phreatic zone interface (Braithwaite, 1983).

Thick sequences of caliche such as those encountered within the local study area, are probably remnants from the Pleistocene, and may record episodic accumulations of carbonate in response to Pliocene-Pleistocene climatic fluctuations (Leeder, 1982). Common sources of calcium in the shallow subsurface include weathered rock products and organic sources such as lichen, fungi, algae and bacteria (James and Choquette, 1984). The primary factors controlling caliche formation include: meteoric precipitation rate; carbon dioxide content of meteoric water and carbon dioxide donation by organic material (increased carbon dioxide concentrations increase the rate of calcium carbonate dissolution); and temperature (increased temperature promotes calcium carbonate precipitation) (James and Choquette, 1984).

A local surface exposure of caliche, Ogallala Formation and Dockum Group sediments was observed at Baker Spring (Plate VI.A.3). At this location, the caliche cap consists of: approximately six feet of white, highly fractured calcium carbonate cemented feldspathic and quartzitic silt and very fine grained sand; overlying approximately 12 feet of white and pinkish white, massive caliche with extensive concretionary nodule growths (i.e., pisolites) and feldspathic and quartzitic silt and very fine grained sand; resting on top of approximately six feet of pinkish white, calcium carbonate cemented feldspathic and quartzitic silt, sand and gravel which becomes less cemented with depth. This lower six feet of caliche material appears to be calcium carbonate cemented Ogallala Formation sediments. This caliche altered Ogallala Formation material has an irregular basal contact and indicates a gradational transition into primarily uncemented Ogallala Formation sands and gravels below.

Caliche was encountered during the drilling program and was observed to be laterally extensive throughout the local study area, ranging up to 47 feet thick at location 7-A (Figure VI.A.24 through VI.A.33). As seen in the cross-sections, the local caliche cap thickens toward the north and south margins of the study area, similar to the overall thickness trend of the combined overburden sequence (Figure VI.A.37).

The caliche encountered during the drilling program is similar to the caliche exposed at Baker Spring. Matrix color ranges from white to pinkish white, with varying degrees of cementation, hardness, fracturing and pisolitic concretions. The caliche horizon contained varying amounts of feldspathic and quartzitic silt, sand and gravel fragments with a general trend of decreased cementation and increased silt, sand and gravel content with depth. In many areas, the caliche cap material included altered eolian silts and sands, as well as cemented Ogallala Formation sediments. Open fractures and vugs were observed within the caliche horizon.

<u>Ogallala Formation</u>

As discussed in Section A.3.2, the Ogallala Formation records a period of fluvial deposition during the Pliocene (3 to 11 million years ago). The Ogallala Formation had a source area in the Rocky Mountains, and was deposited as an eastern-thinning apron of coalescing alluvial fans (Seni, 1980).

A local surface exposure of caliche, Ogallala Formation and Dockum Group sediments was observed at Baker Spring (Plate VI.A.3). The Ogallala Formation sediments consist of approximately six feet of caliche cemented feldspathic and quartzitic silt, sand and gravel, resting on top of approximately 15 feet of planar crossbedded and trough crossbedded sand and gravel, which is indicative of a high energy fluvial system (Seni, 1980). Sediment color ranges from pinkish tan to dark brown with red, pink, white, black and opaque quartzitic gravel clasts and granitic cobbles. The base of the Ogallala Formation has a sharp and irregular contact with the underlying dusky red siltstone and claystone of the Dockum Group.

Ogallala Formation sediments were encountered in numerous soil borings throughout the local study area (Figure VI.A.24 through VI.A.33). These sediments consist of feldspathic and quartzitic sand and gravel with silt and clay, and appeared consistent with the surface exposure at Baker Spring. For the purpose of general classification and cross-section preparation, that portion of the Ogallala Formation that has been cemented as part of the overlying caliche cap, is represented in the cross-sections as caliche. However, it should be noted that a significant portion of the caliche cap within the local study area consists of altered Ogallala Formation sediments. The following discussion focuses on the uncemented portion of the Ogallala Formation, below the base of the caliche cap.

