# Evaluation of Potential Groundwater Impacts by the WCS Facility in Andrews County, Texas

by

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Prepared for

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# Executive Summary

The Andrews Industrial Foundation retained Dr. Ken Rainwater to evaluate the suitability of the Waste Control Specialists, Inc. waste treatment, storage, and disposal facility currently under construction in western Andrews County with respect to its potential impact on local and regional groundwater resources. The site was already permitted for acceptance of hazardous wastes, and a new permit for low-level radioactive wastes is sought. Special concern was placed on the possible presence of the Ogallala aquifer at the site location. The identification of the presence or absence of the Ogallala aquifer at the site was based on the definition of an aquifer as containing sufficient saturated permeable material to yield water to wells. The study approach included review of permit documents, site visits, public meeting attendance, inspection of core samples, evaluation of water quality sampling, and review of published descriptions of local and regional hydrogeologic information.

A report was delivered to the Foundation in December, 1996, with these conclusions:

[1] The presence of a thick Triassic clay layer near the ground surface at the site makes it an excellent location for a properly designed and constructed landfill.

[2] A thin stratum at the site was originally identified as the Ogallala formation, but it does not contain sufficient water for classification of the formation as an aquifer.

[3] Previous publications and recent field study of the local hydrogeologic conditions in Andrews County show that the Ogallala aquifer is not present, and the shallow permeable formation is actually the Antlers Sandstone.

[4] Publications about the regional hydrologic conditions in the Southern High Plains implied the presence of water in the Ogallala formation throughout Andrews County, but the assumed saturated thicknesses in the western portion are not well supported by field data.

[5] The siltstone layers in the Dockum group appear to be the uppermost water-bearing zone and may be acceptable for monitoring, but their low permeability and possibly limited extent do not meet the traditional definition of an aquifer.

[6] If properly constructed and operated, the landfill should have no impact on usable groundwater in Andrews County.

It is recommended that the Foundation continue to pursue the use of this site as a waste treatment, storage, and disposal facility. Proper design, construction, and operation should allow the site to serve its purpose without damage to groundwater resources.

# Evaluation of Potential Groundwater Impacts by the WCS Facility in Andrews County, Texas

Objective and Approach

The primary objective of this report is to evaluate the suitability of the western Andrews County site for the Waste Control Specialists (WCS) facility with specific concern to the site's impact on groundwater resources. This report was commissioned by the Andrews Industrial Foundation, Inc. (AIF), as an independent, impartial review of the suitability of the site for development as a hazardous waste treatment and disposal facility. Drs. Lloyd Urban and Ken Rainwater originally collaborated in this study beginning in 1993, and each produced reports based on data available at that time. The site received its permit in 1994, and construction began in 1996. During 1996, Drs. Tom Lehman, Harold Gurrola, and Priyantha Jayawickrama were brought in to address related geological and geotechnical issues as the site owners pursued a permit for low-level radioactive waste disposal at this site. Dr. Rainwater composed this report as an update of the 1993 document, while the other scientists and engineers provided their own documents as appropriate to the AIF. The WCS site is located at the western boundary of Andrews County, north of state highway 176 and east of the Texas-New Mexico border. Due to the lack of dependable fresh surface water, groundwater resources are precious in this county. The major water-bearing aquifer in the Southern High Plains of Texas is the Ogallala formation, which supplies water for agricultural and domestic purposes for much of the region. Site selection for landfill installations for safe, long-term disposal of hazardous materials in this region must minimize or completely prevent future deterioration of this water resource. The state agency with regulatory jurisdiction for this project is the Texas Natural Resource Conservation Commission (TNRCC), and this agency actively enforces waste management regulations with intent of groundwater protection.

A special concern of this report is determination of the local characteristics of the Ogallala formation and other shallow permeable strata, as expressed in the geologic setting and the storage and transmission of water. Many citizens are concerned with the protection of the Ogallala aquifer in the High Plains of Texas as the primary water source for irrigation, rural families, and many municipalities. Some use the presence of the Ogallala aquifer as a reason to oppose any industrial and/or waste disposal projects that involve hazardous chemicals that may somehow enter the aquifer. There is debate as to whether the Ogallala aquifer is actually physically present at the WCS site. The definition of an aquifer is given by Freeze and Cherry (1979) as "a saturated permeable geologic unit that can transmit significant amounts of water under ordinary hydraulic gradients," and also states that "an aquifer is permeable enough to yield economic quantities of water to wells" (p. 47). Todd (1980) defined an aquifer as "a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs" (p. 25). The operative words in these two definitions are "saturated" and "permeable," implying water must be present in adequate amounts to move through the geologic stratum. This investigation of the subsurface hydrogeologic conditions at the proposed WCS site specifically considers whether the formation, whether or not it is the Ogallala, at this location fits both these criteria for definition as an aquifer.

The approach taken in this study can be described as a series of tasks. These tasks are summarized in the following list:

[1] Review of the 1993 permit documents and recent site-specific hydrogeologic data;

[2] Visits to the WCS site;

[3] Attendance at TNRCC public meeting in Andrews to hear local concerns;

[4] Inspection of core samples collected during subsurface investigation;

[5] Recommendation and evaluation of water quality sampling and analyses; and

[6] Review of regional and local hydrogeologic information.

In this report, the efforts and results associated with each task are briefly presented in separate sections. It should be noted that this updated report benefits greatly from the recent work by Dr. Tom Lehman on the description of the local geologic setting (Lehman, 1996). The last section of the report summarizes the major conclusions and recommendations appropriate to the information reviewed.

Review of Permit Documents and Recent Monitoring Data

Copies of Volumes II, IV, and V of the "RCRA Permit Application For A Hazardous Waste Storage, Treatment, and Disposal Facility" (AME, 1993) were provided by the design firm, AM Environmental, Inc. (AME), of Austin, Texas. The material of concern to the groundwater evaluation in these volumes included the landfill engineering design documents (Vol. II), geotechnical investigation results and groundwater monitoring plan (Vol. IV), and local geologic and hydrogeologic descriptions (Vol. V). These documents were submitted to the TNRCC for regulatory review. This report does not constitute another form of regulatory approval, but does provide additional expert evaluation of the environmental suitability of the site for the proposed facility. The regulatory agency is also interested in protection of groundwater resources, and the permit application contains much useful site-specific information for evaluation of the possible impacts, if any, of the site on the local and regional groundwater. The principal points associated with the local groundwater are summarized in this section. AME also provided summaries of the results of groundwater monitoring events since 1993 (Messenger, personal communication). The regional geologic evaluation by Lehman (1996) was also used in evaluation of this information.

The main strength of this specific location for a hazardous waste landfill is the presence of a thick natural clay (or claystone) layer at less than 30 ft below the ground surface. This red clay material is referred to as the upper portion of the Triassic Dockum Group, sometimes referred to separately as the Chinle formation. The upper surface of this formation has a local topographic high directly beneath the proposed site as shown in Figure 1 (AME, 1993). Lehman (1996) demonstrated that this local high is actually part of regional "Red Bed Ridge" that extends from eastern New Mexico through western Andrews County southward to Winkler and Ector Counties. At the WCS site, the clay layer is over 200 ft thick, with three to four separate interbedded siltstone/sandstone layers. The hydraulic conductivities of the clay and siltstone were measured in the laboratory at $1.76\times10^{-8}$ cm/sec ($5.0\times10^{-5}$ ft/d or $3.7\times10^{-4}$ gpd/ft$^2$) and $3.20\times10^{-6}$ cm/sec ($9.1\times10^{-3}$ ft/d or $6.8\times10^{-2}$ gpd/ft$^2$), respectively. The natural permeability of the clay is in the range of design hydraulic conductivity for engineered landfill liner materials. The selection of the landfill

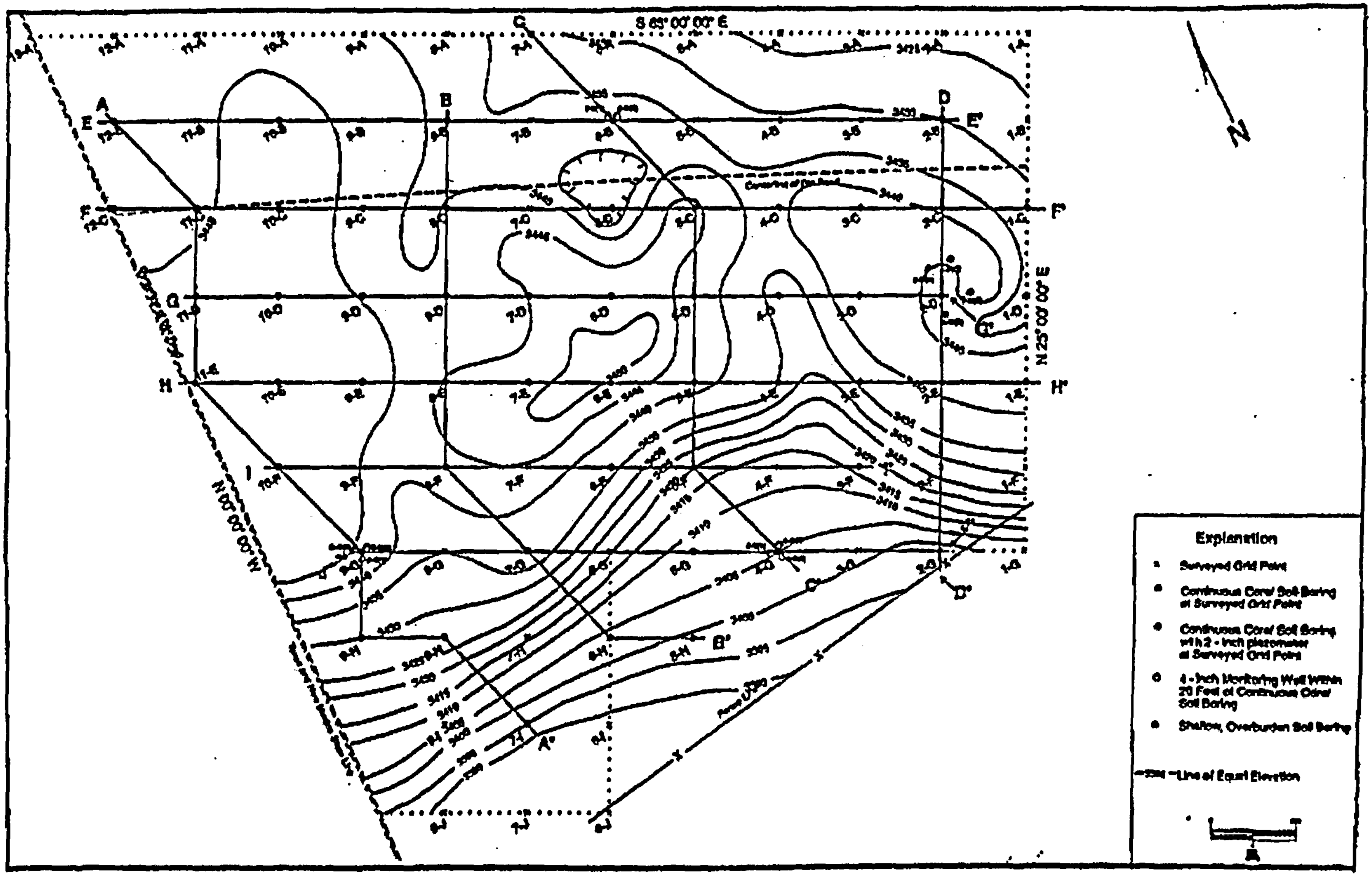


Figure 1. Topographic contour map of the upper surface of the Dockum group beneath the WCS site [Source: AME (1993)]

dimensions takes advantage of the shallow depth to this low permeability material by locating the bottom of the landfill excavation within the Triassic clay, completely penetrating the more permeable materials above the top of the Dockum group. The constructed landfill double liner system will rest atop the Triassic clay. The conventional double liner system includes two geomembranes, two compacted clay layers, and one leachate collection layer and one leachate detection layer. Unless the Triassic clay has significant fractures, it should provide a good foundation for the landfill construction.

The geotechnical investigation of the proposed site included collection of cores from a large number of borings and installation of several monitoring wells in suspected water-bearing zones. As previously stated, the Ogallala aquifer is the principal regional freshwater aquifer. In the geologic descriptions in the permit application, the geologic material above the Triassic clay was referred to as the typical Ogallala formation, with a caliche caprock overlying a layer of permeable alluvial sands and gravels, but the thickness of the permeable sands and gravels was usually less than 15 ft. Based on close examination of the gravels in the exposure of the formation at the WCS site and other outcrops in Andrews County, Lehman (1996) identified this material beneath the caprock as the Antlers Sandstone, not the Ogallala formation. The Antlers Sandstone has sufficient sand and gravel content with limited cementation to have significant permeability, but the thin formation apparently is not continuously saturated over significant areal extent in this vicinity.

Due to the low average rainfall amounts, the local high in the elevation of the top of the Dockum group, and the undulating shape of the top of the Dockum group, the permeable sediments atop the Triassic clay do not store significant amounts of water in this western part of Andrews County. Saturated sediments were only encountered beneath a local depression referred to as a "buffalo wallow," and it was concluded that a similar depression existed in the top of the Dockum beneath the surface depression, trapping the water in a small volume. Domestic and windmill wells that exist in the area do not produce much water during dry periods. Although the Ogallala formation was initially identified at the site, that identification was in error. No matter what the shallow permeable formation is named, it apparently does not hold and transmit sufficient amounts of water for development of wells. Control of stormwater drainage at the site may affect the storage of water in the formation beneath the "buffalo wallow," other natural depressions, or constructed impoundments if the collected runoff is kept on site and allowed to infiltrate.

Within the Dockum group, three or four separate siltstone layers were encountered in the grid of borings. These materials were found to have laboratory-measured hydraulic conductivities two orders of magnitude higher than the claystone. Screened monitoring wells were established in these zones at several locations within the grid. The water levels in these wells were measured several times between November, 1992 and April, 1995. A complete listing, Table A-1, is provided in the Appendix summarizing the well identities (based on original boring grid locations), top-of-casing elevations, screened intervals, depths to water, and water surface elevations for monitoring events by AME (Messenger, personal communication). Table 1 was derived by grouping monitoring wells with approximately similar screened interval locations. These groups roughly align with the identification of three possibly continuous siltstone layers. Groups A and B are most likely the first siltstone, while groups C and D roughly correspond to the second and third siltstone layers, respectively. The lateral and vertical extents of these layers are not completely known.

Inspection of Tables A-1 and 1 allows several important conclusions. First, when bailed to dryness, the water levels in the wells typically took several weeks to return to static levels. This delay indicated either low local permeability, little water volume in storage, or both controlled the return of water to the screened interval. Second, the equilibrated water surface elevations at most of the monitoring wells with similar depths of screen were not close enough to imply hydraulic continuity. For example, only well pairs 4-C and 5-C in group B, 4-G2 and 9-G2 in group C, and 4-G3 and 9-G3 in group D had water surface elevations within a few feet of each other. Third, the height of the water columns above the tops of the screens at wells 7-G, 2-G, 11-D, 6-B1, and 6-B2 were 44.3, 67.4, 107.13, 41.7, and 98.75 ft, respectively. These values indicate that the water in the siltstones at those locations was under pressurized confined conditions, yet the permeability or discontinuity still restricted the flow.

Table 1. Well Screened Intervals and Water Level Elevations Observed on April 19, 1995

| Group with Similar Intervals | Well | Screen Top Elevation (ft) | Screen Bottom Elevation (ft) | Water Surface Elevation (ft) |
|---|---|---|---|---|
| A | 9-G1 | 3330.17 | 3325.17 | dry |
| B | 5-E | 3312.28 | 3302.28 | dry |
| | 5-C | 3307.94 | 3287.94 | 3288.12 |
| | 4-C | 3307.55 | 3285.55 | 3288.79 |
| | 4-G1 | 3294.56 | 3264.56 | 3260.65 |
| | 6-B1 | 3295.66 | 3285.66 | 3337.36 |
| C | 7-G | 3262.72 | 3232.72 | 3307.15 |
| | 11-D | 3241.07 | 3216.07 | 3348.20 |
| | 4-G2 | 3249.69 | 3219.68 | 3245.16 |
| | 9-G2 | 3248.99 | 3238.99 | 3242.36 |
| | 6-B2 | 3220.26 | 3210.26 | 3319.01 |
| D | 2-G | 3214.93 | 3189.93 | 3282.33 |
| | 4-G3 | 3202.11 | 3197.11 | 3194.10 |
| | 9-G3 | 3197.02 | 3187.02 | 3193.06 |

The total dissolved solids (TDS) contents of the water samples taken from these wells were significantly higher (>1,800 mg/L) than typical regional values for the Ogallala aquifer (~500 mg/L). In addition, the TDS values varied significantly between the wells in these layers, possibly indicating little if any flow between the well locations. The upper siltstone layer was identified as the "uppermost aquifer" for monitoring purposes. Due to the difficulties in static water level equilibration and development, dedicated sampling pumps were recommended for future monitoring well installations. Further discussion of the hydrogeologic and geochemical data will be given in a later section of this report.

Site Visits

On July 28, 1993, Drs. Lloyd Urban and Ken Rainwater visited the proposed site. Allen Messenger and Andy Witteveld of AME conducted the tour. The site is currently part of the Flying W Diamond Ranch, a short distance east of Eunice, New Mexico. The property is used as a working ranch, with limited development for oil and gas wells. The grid of soil borings was still evident at the surface, as were the existing monitor wells. Mr. Witteveld described the bailer-development procedure he was using to encourage increased flow in the screened intervals of the wells. He also provided preliminary water quality data from sampling events since the preparation of the permit documents. Mr. Bill Vance, ranch manager, took the group over to the Monument Draw area on the other side of the state line for viewing of the 20- to 30-ft high cutbank of the draw. He also identified the Baker Spring location within the draw. No recent flow was evident at the spring.

During 1996, several visits to the site were made by Drs. Rainwater, Urban, Lehman, Gurrola, and Jayawickrama. On July 17, 1996, Drs. Rainwater, Urban, and Lehman visited the WCS site for their first view of the initial cell excavation, hosted by AME. Over the next three months, various combinations of the five scientists and engineers made additional visits to the site to gather geological and geophysical information about the vicinity.

Public Meeting in Andrews

At the request of the AIF, Drs. Urban and Rainwater attended a public meeting held by the TNRCC at the High School Auditorium in Andrews, Texas, on the evening of September 30, 1993. The purpose of the public meeting was to give local residents opportunity to ask questions of the TNRCC about the landfill and the permitting process. It was apparent that civic group support for the project was quite high, and that the AIF and AME had spent considerable effort describing the facility design to the residents. The TNRCC staff raised no questions at that time.

Inspection of Core Samples

On October 4, 1993, Dr. Rainwater visited the office of Jack H. Holt, Ph.D., and Associates, Inc. (JHA) with Mr. Witteveld to visually examine core samples from selected borings. Cores 6-B and 9-G, which are shown in Figure 1, represent locations in which almost all of the different lithological were penetrated. Of particular concern in this examination was the condition of the red claystone. In the samples from both cores, the red claystone core was typically continuous (few fracture planes not attributable to the sampling process), solid, and tight. As indicated by the results of the laboratory hydraulic conductivity tests, the claystone was probably naturally compacted by the weight of overburden during deposition. The zones identified as siltstone and sandstone were typically grayish or white cohesive materials with fine grains of silt or sand visible on the outside of the cores. The presence of the sand and silt apparently accounts for the higher hydraulic conductivities of these materials relative to that of the claystone. However, the siltstone and sandstone did not appear to have enough porosity to allow significant flow under typical natural gradients.

Recommendation and Evaluation of Water Quality Samples

AME provided the results of the analyses of water samples collected on July 23, 1993, from wells 2-G, 7-G, 11-D, and 6-B1. The surface locations of these wells are shown in Figure 1. The samples were analyzed for several water quality parameters, including some major ions, pH, and TDS. The major ion analyses are of primary concern to this report since ionic composition of groundwater sometimes provides clues about hydraulic connections in the local subsurface. For example, water quality in an aquifer generally deteriorates with distance from the point of recharge, as more materials are dissolved. Also, the nature and amount of dissolved species can indicate the rock types through which the water moved. Table 2 summarizes the results of the analyses. The concentrations of the ionic species were given by the laboratory in mg/L, and then converted to milliequivalents/L (meq/L) to check for electroneutrality. The condition of electroneutrality in a water solution requires that the sum of the meq/L of cations must equal the sum of the meq/L of anions. The "ion %" column lists the portion that each ionic constituent comprises in the major cations or anions as appropriate. The analyses for this sample set included all of the typical major ions in natural waters except for bicarbonate ($HCO_3$).