Caliche alteration of the Ogallala Formation, combined with incomplete recovery of caliche-cemented and uncemented Ogallala Formation samples during the coring program, hampered the accurate recognition and classification of the Ogallala Formation sediments. Therefore, an accurate thickness (i.e., isopach) map of the Ogallala Formation could not be prepared as part of the geologic investigation. However, the geologic cross-sections (Figure VI.A.24 through VI.A.33) provide a general means for determining the local thickness trend of Ogallala Formation.

The local thickness trend of the Ogallala Formation is partially related to the structure of the underlying Dockum Group. As shown in the local cross-sections A-A', B-B', C-C', D-D' and J-J' (Figure VI.A.24, VI.A.25, VI.A.26, VI.A.27 and VI.A.33, respectively), the thickness of the Ogallala Formation generally increases off of the northern and southern flanks of the underlying Dockum Group ridge (Figure VI.A.34).

In addition, small-scale structural lows in the surface of the Dockum Group generally contain an increased thickness of Ogallala Formation. This is particularly evident on cross-sections G-G' (Figure VI.A.30), where Ogallala Formation sediments appear thickest in structural lows between locations 9-D and 7-D, and between locations 5-D and 2-D. This general thickness trend is due to the fact that the Ogallala Formation occurs as an erosional remnant throughout much of the Southern High Plains area (Seni, 1980). As a result, thicker sequences of Ogallala Formation sediments often correspond to structural lows in the underlying formations. It is in these structural lows where the Ogallala Formation is partially protected from erosional activity. In addition, it is within these structural lows where a portion of the Ogallala Formation rests below the base of caliche cementation and is, therefore, clearly recognizable as the Ogallala Formation.

Ground surface topography also determines the local thickness trend of the Ogallala Formation. As discussed in Section VI.A.4.2, the overburden is thinnest where the ground surface has been eroded closest to the surface of the underlying Dockum Group. Since much of the local Ogallala Formation is tied up as cemented caliche, the thickness of the Ogallala Formation has a similar thickness trend as the entire overburden sequence. This general relationship is illustrated in Figure VI.A.37.

Dockum Group

As discussed in Section VI.A.3.2, the Dockum Group records a period of fluvial-deltaic and lacustrine deposition within a restricted continental basin during the Triassic (180 to 260 million years ago). The source areas for the Dockum Group included: the Llano Uplift area to the east; the Amarillo Uplift, Wichita Mountain Uplift and Arbuckle Mountain Uplift to the north and northeast; the Sierra Grande Arch and Sangre De Cristo Uplift to the northwest; the Sacramento Uplift to the west; and the Diablo Platform to the south (Figure VI.A.18) (McGowen et. al., 1979).

In Texas, the Dockum Group is stratigraphically divided into three formations: the basal Tecovas Formation (siltstone and claystone); the middle Trujillo Formation (sandstone and siltstone); and the upper Chinle Formation (claystone and siltstone) (Gawloski, 1983). The Trujillo Formation of West Texas is analogous to the Santa

Rosa Formation of New Mexico. The portion of the Dockum Group encountered at the site is classified as part of the Chinle Formation.

A thin surface outcrop of Dockum Group sediments exists at Baker Spring (Plate VI.A.3). At this location, approximately five feet of dusky red colored siltstone and claystone is exposed at the base of a highwall of caliche and Ogallala Formation sediments. The upper surface of the Dockum Group is irregular and indicates an eroded, disconformable contact with the overlying Ogallala Formation.

The Dockum Group was penetrated to a maximum depth of 300 feet below ground level (location 9-G) during the on-site soil boring program. Continuous cores, drill cuttings and geophysical logs were used to characterize this shallow portion of the Dockum Group at the site. This information is presented in 10 hydrogeologic cross-sections (Figure VI.A.24 through VI.A.33). In addition, the general distribution of Dockum Group silt and sand is presented in Figure VI.A.38.

Based on the results of the on-site drilling program, the Dockum Group consists primarily of reddish brown, maroon and purple siltstone and claystone with intervals of reddish tan and greenish gray siltstone and sandstone. However, as shown in the cross-sections, a number of cycles of predominantly mudstone and siltstone/sandstone deposition indicate the variable depositional history and complexity of the local Dockum Group.

The portion of the Dockum Group encountered during the on-site drilling program can be divided into three major depositional cycles: 1) a lower interval consisting of siltstone with some claystone, below an approximate elevation of 3,250 feet MSL; 2) an intermediate interval of primarily claystone with some siltstone and sandstone, within an approximate elevation range from 3,250 to 3,325 feet MSL; and 3) an upper interval consisting of siltstone and sandstone with some claystone above an approximate elevation of 3,325 feet MSL. These three depositional cycles are particularly well defined in cross-sections A-A' and J-J' (Figure VI.A.24 and VI.A.33, respectively).

The upper and lower depositional cycles represent periods of increased depositional activity. Reddish brown, massive to parallel-laminated claystones typically indicate lacustrine or prodelta sedimentation, while greenish gray and reddish brown, parallel-laminated and cross-laminated siltstones and very fine grained sandstones indicate delta-front deposition (McGowen et. al., 1979). A predominant greenish gray coloration of the siltstones and sandstones indicates deposition during periods of high lake levels (i.e., high stand), which corresponds to periods of relatively high rainfall rates. During these periods, the fluvial system is actively transporting material to the basin from distant source areas. This sediment is rich in lighter colored granitic minerals and often contains flakes of mica and biotite. A predominant reddish brown coloration of the siltstones and sandstones indicates deposition during periods of low lake level (i.e., low stand). This is when rainfall rates are relatively low, and the fluvial system is no longer transporting sediment into the basin from distant source areas. The primary sediment source consists of pre-existing Triassic strata located along the margin of the lacustrine basin.

The middle depositional cycle represents a period of relatively quite lacustrine deposition. This interval consists primarily of reddish brown, maroon and purple claystone with some siltstone and sandstone. The claystone intervals record periods of both high stand and low stand lacustrine deposition. However, a predominance of maroon and purple, worm-burrowed claystone is indicative of high stand lacustrine deposition. A dominantly reddish brown and purple claystone, mottled with greenish gray, is indicative of high stand mud flat deposition. Mud flat sediments also exhibit clay and mineral infilling of fractures (i.e., mud cracks) and contain disseminated calcium carbonate cementation and caliche nodules. Siltstone and sandstone intervals that do not exhibit observable grain size sorting trends are typically the result of fan delta deposition associated with low stand braided stream systems. Massive, reddish brown claystones which exhibit abundant worm burrows and slickensides are associated with low stand lacustrine and mud flat deposition (McGowen et. al., 1979).

The local distribution pattern of Dockum Group sandstone and siltstone indicates a sediment transportation network which is oriented in a general west to east direction. A percent sandstone and siltstone map was generated for the uppermost depositional cycle (Figure VI.A.38). The sandstone and siltstone within the upper depositional cycle exhibits a sinuous to dendritic distribution pattern, with a distribution axis running through the middle portion of the local study area. This configuration is consistent with the regional distribution pattern which indicates an east to northeast progradation of Dockum Group sands extending from a source area in the Diablo Platform to the west/southwest (Figure VI.A.39).

A sandstone and siltstone distribution map for the lower depositional cycle was not generated due the minimal number of borings which penetrate this interval. However, a geophysical logging program was conducted at eight deep locations at the proposed WCS landfill site, which provides information regarding the lateral continuity of the lower depositional cycle. These logs, combined with the results from the continuous coring/soil boring program, indicate a laterally continuous sandy silt interval within the lower depositional cycle, at an approximate subsurface elevation of 3,225 feet to 3,250 feet MSL (Figure VI.A.24 and VI.A.33).