Table 2 shows that there was little similarity in the waters from the four wells. The measured TDS varied from 1800 to 5500 mg/L. In each sample, sodium (Na) was the dominant cation and sulfate ($SO_4$) was the dominant anion, but the relative concentrations varied by a factor of almost 3. It is possible to check a major ion analysis by comparing the measured and calculated TDS values. The measured TDS is normally done with a conductivity meter based on the ionic strength of the solution. The calculated TDS is found by summing the total mg/L of the cations

Table 2. Water Quality Analyses for Samples Collected 7/23/93

| Well | 2-G | | | 7-G | | | 11-D | | | 6B-1 | | | 26-40-602(Ogallala) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constituent | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % |
| Cations | | | | | | | | | | | | | | | |
| Ca | 28 | 1.40 | 4.1 | 64 | 3.20 | 4.2 | 60 | 3.00 | 6.1 | 7 | 0.35 | 1.3 | 78 | 3.90 | 53.3 |
| Mg | 20 | 1.65 | 4.8 | 58 | 4.77 | 6.3 | 51 | 4.20 | 8.5 | 11 | 0.91 | 3.3 | 21 | 1.73 | 23.6 |
| Na | 710 | 30.87 | 90.5 | 1560 | 67.83 | 88.8 | 960 | 41.74 | 84.7 | 590 | 25.65 | 94.0 | 36 | 1.57 | 21.4 |
| K | 8 | 0.19 | 0.6 | 22 | 0.56 | 0.7 | 13 | 0.32 | 0.6 | 15 | 0.37 | 1.4 | 5 | 0.13 | 1.7 |
| Total | 766 | 34.1 | 100.0 | 1704 | 76.36 | 100.0 | 1084 | 49.26 | 100.0 | 623 | 27.28 | 100.0 | 140 | 7.32 | 100.0 |
| Anions | | | | | | | | | | | | | | | |
| Cl | 200 | 5.63 | 17.1 | 1157 | 32.59 | 38.6 | 290 | 8.17 | 24.4 | 200 | 5.63 | 23.1 | 39 | 1.10 | 15.3 |
| SO4 | 1300 | 27.08 | 82.3 | 2460 | 51.25 | 60.7 | 1200 | 25.00 | 74.7 | 900 | 18.75 | 76.9 | 39 | 0.81 | 11.3 |
| HCO3 | nr | | | nr | | | nr | | | nr | | | 304 | 4.98 | 69.4 |
| NO3 | 12 | 0.19 | 0.6 | 33 | 0.53 | 0.6 | 19 | 0.31 | 0.9 | 0 | 0.00 | 0.0 | 18 | 0.29 | 4.0 |
| Total | 1512 | 32.91 | 100.0 | 3650 | 84.37 | 100.0 | 1509 | 33.48 | 100.0 | 1100 | 24.38 | 100.0 | 400 | 7.19 | 100.0 |
| Neutral | | | | | | | | | | | | | | | |
| SiO2 | 11 | | | 13 | | | 11 | | | 13 | | | 43 | | |
| TDS(meas) | 2600 | | | 5500 | | | 4000 | | | 1800 | | | 431 | | |
| TDS(sum) | 2289 | | | 5367 | | | 2604 | | | 1736 | | | 583 | | |
| TDS Error(%) | 6.4 | | | 1.2 | | | 21.1 | | | 1.8 | | | 15.0 | | |
| Ion Error(%) | | 1.8 | | | 5.0 | | | 19.1 | | | 5.6 | | | 0.9 | |

Well 24-40-602 (Ogallala) - Flying W Diamond Ranch well, sampled by TWDB on 10/10/1990, included for comparison
TDS Error(%) = 100 |TDS(sum) - TDS(meas)| / [TDS(sum) + TDS(meas)]
Ion Error(%) = 100 |Total Cations(meq/L)-Total Anions(meq/L)| / [Total Cations(meq/L)+Total Anions(meq/L)]
nr = not run

(Ca, Mg, Na, and K), the anions (Cl, $SO_4$, $NO_3$), and neutral compounds ($SiO_2$). The TDS (meas) and TDS (sum) should agree within 5 percent, as shown for wells 7-G and 6B-1. Electroneutrality is checked by comparing the total meq/L of the cations with the total meq/L of the anions in what is called the ion balance error. The ion balance error should also be less than 5 percent for an acceptable analysis, as it is for wells 2-G and 7-G. When these two checks are not consistent for all the analyses, especially when the TDS (sum) is less than the TDS (meas) for all the samples, it is quite possible that one or more other significant ions should be analyzed in the samples. Other errors could have taken place in one or more of the analyses which were performed on the samples. Dr. Rainwater suggested to Mr. Witteveld that bicarbonate should be added to the list of analyses for the next round of samples. A fifth water sample is included in Table 2 for comparison of typical local shallow groundwater quality to that in the Dockum group. Well 26-40-602 is located on the Flying W Diamond Ranch near state highway 176, and this well is occasionally monitored and sampled by the Texas Water Development Board (TWDB). The well is referred to as an "Ogallala" well by the TWDB.

A second set of samples was collected by AME on September 21, 1993, from wells 2-G, 7-G, 11-D, 6B-1, and 6B-2. Table 3 summarizes the results of the ion analyses. Comparison of Tables 2 and 3 show limited agreement between the two sets of analyses of wells 2-G, 7-G, 11-D, and 6B-1. This disagreement is not surprising, considering the difficulty of purging and sampling the wells in these siltstone layers. It is possible that there were sampling, handling, or analytical errors between the two sample sets, but it is also possible that the chemical composition of the water in the vicinity of each well has not been homogenized by mechanical mixing due to flow. This question would hopefully be resolved as additional samples were collected from these wells in subsequent monitoring events. The TDS values for well 2-G were similar, while the TDS values were higher in September for wells 7-G, 11-D, and 6B-1. Well 6B-2 showed very poor agreement between TDS (meas) and TDS (sum), and only well 7-G had acceptable agreement between TDS (meas) and TDS (sum).

With the addition of $HCO_3$ to the ion analyses, it was hoped that the ion balance errors

Table 3. Water Quality Analyses for Samples Collected 9/21/93

| Well | 2-G | | | 7-G | | | 11-D | | | 6B-1 | | | 6B-2 | | | 26-40-602(Ogallala) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constituent | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % |
| Cations | | | | | | | | | | | | | | | | | | |
| Ca | 53 | 2.65 | 12.2 | 170 | 8.50 | 10.4 | 156 | 7.80 | 16.0 | 28 | 1.40 | 8.4 | 33 | 1.65 | 11.5 | 78 | 3.90 | 53.3 |
| Mg | 25 | 2.06 | 9.5 | 55 | 4.53 | 5.5 | 33 | 2.72 | 5.6 | 11 | 0.91 | 5.5 | 12 | 0.99 | 6.9 | 21 | 1.73 | 23.6 |
| Na | 387 | 16.83 | 77.4 | 1560 | 67.83 | 82.6 | 870 | 37.83 | 77.8 | 324 | 14.09 | 84.9 | 264 | 11.48 | 80.2 | 36 | 1.57 | 21.4 |
| K | 8 | 0.20 | 0.9 | 49 | 1.25 | 1.5 | 11 | 0.28 | 0.6 | 8 | 0.20 | 1.2 | 8 | 0.20 | 1.4 | 5 | 0.13 | 1.7 |
| Total | 473 | 21.74 | 100.0 | 1834 | 82.11 | 100.0 | 1070 | 48.62 | 100.0 | 371 | 16.60 | 100.0 | 317 | 14.32 | 100.0 | 140 | 7.32 | 100.0 |
| Anions | | | | | | | | | | | | | | | | | | |
| Cl | 200 | 5.63 | 15.6 | 1700 | 47.89 | 45.7 | 590 | 16.62 | 32.1 | 210 | 5.92 | 16.6 | 200 | 5.63 | 21.8 | 39 | 1.10 | 15.3 |
| SO4 | 1300 | 27.08 | 75.0 | 2600 | 54.17 | 51.7 | 1600 | 33.33 | 64.4 | 1200 | 25.00 | 70.1 | 740 | 15.42 | 59.6 | 39 | 0.81 | 11.3 |
| HCO3 | 190 | 3.11 | 8.6 | 150 | 2.46 | 2.3 | 100 | 1.64 | 3.2 | 290 | 4.75 | 13.3 | 290 | 4.75 | 18.4 | 304 | 4.98 | 69.4 |
| NO3 | 18 | 0.29 | 0.8 | 12 | 0.19 | 0.2 | 10 | 0.16 | 0.3 | 0 | 0.00 | 0.0 | 4 | 0.06 | 0.2 | 18 | 0.29 | 4.0 |
| Total | 1708 | 36.12 | 100.0 | 4462 | 104.71 | 100.0 | 2300 | 51.75 | 100.0 | 1700 | 35.67 | 100.0 | 1234 | 25.87 | 100.0 | 400 | 7.19 | 100.0 |
| Neutral | | | | | | | | | | | | | | | | | | |
| SiO2 | 10 | | | 22 | | | 10 | | | 11 | | | 12 | | | 43 | | |
| TDS(meas) | 2700 | | | 6900 | | | 4600 | | | 1900 | | | 2600 | | | 431 | | |
| TDS(sum) | 2191 | | | 6318 | | | 3380 | | | 2082 | | | 1563 | | | 583 | | |
| TDS Error(%) | 10.4 | | | 4.4 | | | 15.3 | | | 4.6 | | | 24.9 | | | 15.0 | | |
| Ion Error(%) | | 24.9 | | | 12.1 | | | 3.1 | | | 36.5 | | | 28.7 | | | 0.9 | |

Well 24-40-602 (Ogallala) - Flying W Diamond Ranch well, sampled by TWDB on 10/10/1990, included for comparison

TDS Error(%) = 100 |TDS(sum)-TDS(meas)| / [TDS(sum)+TDS(meas)]

Ion Error(%) = 100 |Total Cations(meq/L)-Total Anions(meq/L)| / [Total Cations(meq/L)+Total Anions(meq/L)]

would be reduced. In this sample set, however, only the analyses from well 11-D met the 5 percent limit. It is difficult to identify a specific explanation for the larger ion balance errors. Analytical laboratories sometimes have difficulty with these balances in saline waters due to the differing concentration ranges measurable in the different ion procedures. The cations are normally quantified in elemental analyses by atomic spectrophotometry, which requires dilution of the sample, while anions may be analyzed by ion chromatography, titrations, colorimetry, or ion specific electrode methods which may or may not require dilution. The different methods are sometimes interfered with by high concentrations of other compounds. In any case, the accuracy of these analyses is in question. However, it is possible to make some useful comparisons. The ion percentages were used to visually compare ion grouping among these water samples using a trilinear, or Piper, diagram (Freeze and Cherry, 1979) in Figure 2. From this figure, the waters at all of the Dockum group wells are classified as $Na\text{-}SO_4\text{+}Cl$ dominated solutions. Note that the sample from well 26-40-602 plots far away from the Dockum samples, as a $Ca\text{+}Mg\text{-}HCO_3$ water. The 26-40-602 water is essentially a much "younger" water, more recently recharged from the atmosphere. Although the Dockum water samples show somewhat similar ionic distributions, the large differences in their TDS values cannot be directly correlated to a reasonable flow phenomenon in the siltstone.