The geophysical log signature observed in Figure VI.A.24 and VI.A.33 can also be seen on the two deep cross-sections (Plate VI.A.4 and VI.A.5) within the same approximate subsurface elevation range. As shown on the two deep cross-sections, the long axis of this sandy silt interval is oriented in a generally southwest to northeast direction. This interval is shown on Plate VI.A.5 extending over four miles from location #12 to location #15. As shown on Plate VI.A.4, the short axis of this sandy silt unit extends a minimum distance of 1.3 miles from location #4 to location #9. The southwest to northeast distribution pattern of this lower cycle sandy silt interval is consistent with the distribution pattern of the upper cycle (Figure VI.A.38) and is consistent with the regional Dockum Group sand distribution pattern (Figure VI.A.39).

A.4.4. Hydrogeologic Framework

The local hydrogeologic framework consists of unsaturated caliche and Ogallala Formation deposits overlying Dockum Group sediments which appear to be under both confined and water table conditions. Saturated conditions were encountered in the Ogallala Formation beneath the buffalo wallow at location 2-D. However, the Ogallala Formation did not yield water from any of the borings surrounding the buffalo wallow, or at any of the other locations at the proposed WCS landfill site.

This isolated occurrence of shallow groundwater in the Ogallala Formation is attributed to the localized perching of groundwater within a shallow depression in the paleotopographic surface of the Dockum Group immediately beneath the buffalo wallow. Based on the results of the site-wide drilling program, this isolated occurrence of shallow Ogallala Formation groundwater does not constitute an aquifer. See Section VI.A.4.2 for a complete discussion of local Dockum Group structure and its relationship to the 2-D buffalo wallow. A complete discussion of the local hydrogeologic system is provided in Section B.2.

A.4.5. Geotechnical Properties of the Subsurface Soils

A discussion of the subsurface soil geotechnical properties is provided in the companion report provided by JHA. Selected data based on laboratory permeameter testing are used in the discussion of local groundwater conditions contained in Section VI.B.2.

VI.B. Facility Groundwater

B.1. Regional Aquifers

The High Plains Aquifer of West Texas consists of water bearing units within: Quaternary alluvial deposits; the Pliocene Ogallala Formation; and Createceous rocks (Nativ and Gutierrez, 1988). Regionally, the Ogallala Formation is the primary component of the High Plains Aquifer (Dutton and Simpkins, 1986). The High Plains Aquifer is viewed as one, hydraulically connected aquifer system, and groundwater typically exists under both unconfined and confined conditions.

B.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 (Cronin, 1969). The general characteristics of the Ogallala Formation, which have been discussed previously in Sections A.3.1, A.3.2 and A.4.3 indicate the fluvial origin of the Ogallala Formation. There is complex vertical and lateral variability found within the Ogallala Formation.

Regionally, the Ogallala Formation thickens to the north and west. The saturated thickness of the Ogallala Aquifer ranges from a few feet to approximately 300 feet in the Southern High Plains (Nativ, 1988). Groundwater within the Ogallala Aquifer is typically under water table conditions, with a regional hydraulic gradient toward the southeast (Figure VI.B.1) ranging from approximately 10 feet/mile (Stone and Webster, 1983) to 15 feet/mile (Knowles et. al., 1984). The average hydraulic conductivity of the Ogallala Aquifer ranges from 1 foot/day (Knowles et. al., 1984) to 27 feet/day (Stone and Webster, 1983).

The Ogallala Aquifer is recharged primarily through the infiltration of precipitation. The rate of recharge is believed to be less than 1 inch/year (Stone and Webster, 1983). Groundwater discharge from the Ogallala Aquifer occurs naturally through springs, underflow, evaporation and transpiration, but is also removed artificially through pumpage and catchment. Currently, the rate of withdrawal exceeds the rate of recharge for much of the Ogallala Aquifer (Stone and Webster, 1983).

Water quality data for three Ogallala Aquifer wells, located within two miles of the site, resulted from a review of Texas and New Mexico state records for western Andrews County, Texas and eastern Lea County, New Mexico. These water well locations are tabulated in Table VI.B.1.a, and water quality data for these wells are presented in Table VI.B.1.b. The well locations are spotted on Plate VI.A.1.

Review of the water quality data indicates that the local Ogallala Aquifer contains fresh to slightly saline water (TDS $\leq$ 3,000 mg/L). The TDS value for well 26-40-201 (1,070 mg/L) is slightly above the Recommended Secondary Constituent Level of 1,000 mg/L (25 TAC Chapter 337). However, the Ogallala Formation does not appear to be water bearing at the proposed WCS landfill site.

<u>Tertiary-Quaternary Aquifer</u>

The Tertiary-Quaternary Aquifer is a minor regional aquifer and is not present at the proposed WCS landfill site. Quaternary-age alluvium occurs as channel deposits composed of alternating thickly bedded calcareous silt, fine sand, and clay that overlie Ogallala Formation and Chinle Formation sediments along Monument Draw (Nicholson and Clebsch, 1961). From the north end of Monument Draw southward, groundwater moves through both the Quaternary alluvium and through the large outliers of the Ogallala Formation underlying the Eunice Plain area. The sediments along Monument Draw and under the Eunice Plain to the west of the draw have an average saturated thickness of about 30 feet (Nicholson and Clebsch, 1961). The bulk of the water in the Tertiary-Quaternary Aquifer is derived by underground flow from the Laguna Valley area to the north-northwest, as local recharge by precipitation is probably negligible. East of Monument Draw, the buried Triassic strata form a north-trending barrier which is reflected topographically by Rattlesnake Ridge (Nicholson and Clebsch, 1961). Groundwater flow is diverted southward by this barrier. In the Rattlesnake Ridge area, the base of the Ogallala Formation is generally above the water table.

B.1.2. Cretaceous Aquifer

The Cretaceous Aquifer of the Southern High Plains is typically considered as part of the High Plains Aquifer (Nativ and Gutierrez, 1988). Recharge to the Cretaceous Aquifer is provided by overlying Quaternary and Ogallala Formation sediments in Texas, and by upward leakage from the underlying Dockum Group in eastern New Mexico. The regional hydraulic gradient of the Cretaceous Aquifer is toward the southeast (Figure VI.B.2).

The Cretaceous Aquifer in the Southern High Plains consists of: a basal unit - Trinity Formation sandstone; an intermediate unit - Edwards Formation limestone; and an upper unit - Kiamichi/Duck Creek Formation sandstone and limestone. Where present in the subsurface, the Cretaceous Aquifer is used in the Southern High Plains as a primary source of groundwater (Nativ and Gutierrez, 1988). However, within Andrews County, the Cretaceous Aquifer is only present in the extreme southeastern portion of the county. Therefore, the Cretaceous Aquifer is not considered to be of importance to this report and is not discussed further in this section.

B.1.3. Dockum Group Aquifer

The Dockum Group regionally consists of Triassic fluvial and lacustrine clay, shale, siltstone, sandstone and conglomerate. The Dockum Group is divided into three stratigraphic units (bottom section to top section): the Tecovas Formation; Trujillo Formation (analogous to the Santa Rosa Formation) and Chinle Formation. The Tecovas Formation is not present within the regional or local study area. Water from the Dockum Aquifer is used as a replacement for, or in combination with the Ogallala Aquifer as a regional source for irrigation, stock and municipal water (Dutton and Simpkins, 1986).