Three more monitoring events occurred in October, 1993, January, 1994, and March, 1994. The results of these sampling events are summarized in Tables 4, 5, and 6, respectively. The results from these three events compare somewhat more closely overall than the first two sampling events. The ion and TDS balance errors often exceeded the 5 percent target, but the TDS values are much more comparable across events. In addition, the concentrations of the ionic constituents in each well are much more similar across events. When plotted on trilinear diagrams, the results are practically identical to those in Figure 2 within the scale of that configuration, so additional figures are not provided. The improved consistency is encouraging, and does not change the conclusions drawn in the previous paragraph.

In summary, the ionic analyses of the sampled wells were useful in describing the potential

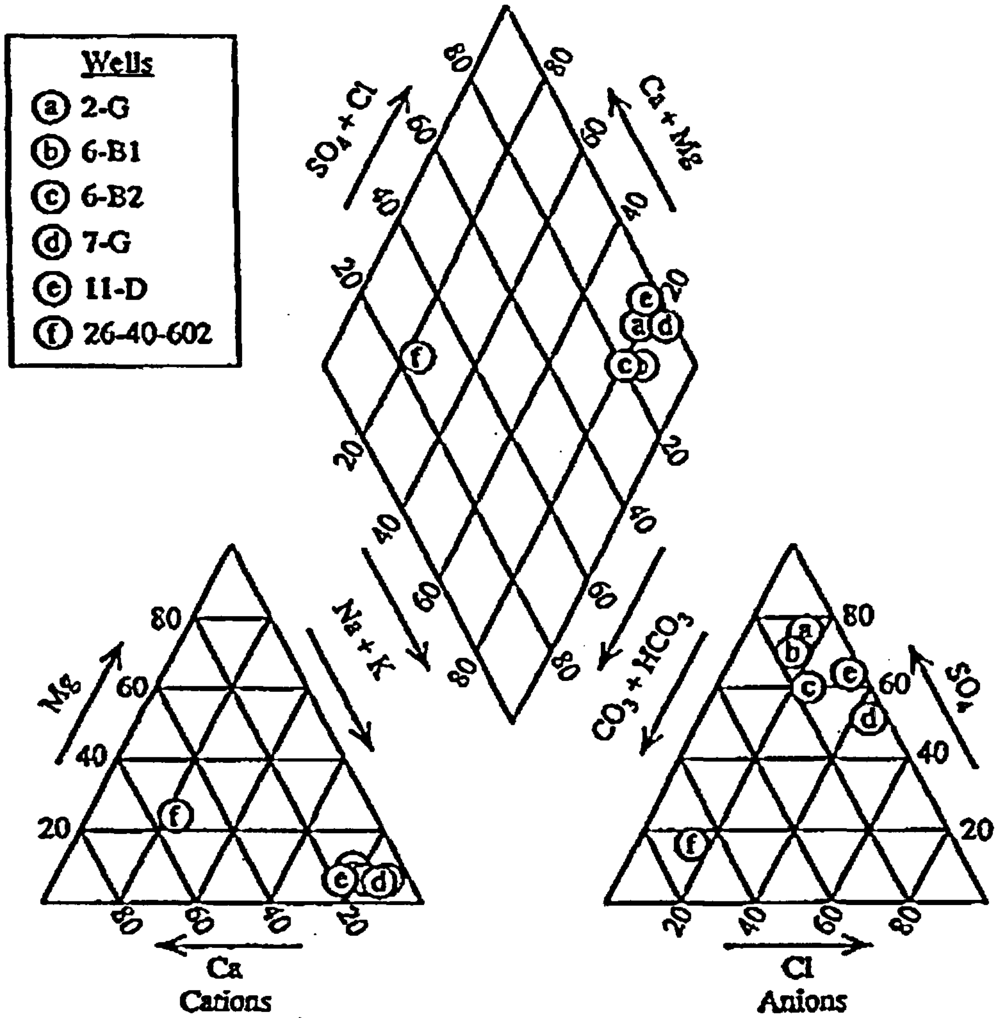


Figure 2. Trilinear Representation of Major Ion Analyses

### Table 4. Water Quality Analyses for Samples Collected 10/20/93

| Well | 2-G | | | 7-G | | | 11-D | | | 6B-1 | | | 6B-2 | | | 26-40-602(Ogallala) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constituent | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % |
| Cations | | | | | | | | | | | | | | | | | | |
| Ca | 72 | 3.60 | 10.4 | 126 | 6.30 | 6.3 | 158 | 7.90 | 12.6 | 42 | 2.10 | 8.5 | 33 | 1.65 | 4.4 | 78 | 3.90 | 53.3 |
| Mg | 36 | 2.96 | 8.6 | 106 | 8.72 | 8.7 | 68 | 5.60 | 9.0 | 17 | 1.40 | 5.7 | 15 | 1.23 | 3.3 | 21 | 1.73 | 23.6 |
| Na | 640 | 27.83 | 80.4 | 1940 | 84.35 | 84.0 | 1120 | 48.70 | 77.9 | 480 | 20.87 | 84.9 | 800 | 34.78 | 91.9 | 36 | 1.57 | 21.4 |
| K | 8 | 0.20 | 0.6 | 41 | 1.05 | 1.0 | 11 | 0.28 | 0.5 | 8 | 0.20 | 0.8 | 7 | 0.18 | 0.5 | 5 | 0.13 | 1.7 |
| Total | 756 | 34.59 | 100.0 | 2213 | 100.42 | 100.0 | 1357 | 62.47 | 100.0 | 547 | 24.57 | 100.0 | 855 | 37.85 | 100.0 | 140 | 7.32 | 100.0 |
| Anions | | | | | | | | | | | | | | | | | | |
| Cl | 180 | 5.07 | 11.2 | 1300 | 36.62 | 34.4 | 550 | 15.49 | 21.1 | 190 | 5.35 | 18.9 | 200 | 5.63 | 15.3 | 39 | 1.10 | 15.3 |
| SO4 | 1700 | 35.42 | 78.1 | 3200 | 66.67 | 62.5 | 2700 | 56.25 | 76.5 | 880 | 18.33 | 64.7 | 1260 | 26.25 | 71.3 | 39 | 0.81 | 11.3 |
| HCO3 | 190 | 3.11 | 6.9 | 150 | 2.46 | 2.3 | 100 | 1.64 | 2.2 | 280 | 4.59 | 16.2 | 300 | 4.92 | 13.4 | 304 | 4.98 | 69.4 |
| NO3 | 110 | 1.77 | 3.9 | 52 | 0.84 | 0.8 | 10 | 0.16 | 0.2 | 3 | 0.05 | 0.2 | 1 | 0.02 | 0.0 | 18 | 0.29 | 4.0 |
| Total | 2180 | 45.38 | 100.0 | 4702 | 106.58 | 100.0 | 3360 | 73.54 | 100.0 | 1353 | 28.32 | 100.0 | 1761 | 36.82 | 100.0 | 400 | 7.19 | 100.0 |
| Neutral | | | | | | | | | | | | | | | | | | |
| SiO2 | 10 | | | 12 | | | 11 | | | 13 | | | 12 | | | 43 | | |
| TDS(meas) | 2500 | | | 6700 | | | 4400 | | | 1800 | | | 2500 | | | 431 | | |
| TDS(sum) | 2946 | | | 6927 | | | 4728 | | | 1913 | | | 2628 | | | 583 | | |
| TDS Error(%) | 8.2 | | | 1.7 | | | 3.6 | | | 3.0 | | | 2.5 | | | 15.0 | | |
| Ion Error(%) | | 13.5 | | | 3.0 | | | 8.1 | | | 7.1 | | | 1.4 | | | 0.9 | |

Well 24-40-602 (Ogallala) - Flying W Diamond Ranch well, sampled by TWDB on 10/10/1990, included for comparison
TDS Error(%) = 100 |TDS(sum)-TDS(meas)| / [TDS(sum)+TDS(meas)]
Ion Error(%) = 100 |Total Cations(meq/L)-Total Anions(meq/L)| / [Total Cations(meq/L)+Total Anions(meq/L)]

Table 5. Water Quality Analyses for Samples Collected 1/26-27/94

| Well | 2-G | | | 7-G | | | 11-D | | | 6B-1 | | | 6B-2 | | | 26-40-602(Ogallala) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constituent | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % |
| Cations | | | | | | | | | | | | | | | | | | |
| Ca | 94 | 4.70 | 7.7 | 186 | 9.30 | 8.3 | 194 | 9.70 | 13.7 | 46 | 2.30 | 4.9 | 34 | 1.70 | 2.9 | 78 | 3.90 | 53.3 |
| Mg | 42 | 3.46 | 5.7 | 104 | 8.56 | 7.6 | 19 | 1.56 | 2.2 | 9 | 0.74 | 1.6 | 9 | 0.74 | 1.2 | 21 | 1.73 | 23.6 |
| Na | 1200 | 52.17 | 85.9 | 2150 | 93.48 | 83.1 | 1350 | 58.70 | 83.2 | 1000 | 43.48 | 92.7 | 1300 | 56.52 | 95.3 | 36 | 1.57 | 21.4 |
| K | 17 | 0.43 | 0.7 | 44 | 1.13 | 1.0 | 24 | 0.61 | 0.9 | 15 | 0.38 | 0.8 | 13 | 0.33 | 0.6 | 5 | 0.13 | 1.7 |
| Total | 1353 | 60.77 | 100.0 | 2484 | 112.46 | 100.0 | 1587 | 70.57 | 100.0 | 1070 | 46.90 | 100.0 | 1356 | 59.29 | 100.0 | 140 | 7.32 | 100.0 |
| Anions | | | | | | | | | | | | | | | | | | |
| Cl | 200 | 5.63 | 11.5 | 1500 | 42.25 | 37.0 | 730 | 20.56 | 27.2 | 230 | 6.48 | 21.9 | 230 | 6.48 | 13.2 | 39 | 1.10 | 15.3 |
| SO4 | 1900 | 39.58 | 80.8 | 3300 | 68.75 | 60.2 | 2500 | 52.08 | 68.8 | 890 | 18.54 | 62.6 | 1800 | 37.50 | 76.6 | 39 | 0.81 | 11.3 |
| HCO3 | 190 | 3.11 | 6.4 | 150 | 2.46 | 2.2 | 130 | 2.13 | 2.8 | 280 | 4.59 | 15.5 | 300 | 4.92 | 10.0 | 304 | 4.98 | 69.4 |
| NO3 | 41 | 0.66 | 1.3 | 42 | 0.68 | 0.6 | 56 | 0.90 | 1.2 | 0 | 0.00 | 0.0 | 5 | 0.08 | 0.2 | 18 | 0.29 | 4.0 |
| Total | 2331 | 48.99 | 100.0 | 4992 | 114.14 | 100.0 | 3416 | 75.68 | 100.0 | 1400 | 29.61 | 100.0 | 2335 | 48.98 | 100.0 | 400 | 7.19 | 100.0 |
| Neutral | | | | | | | | | | | | | | | | | | |
| SiO2 | 11 | | | 12 | | | 12 | | | 14 | | | 12 | | | 43 | | |
| TDS(meas) | 2700 | | | 7100 | | | 4500 | | | 1900 | | | 2700 | | | 431 | | |
| TDS(sum) | 3695 | | | 7488 | | | 5015 | | | 2484 | | | 3703 | | | 583 | | |
| TDS Error(%) | 15.6 | | | 2.7 | | | 5.4 | | | 13.3 | | | 15.7 | | | 15.0 | | |
| Ion Error(%) | | 10.7 | | | 0.7 | | | 3.5 | | | 22.6 | | | 9.5 | | | 0.9 | |

Well 24-40-602 (Ogallala) - Flying W Diamond Ranch well, sampled by TWDB on 10/10/1990, included for comparison
TDS Error(%) = 100 |TDS(sum)-TDS(meas)| / [TDS(sum)+TDS(meas)]
Ion Error(%) = 100 |Total Cations(meq/L)-Total Anions(meq/L)| / [Total Cations(meq/L)+Total Anions(meq/L)]

Table 6. Water Quality Analyses for Samples Collected 3/17-18/94

| Well | 2-G | | | 7-G | | | 11-D | | | 6B-1 | | | 6B-2 | | | 26-40-602(Ogallala) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constituent | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % | mg/L | meq/L | ion % |
| Cations | | | | | | | | | | | | | | | | | | |
| Ca | 84 | 4.20 | 8.9 | 200 | 10.00 | 7.6 | 180 | 9.00 | 9.3 | 31 | 1.55 | 3.7 | 30 | 1.50 | 3.0 | 78 | 3.90 | 53.3 |
| Mg | 26 | 2.14 | 4.5 | 98 | 8.07 | 6.1 | 56 | 4.61 | 4.8 | 19 | 1.56 | 3.7 | 12 | 0.99 | 1.9 | 21 | 1.73 | 23.6 |
| Na | 930 | 40.43 | 85.6 | 2600 | 113.04 | 85.5 | 1900 | 82.61 | 85.3 | 890 | 38.70 | 91.6 | 1100 | 47.83 | 94.2 | 36 | 1.57 | 21.4 |
| K | 19 | 0.49 | 1.0 | 45 | 1.15 | 0.9 | 23 | 0.59 | 0.6 | 17 | 0.43 | 1.0 | 17 | 0.43 | 0.9 | 5 | 0.13 | 1.7 |
| Total | 1059 | 47.26 | 100.0 | 2943 | 132.26 | 100.0 | 2159 | 96.81 | 100.0 | 957 | 42.24 | 100.0 | 1159 | 50.75 | 100.0 | 140 | 7.32 | 100.0 |
| Anions | | | | | | | | | | | | | | | | | | |
| Cl | 220 | 6.20 | 15.0 | 1640 | 46.20 | 40.7 | 610 | 17.18 | 25.5 | 230 | 6.48 | 23.7 | 230 | 6.48 | 17.8 | 39 | 1.10 | 15.3 |
| SO4 | 1500 | 31.25 | 75.6 | 3100 | 64.58 | 56.9 | 2300 | 47.92 | 71.0 | 780 | 16.25 | 59.6 | 1200 | 25.00 | 68.7 | 39 | 0.81 | 11.3 |
| HCO3 | 191 | 3.13 | 7.6 | 148 | 2.43 | 2.1 | 125 | 2.05 | 3.0 | 278 | 4.56 | 16.7 | 298 | 4.89 | 13.4 | 304 | 4.98 | 69.4 |
| NO3 | 48 | 0.77 | 1.9 | 13 | 0.21 | 0.2 | 22 | 0.35 | 0.5 | 0 | 0.00 | 0.0 | 0 | 0.00 | 0.0 | 18 | 0.29 | 4.0 |
| Total | 1959 | 41.35 | 100.0 | 4901 | 113.42 | 100.0 | 3057 | 67.50 | 100.0 | 1288 | 27.29 | 100.0 | 1728 | 36.36 | 100.0 | 400 | 7.19 | 100.0 |
| Neutral | | | | | | | | | | | | | | | | | | |
| SiO2 | 11 | | | 12 | | | 11 | | | 14 | | | 12 | | | 43 | | |
| TDS(meas) | 2660 | | | 7300 | | | 4650 | | | 1790 | | | 2700 | | | 431 | | |
| TDS(sum) | 3029 | | | 7856 | | | 5227 | | | 2259 | | | 2899 | | | 583 | | |
| TDS Error(%) | 6.5 | | | 3.7 | | | 5.8 | | | 11.6 | | | 3.6 | | | 15.0 | | |
| Ion Error(%) | | 6.7 | | | 7.7 | | | 17.8 | | | 21.5 | | | 16.5 | | | 0.9 | |

Well 24-40-602 (Ogallala) - Flying W Diamond Ranch well, sampled by TWDB on 10/10/1990, included for comparison
TDS Error(%) = 100 |TDS(sum)-TDS(meas)| / [TDS(sum)+TDS(meas)]
Ion Error(%) = 100 |Total Cations(meq/L)-Total Anions(meq/L)| / [Total Cations(meq/L)+Total Anions(meq/L)]

for flow and mixing in the sampled siltstone. Although the TDS and ion error values are higher than those typically accepted in fresh water analyses, they are not uncommon in more saline waters with high ion concentrations that can cause interferences for some of the analytical techniques. These results are sufficient to verify the large difference in quality between the shallow fresh groundwater and the Dockum waters. In addition, the large differences in composition of the Dockum water samples indicate little mixing due to flow in the siltstone.

Review of Geologic and Hydrogeologic Information on Andrews County

As stated previously in this report, protection of existing groundwater resources is of utmost concern in siting and design of hazardous waste facilities. The major high quality groundwater source in the Southern High Plains of Texas is the Ogallala aquifer. In this section, the direct impacts of the WCS facility on the Ogallala aquifer in both the local and regional scale are considered. The site investigation results from the permit application (AME, 1993) and the historical findings published in the professional literature are combined in this evaluation.

As stated previously, the shallow permeable formation in the site vicinity is evaluated under the two aquifer criteria of [1] presence of geologic media that easily transmit water flow and [2] presence of sufficient volume of water for flow to production wells. This section includes discussion of geologic and hydrogeologic information from the AME (1993) permit documents, existing literature descriptions, and the most recent field work by Lehman (1996). Please note that all of the references prior to Lehman (1996) refer to the shallow permeable formation in western Andrews County as the Ogallala formation. Lehman's (1996) clarification is presented at the end of this section.

As reported in the hydrogeologic section in the permit application (AME, 1993), the borings drilled in the subsurface investigation encountered permeable sands and gravels identified as the lower portion of the Ogallala formation. Saturated conditions in these sediments were only rarely encountered, and then only beneath a surface depression. The saturated zone beneath the "buffalo wallow" was not sufficient to allow water to collect in the borehole. The conclusion of the site characterization was that the Ogallala formation is present beneath the site, but the formation does not contain an extensive, continuous volume of water suitable for development. The experience of Mr. Vance with the shallow Ogallala well at the Flying W Diamond Ranch corroborated this view, since the well was known to produce water only sporadically after sizable rainfall events. The mounded shape, as shown in Figure 1, of the top of the Dockum group, apparently encourages water that infiltrates into the shallow permeable formation from the surface to flow away from beneath the WCS site. It is also possible that rainfall may be so low in this location that soil and vegetation combinations in the area may prevent infiltration of significant amounts of water.

Documents describing the Ogallala aquifer conditions in the Andrews County vicinity were obtained from the TWDB and the holdings of the Texas Tech libraries. Six documents directly addressed the groundwater resources in the county, but, as will be shown in the following discussion, little accurate historical information exists that describe the conditions in the western portion of the county.

In 1940, the Texas Board of Water Engineers published a report on the groundwater development in Andrews County (TBWE, 1940). This report was a compilation of drillers' logs, well and test hole reports, and chemical analyses from wells in existence prior to 1940. The reports referred to a few hundred wells in the county, with most of the pumping wells in the eastern two-thirds of the county near the city of Andrews. No wells were shown in the vicinity of the WCS site.

Cronin (1961) presented a report on the occurrence and use of groundwater in the Southern High Plains as part of a joint effort between the U.S. Geological Survey (USGS), TBWE, and the High Plains Underground Water Conservation District. The report included a thorough discussion of the regional lithology as understood at that time and a number of contour maps that showed the elevation of the water table in the Ogallala aquifer, the elevation of the base of the Ogallala, and the saturated thickness of the aquifer across the region. Figure 3, which shows the elevation of the base of the Ogallala, provides no resolution of that quantity in the western one-fifth of Andrews County, implying that acceptably accurate records were not available to the author. Figure 4,