<u>Lower Dockum Aquifer</u>

Topographically controlled groundwater basin divides were developed during the Pleistocene, by the erosion of the Pecos and Canadian River valleys (Figure VI.B.3). Prior to the development of these groundwater basin divides, the lower Dockum Aquifer was recharged by precipitation on its outcrop area in eastern New Mexico (Figure VI.B.3, view a and b). However, since the development of the Pecos and

Canadian River valleys, the lower Dockum Aquifer in Texas has been cut-off from its recharge area. Without recharge, the lower Dockum Aquifer experiences a net loss of groundwater from withdrawal by wells and by seepage (Figure VI.B.3, view c and d) (Dutton and Simpkins, 1986).

Hydraulic head levels, hydrochemical facies analyses and groundwater oxygen isotope values for the Dockum Aquifer, compared to the High Plains Aquifer, indicate that the confined Dockum Aquifer is separated from the overlying High Plains Aquifer by the thick confining claystones of the upper Dockum Group (Dutton and Simpkins, 1986). Groundwater oxygen isotope values indicate that the confined Dockum Aquifer was recharged in eastern New Mexico during a cool climate, at elevations above approximately 5,900 feet MSL (Dutton and Simpkins, 1986). However, due to the Pleistocene cut-off of the lower Dockum recharge area, current recharge is negligible (Figure VI.B.3). Therefore, groundwater within the lower, confined Dockum Aquifer is "old" (up to 3 million years old) and storage is irrevocably depleted by pumpage.

The regional hydraulic gradient of the lower Dockum Aquifer, which is toward the southeast, is presented in Figure VI.B.4. It can be inferred from this map that the potentiometric surface of the water bearing zones within the lower Dockum Group is located at an approximate elevation of 3,100 feet MSL (350 feet BGL) in the area of the proposed WCS landfill site.

<u>Upper Dockum Aquifer</u>

The upper portion of the Dockum Group (Chinle Formation) serves as an aquitard in the regional and local study area (Nicholson and Clebsch, 1961; Dutton and Simpkins, 1986). This is supported by the fact that the hydraulic head of the lower Dockum Aquifer is significantly lower than that of the overlying Ogallala Aquifer throughout much of the regional study area (Figure VI.B.5). This relative head difference, approximately 200 to 300 feet in western Andrews County, suggests that the lower Dockum Aquifer is receiving essentially no recharge (Nativ, 1988). The primary limiting factors on recharge include: the aquitard characteristic of the upper Dockum Group; and the cut-off, by the Pecos River Valley, of historical recharge areas in eastern New Mexico (Figure VI.B.3).

Permeable zones do exist within the upper Dockum Group which produce low quantities of good to poor quality water. Recharge to the upper Dockum Aquifer is provided by vertical infiltration of precipitation from the overlying units of the Quaternary-Tertiary Aquifer and High Plains Aquifer. This occurs where relatively permeable zones within the Dockum Aquifer are in contact with the overlying aquifer units (Nicholson and Clebsch, 1961). Within the regional study area, the flow direction in the upper Dockum Aquifer system is toward the east, away from outcrop areas to the west (Dutton and Simpkins, 1986).

B.2. Local Groundwater Conditions

The local groundwater system consists of unsaturated caliche and Ogallala Formation deposits resting on top of Dockum Group sediments which appear to be under both confined and water table conditions. Saturated conditions were encountered in the Ogallala Formation beneath the buffalo wallow at location 2-D. However, the Ogallala Formation did not yield water from any of the borings surrounding the buffalo wallow, or at any other locations within the local study area, and therefore does not constitute an aquifer. This isolated occurrence of Ogallala Formation groundwater is attributed to the localized perching of groundwater within a shallow depression in the paleotopographic surface of the Dockum Group immediately beneath the buffalo wallow (see Section VI.A.4.2 for a complete discussion of local Dockum Group structure and its relationship to the 2-D buffalo wallow). Water bearing units within the shallow Dockum Group consist of isolated to laterally extensive prodelta and delta-front siltstones and sandstones.

B.2.1. Uppermost Aquifer

The uppermost aquifer at the site consists of the saturated portion of the Dockum Group. Insufficient data are currently available to conclusively determine the character of the uppermost aquifer. This is due to the fact that the water levels in many of the 12 groundwater monitoring wells and piezometers, which were installed as part of the field investigation, have not yet equilibrated. In some cases, this water level equilibration period currently exceeds 90 days (Table VI.B.2). However, four of the piezometers installed have approximately reached stabilization, and form the basis for the following discussion. Regardless of which portion of the local Dockum Group is ultimately defined as the uppermost aquifer, the results of the on-site drilling program and deep cross-section preparation indicate an interval of underlying clay that is in excess of 30 feet in thickness (Figure VI.A.24 through VI.A.33; Plate VI.A.4 and VI.A.5).

Hydraulic Gradient

Water level elevations at four on-site piezometers have approximately reached static conditions. The water elevations at these locations range from 3,322.11 feet MSL (150.23 feet BGL) at location 11-D, to 3,257.45 feet MSL (181.10 feet BGL) at location 2-G (Table VI.B.2). Based on this preliminary information, a east/southeast gradient of approximately 75 feet per mile (0.014 feet per foot) is inferred for the local Dockum Group (Figure VI.B.5). This information corresponds well with the regional potentiometric surface map (Figure VI.B.4), which indicates a southeast hydraulic gradient for lower Dockum Group. The regional potentiometric surface map (Figure VI.B.4) also indicates a potentiometric surface for the lower Dockum Group of approximately 3,100 feet MSL in western Andrews County.

Aquifer System

As shown in the cross-sections at locations 2-G, 7-G and 11-D (Figure VI.A.24 and VI.A.33), the present hydraulic head level in these piezometers extends well above the top of the completion interval. This suggests that the water bearing intervals at these locations are under confined conditions. However, the water levels in the supplemental wells installed in the claystone above these water bearing intervals have not yet equilibrated. Therefore, it can not be confirmed at this time whether the head levels in piezometers 2-G, 7-G and 11-D, indicate confined conditions or simply reflect the uppermost zone of saturation within the surrounding claystones (i.e., water table conditions).

The water level at piezometer 4-C has equilibrated, and is within the completion interval (Figure VI.A.29). This indicates that the Dockum Group sandstone in which piezometer 4-C is completed, is under water table conditions.

Nested wells have been installed at three locations at the site (4-G, 6-B and 9-G), to obtain data regarding vertical hydraulic gradients. Once water levels reach static conditions, a more complete understanding of the local hydrogeologic system will be gained.

Groundwater Seepage Velocity

As discussed above, the analysis of the preliminary water level data from four of the on-site piezometers, indicates a hydraulic gradient of approximately 75 feet per mile (0.014 feet per foot) towards the southeast (Figure VI.B.6). Since water levels at the site have not reached static conditions, no field testing (i.e., slug testing or aquifer pump testing) has been performed to this point to evaluate in-situ hydraulic conductivity values. The fact that most wells at the site require many weeks for their water levels to reach static conditions, provides a qualitative indication of relatively low hydraulic conductivities for the local Dockum Aquifer.

Since in-situ pumping or slug test data are not currently available, hydraulic conductivity values based on laboratory permeameter testing results were used. These hydraulic conductivity values were derived from the testing of subsurface soil samples obtained during the on-site drilling program. Porosity values are based on assumptions from Walton (1991). A discussion of the permeameter testing, and other geotechnical testing programs, is provided in the companion report prepared by JHA.