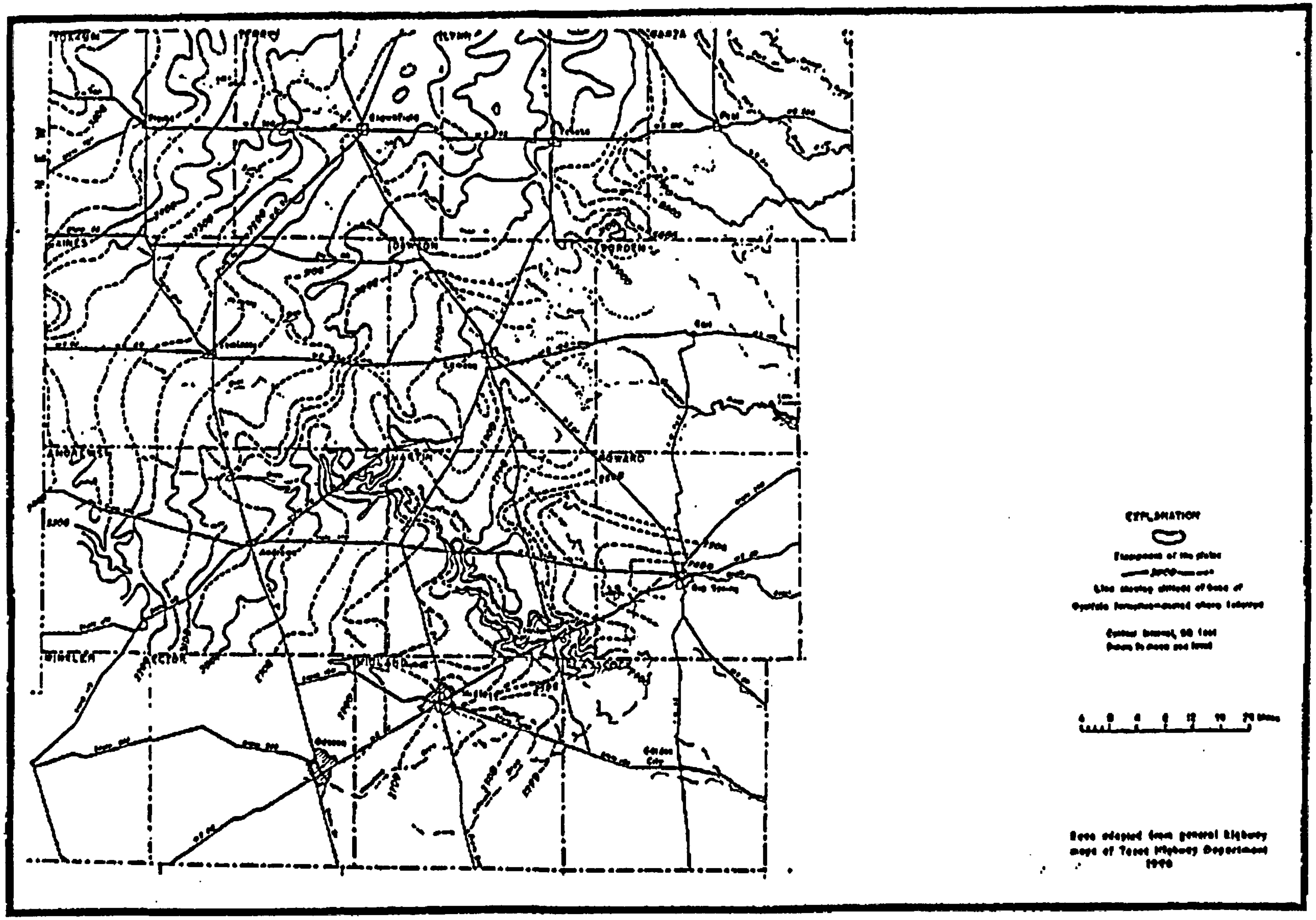

Figure 3. Contour Map of Base of Ogallala Formation. [Source: Cronin (1961)]

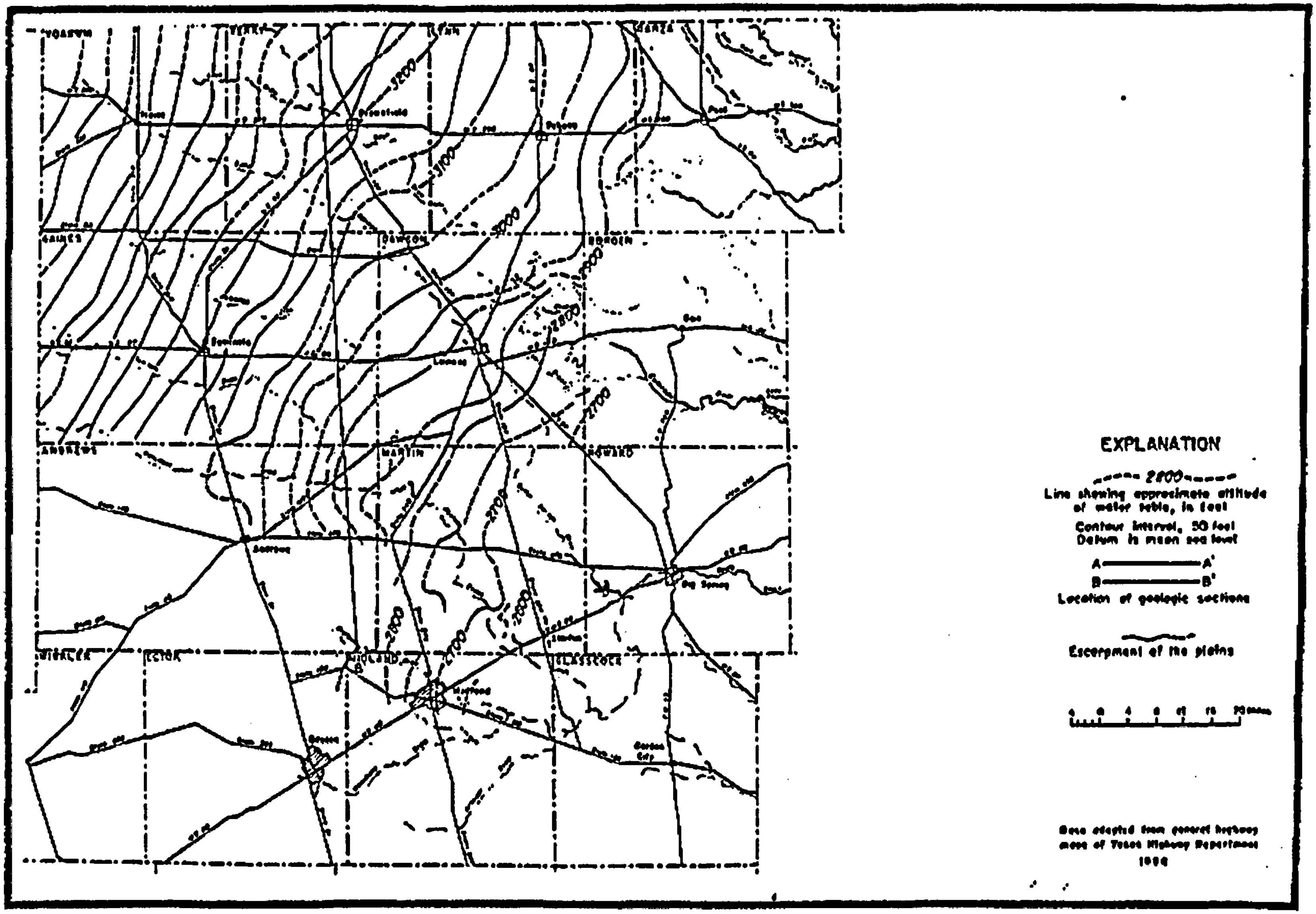


Figure 4. Contour Map of Water Level Elevation in Ogallala Formation. [Source: Cronin (1961)]

which shows the elevation of the water table in 1958, only indicates measured values in the northeast corner of Andrews County. Figure 5, the contour map of saturated thickness in the Ogallala, is directly related to the limited information in Figures 3 and 4. Figure 5 displays the estimated saturated thickness at the intersection of state highway 176 and the state line, near the WCS site, to be 0 (zero) ft. The method used to derive this estimate was not explained in the report. Apparently, the only appreciable Ogallala water storage in Andrews County was believed to be in the eastern portion of the county.

The TWDB is now the state agency that manages the database describing the state's surface and groundwater resources. Within this responsibility, the TWDB monitors groundwater levels and water quality at selected locations around the state. This data is then used in modeling efforts for projections of groundwater usage and storage for periods 20 to 50 years in the future. Three TWDB wells were identified within 2 miles of the WCS site (AME, 1993, Plate VI.A.1). A visit was made on October 4, 1993 to the TWDB office in Austin to obtain the records for these three wells. Well 26-40-201, owned by Mr. Ed Tinsley, is located approximately 1.2 miles northeast of the WCS site. Wells 26-40-601 and 26-40-602 (about 1200 ft east of 26-40-601), both associated with the Flying W Diamond Ranch, are located about 1.4 miles east-southeast of the WCS site. Table 7 summarizes the reported water depth measurements at these wells. Without a site-specific value of the elevation of the base of the Ogallala at wells 26-40-201 and -601, it is impossible to estimate the local saturated thickness. Also, it appears that no water depth measurement was made by the TWDB at well 26-40-602. Therefore, the wells monitored and reported by the TWDB provide no assistance in estimating local storage in the Ogallala aquifer. A total of four water samples have been collected from the three wells since 1974, with the most recent at well 26-40-602 (Table 2). The water quality at wells 26-40-601 and -602 have been quite similar, as would be expected due to their proximity. Well 26-40-201 has about twice the TDS of the other two wells, due to larger concentrations of calcium, sulfate, and chloride.

Ashworth and Flores (1991) of the TWDB published a set of two maps that delineated the areal extents of the major and minor aquifers in Texas, along with a report which described the

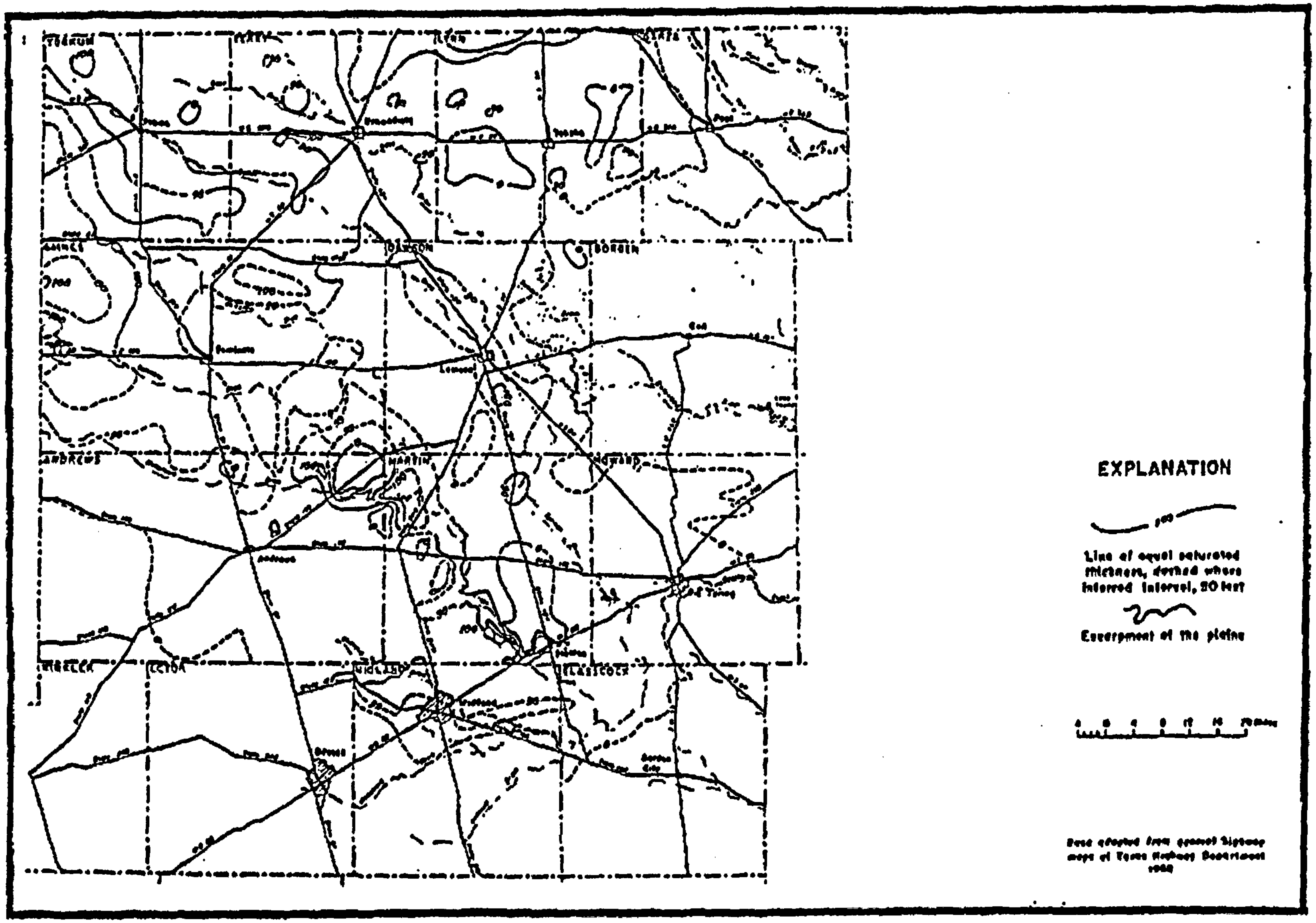


Figure 5. Contour Map of Saturated Thickness in Ogallala Formation. [Source: Cronin (1961)]