Groundwater seepage velocities were calculated for three types of lithologic material: claystone, siltstone and sandstone. The highest measured hydraulic conductivity values available, derived from laboratory permeameter testing, were used to calculate the seepage velocity for each of the three lithology types. In addition, the assumed porosity value for each lithology was selected from the low end of the published range (Walton, 1991), to maximize the calculated seepage velocity. Groundwater seepage velocities were calculated using Darcy's Law as follows:

$$v = (K/n)\,(dh/dl) \qquad \text{(Freeze and Cherry, 1979, p 71)}$$

where:

v = seepage velocity
K = hydraulic conductivity
n = porosity
dh/dl = hydraulic gradient

The results of these calculations are summarized as follows:

Lithology	K (cm/sec)	n (0.20 =20%)	(dh/dl)	V (ft/day)	V (ft/year)
claystone	1.76×10^{-8}	0.10	0.014	7.0×10^{-6}	0.003
siltstone	3.20×10^{-6}	0.25	0.014	5.2×10^{-4}	0.2
sandstone	2.58×10^{-6}	0.25	0.014	4.3×10^{-4}	0.2

Groundwater Quality Data

Water quality samples have not been obtained from wells at the site. This is due to the fact that the wells have not equilibrated and have not been developed. However, a search of available state water quality data for Texas and New Mexico provided a groundwater analysis of a Dockum Aquifer well within two miles of the proposed landfill site (Table VI.B.1.b and Plate VI.A.1). This well is used as a groundwater monitoring well (MW-79) at the nearby Parabo, Inc. facility. The chemical analysis indicates slightly saline water (1,000 $\leq$ TDS $\leq$ 3,000 mg/L). The TDS (2,386 mg/L), sulfate (359 mg/L) and chloride (723 mg/L) values are above the Recommended Secondary Constituent Levels (25 TAC Chapter 337) of 1,000 mg/L, 300 mg/L and 300 mg/L, respectively.

B.2.2. Aquiclude

As discussed in Section VI.B.1.3, the Chinle Formation of the Dockum Group serves as a regional aquitard (Dutton and Simpkins, 1986). The portion of the Dockum Group encountered during the on-site drilling program consists of a complex assemblage of Chinle Formation claystone, siltstone and sandstone. As discussed in Section VI.B.2.1, laboratory-measured maximum hydraulic conductivities for site-specific Chinle Formation samples range from 1.76×10^{-8} cm/sec for claystone, to 3.20×10^{-6} cm/sec for siltstone and 2.58×10^{-6} for sandstone. These hydraulic conductivity values, combined with the massive to horizontally bedded character of local Chinle Formation, indicate that it will serve as an effective aquitard or aquiclude.

B.2.3. Underground Sources of Drinking Water (USDW)

An inventory of water wells within a 2-mile radius of the proposed landfill site was performed, based on existing state agency records. This information is summarized in

Table VI.B.1.a, and the well locations are posted on Plate VI.A.1. The 2-mile search area was initiated when no wells were found to be located within one mile of the site. A summary of groundwater quality analyses for these wells is provided in Table VI.B.1.b.

Based on geophysical log response and limited water chemistry data (Table VI.B.1.b), the Dockum Group appears to contain moderately saline water (TDS $\leq$ 10,000 mg/L). The underlying Permian units contain salt deposits and are not locally used as a water supply. Therefore, the base of the local USDW is determined to be at the base of the Dockum Group (i.e., approximately 1,400 feet BGL).

As discussed in Section B.1.1, the primary source of potable groundwater within the regional area is the Ogallala Aquifer. However, as discussed in this section, the base of the local USDW is considered to include water bearing zones within the lower Dockum Group. The local groundwater system will be insulated from proposed landfill activities at the WCS facility by the aquitard characteristics of the upper Dockum Group, and by the proposed landfill design and engineering controls. The proposed landfill design and engineering controls are discussed in the companion report provided by AME.

B.3. Detection Monitoring System

The detection monitoring system, including proposed well system (Section VI.B.3.1) and sampling parameters (Section VI.B.3.2), is discussed in the companion report provided by AME.

VI.C. Exemption from Groundwater Monitoring for an Entire Facility

WCS does not, at this time, wish to request an exemption from groundwater monitoring for the proposed landfill facility.

VI.D. Unsaturated Zone Monitoring

This section does not apply to this Part B Permit Application, because the proposed WCS facility is not a land treatment unit and is not associated with any Corrective Action.

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