Table 7. Water Depth Measurements at TWDB Wells Near WCS Site
(na = information not available)

| Well | Depth of Well (ft) | Date Measured | Depth to Water (ft) | Water Surface Elevation (ft) |
|---|---|---|---|---|
| 26-40-201 | na | 11/25/79<br>1/13/93 | 82.47<br>87.14 | 3408.53<br>3403.86 |
| 26-40-601 | na | 12/10/69<br>1/13/93 | 78.55<br>80.03 | 3411.45<br>3409.97 |
| 26-40-602 | 80 | na | na | na |

criteria used to define the aquifer locations on the maps. Figure 6 is a color copy of their major aquifer map, which identifies the presence of the Ogallala aquifer in virtually all of Andrews County. The primary reference for this map was Cronin (1961). According to Ashworth (personal communication), this classification was based on the presence of the geologic formation, with only secondary consideration of the amount of water in storage at any given location. The fact that the western portion of Andrews County is identified as underlain by the Ogallala aquifer does not mean that the formation holds sufficient, if any, water for production. The publication of the maps was intended to show regional distribution of the formations that serve as aquifers across the state, not to define site-specific representation of available water.

Ashworth and others (1991) published an "Evaluation of the Ground-Water Resources in the Southern High Plains of Texas" under the direction of the state legislature as part of a state-wide effort to identify areas with potentially critical problems of groundwater quantity or quality in the next 20 years. This report was supported by the TWDB's on-going computer modeling of the aquifer's response to recharge and withdrawal, later published by Peckham and Ashworth (1993). Ashworth and others (1991) included data describing historical groundwater usage in Andrews County for municipal, agricultural, and industrial purposes as well as contour maps of water level changes and storage in the aquifer. Of particular interest to this study of the WCS site is Figure 7, a regional contour map of the water table elevation that shows that the approximate altitude of the water table in the Ogallala at the WCS location as of 1990 was 3400 ft. This value of 3400 ft cannot be accurate in the site-specific sense for the WCS site, since the elevation of the base of the

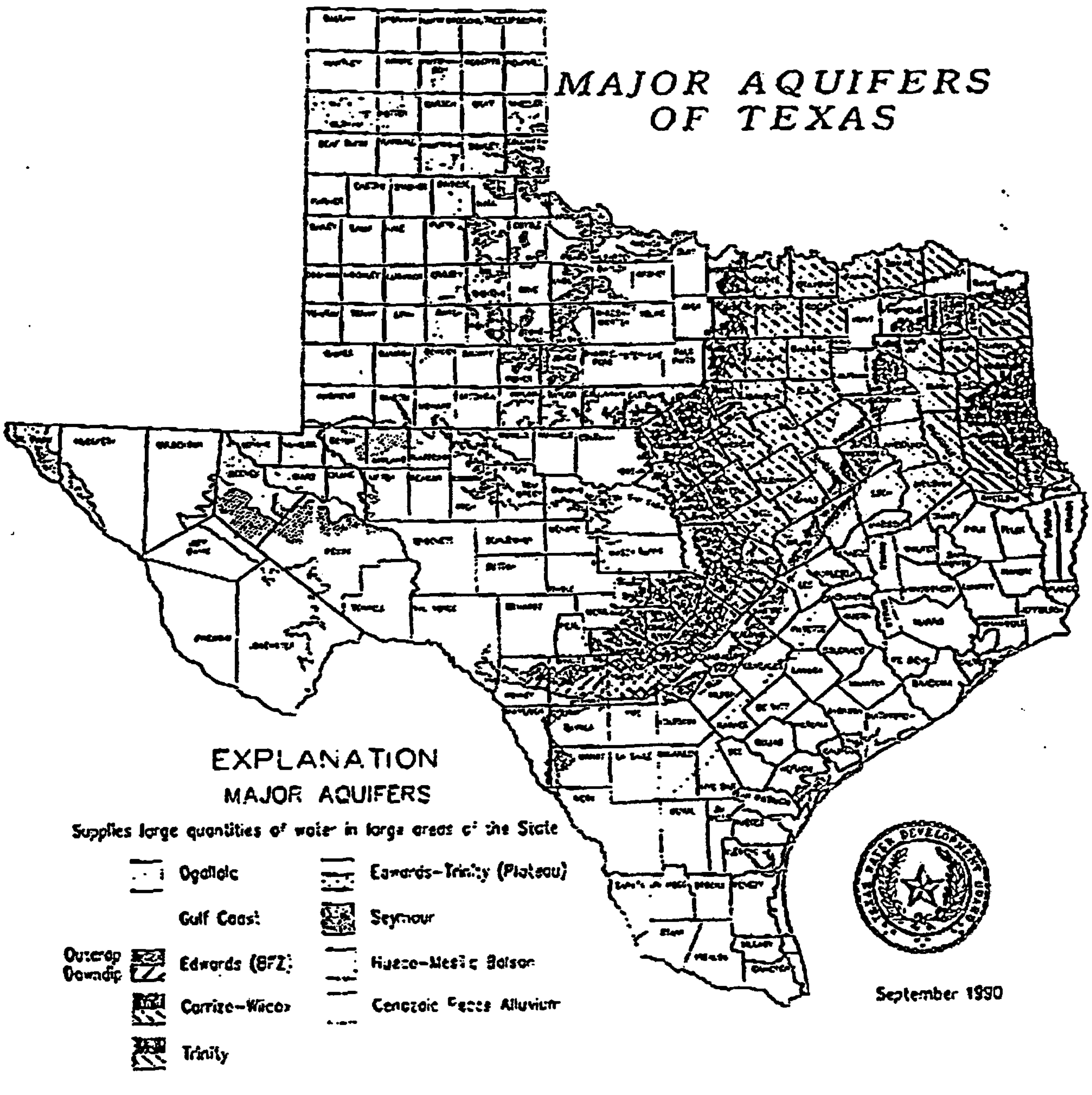


Figure 6. Major Aquifers in Texas. [Source: Ashworth and Flores (1991)]

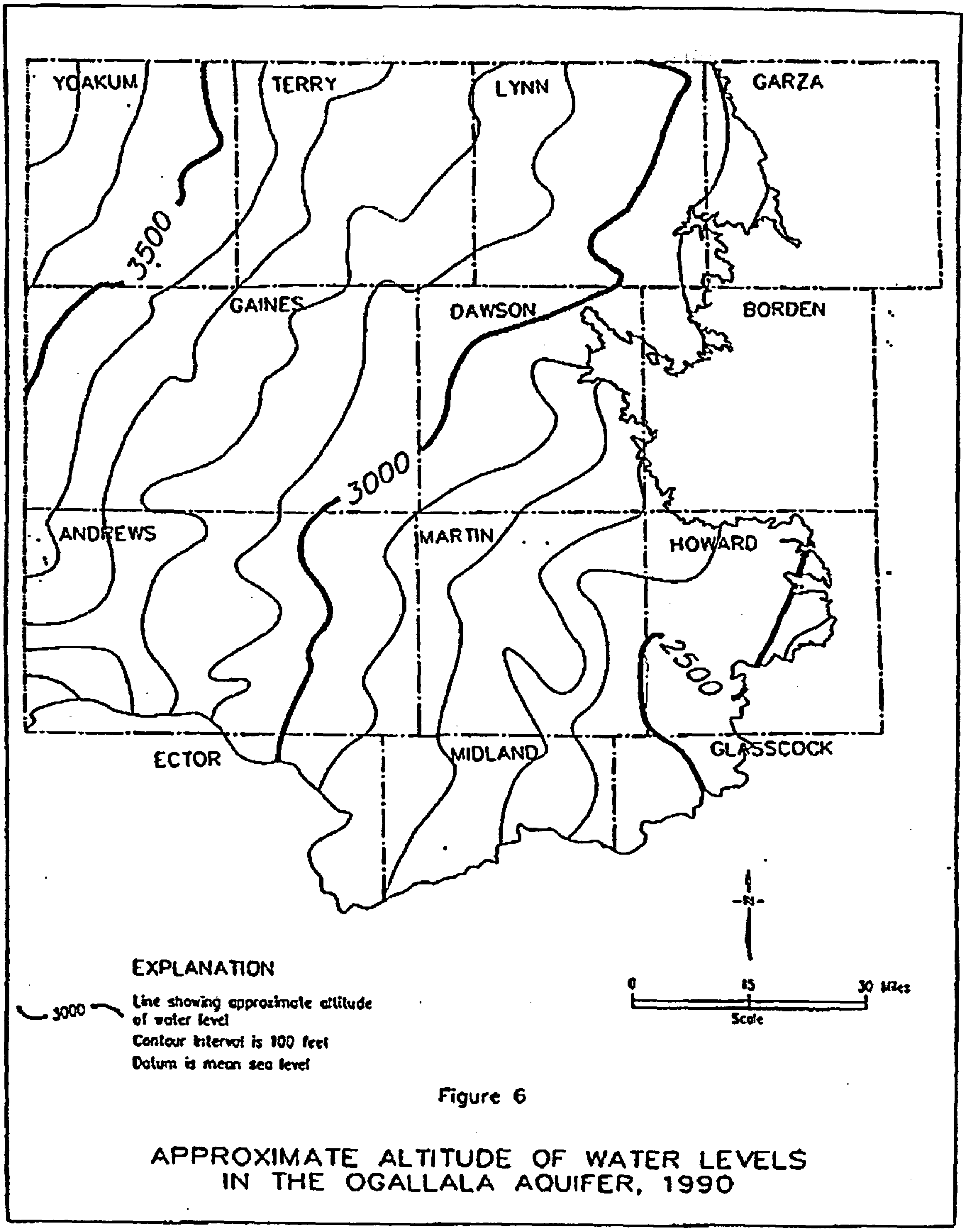


Figure 7. Contour Map of Water Levels in Ogallala Formation, 1990
Source: Peckham and Ashworth, 1993)

Ogallala at the WCS site ranges from 3400 to 3450 ft as shown in Figure 1. In addition, Figure 8, a contour map of regional saturated thickness, shows an approximate saturated thickness for 1990 at the WCS site location of 50 ft. This thickness is also not possible at the WCS location since the thickness of the shallow permeable formation is less than 40 ft, most of which is caliche. Again, it is not surprising that the regional information in the report by Ashworth and others (1991) does not accurately represent the conditions at the WCS site. The publication was intended to show regional distribution of the water in the Ogallala formation, not to define site-specific description of storage. The detailed subsurface investigation reported in the permit application (AME, 1993) provides the necessary spatial resolution for description of the site-specific conditions for the proposed WCS facility.

Two very recent publications of the TWDB also included Andrews County within their study areas. Peckham and Ashworth (1993) described their efforts to calibrate a computer model for the behavior of the Ogallala aquifer in terms of changes in storage from 1980 to 1990. The intent of the effort was to align the model's output with the observed changes in water levels during that decade by manipulation of the input to the model, especially local aquifer recharge. The initial 1980 conditions assumed a saturated thickness of approximately 50 ft near the WCS site. The report did not detail how the initial saturated thicknesses were assigned at specific points in the region. It is interesting that the simulation of the 50-yr period from 1990 to 2040 with the calibrated model showed no appreciable change in saturated thickness in the western half of Andrews County. This result implies little withdrawal activity relative to that predicted for counties with more irrigated acreage. Hopkins (1993) summarized regional water quality information for the Ogallala aquifer in Texas. Samples were collected and analyzed over a 6-yr period. The only point of interest in this report is that only 4 wells were sampled in the western third of Andrews County. The scarcity of wells in this poorly productive area limited the number of wells available for analyses.

Lehman (1996) evaluated the literature and field evidence in western Andrews County as a direct attempt to determine the presence or absence of the Ogallala formation at the WCS site. His

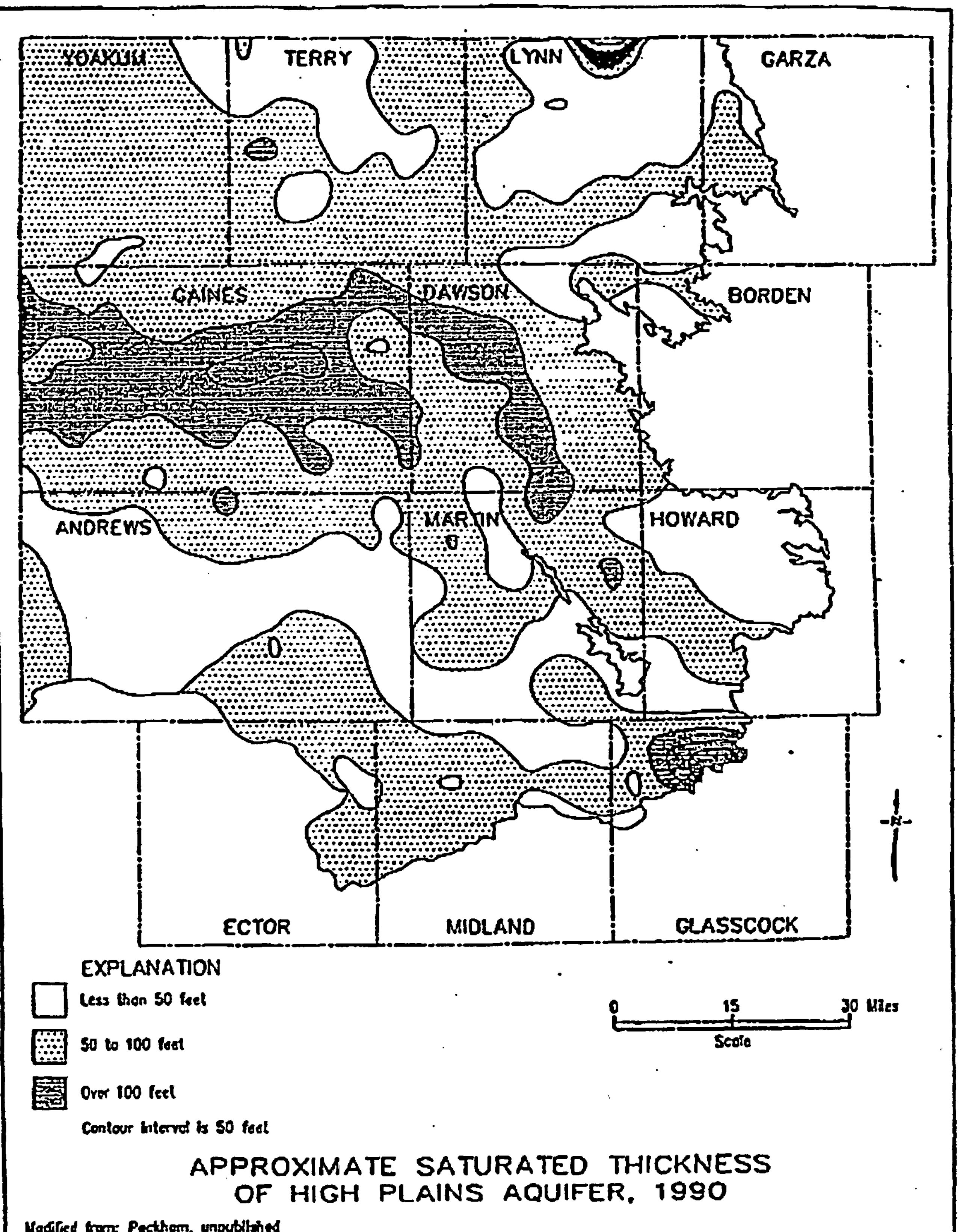


Figure 8. Contour Map of Saturated Thickness in Ogallala Formation, 1990
Source: Peckham and Ashworth, 1993)

study indicated that the "Red Bed Ridge" that makes the WCS site so desirable is a regional feature over 160 km in length and 5 to 10 km in width. His map of the ridge extent is not included with this report due to its large size. The ridge runs from the northwest to the southeast from the state line through Andrews County into Winkler and Ector Counties. It serves as a paleo-drainage divide that separates the Ogallala aquifer on the northeast from the Cenozoic basin fill aquifer to the southwest. Directly above the ridge, the shallow permeable sediments are the Cretaceous Edwards Limestone, Comanche Peak formation, or the Antlers Sandstone. These formations may be overlain by a caprock caliche, which in turn may have a thin veneer of younger sediments. The Ogallala likely pinches out near the line defined by Monument Draw in northern Andrews County, and it may be hydraulically connected to the Cretaceous sediments. However, the lack of developable groundwater resources in western Andrews County south of Monument Draw makes it unlikely that significant flow could move from the WCS site northward to the producing areas in Gaines County. At the WCS site, the shallow permeable formation was positively identified as the Antlers Sandstone by its characteristic gravels and absence of Cretaceous *Gryphaea* shells that occur in the Ogallala formation. The exposure of the Antlers Sandstone at the WCS excavation and other locations in Andrews County show that this formation is permeable, but it does not have significant water storage for development of dependable water wells other than low-flow windmills. In light of these findings, the water wells monitored by the TWDB in the vicinity may also not be in the Ogallala formation. Groundwater collects in the Antlers Sandstone only where the Triassic surface relief allows storage volume. The combination of low rainfall and high evapotranspiration likely limit recharge to this formation in the site vicinity.

In summary, the TWDB and TBWE generated several reports over the years that have included descriptions of the groundwater resources of Andrews County. In all cases, the vast majority of the water in storage was located in the eastern portion of the county. Close examination of the contour maps in these reports results in estimated saturated thickness of the Ogallala at the WCS site to be 0 (zero) ft. The shallow permeable formation at the site was originally identified as the Ogallala in the subsurface investigation. Lehman (1996) showed that the Ogallala formation is not present at the WCS site, nor is it present in a significant portion of Andrews County. No matter what the name of the local shallow permeable formation is, the local high in the upper surface of the Dockum group apparently encourages water that infiltrates, if there is enough for recharge, into this formation to flow away from the site. According to typical definitions of an aquifer, both sufficient permeability and saturated conditions are necessary for a stratum to be an economical water source. The shallow permeable formation at the WCS site does not meet both requirements.

Conclusions and Recommendations

After review of the permit documents and available information about the local hydrogeology, the operation of the WCS facility should have no significant impact on local groundwater resources. The installation of the landfill with its bottom excavated through the Antlers Sandstone formation into the red clays of the Dockum group should prevent transport of contaminants into that shallow permeable formation. The conventional double liner system coupled with the thick Triassic clay foundation provide multiple barriers to contaminant migration. Careful operation of the facility during construction and over its useful life as controlled by state and federal regulations should meet the objectives of safe disposal and protection of the environment.

The Ogallala aquifer does not exist at the site. The shallow permeable formation is more correctly identified as the Antlers Sandstone. This formation does not meet both criteria for classification as an aquifer at this location. The presence of the "Red Bed Ridge" in the Dockum group apparently encourages water that infiltrates into the sands and gravels in the base of the formation to move away to the northeast and southwest. The shallow permeable formation does not contain sufficient water at this location for development with pumping wells. Low rainfall and high evapotranspiration in this area limit the potential for groundwater recharge.

It is recommended that questions about the Ogallala aquifer as this site be considered be put aside as irrelevant based on the available information and landfill design. Emphasis should be placed on the positive features of the site, primarily the proximity of the Triassic clay as the foundation for the landfill bottom, in presentation to regulatory and public groups.

The siltstone layers in the Dockum group, identified as the "uppermost aquifer " for monitoring purposes, also do not fit the two criteria for an aquifer in the water resource development sense. The monitoring wells established in the siltstone are the only alternative for detection of leachate in the remote possibility that the landfill's multiple liner systems fail. The lack of a typical productive aquifer beneath the proposed site is an advantage, since that type of medium could easily transport contaminants if the double liner system failed.

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## Appendix

Water Level Measurements Provided by AME (Messenger, personal communication)

## Table A-1. Water Level Measurements
(Source, AM Environmental [Messenger, personal communication])

| WELL NO./ GRID LOC. | 7-G | 4-C | 2-G | 11-D | 4-G1 | 4-G2 | 4-G3 | 9-G1 | 9-G2 | 9-G3 | 6-B1 | 6-B2 | 5-E | 5-C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE INSTALLED | 12/2/92 | 12/1/92 | 12/22/92 | 12/22/92 | 1/23/93 | 2/11/93 | 1/27/93 | 1/29/93 | 1/24/93 | 1/25/93 | 1/30/93 | 1/20/93 | 1/28/93 | 1/28/93 |
| T.O.C. ELEV. (FT) | 3447.72 | 3476.55 | 3439.93 | 3473.07 | 3439.56 | 3439.68 | 3439.11 | 3460.17 | 3459.99 | 3460.02 | 3486.66 | 3482.26 | 3457.28 | 3480.94 |
| SCREENED INTERVAL DEPTHS | 185-215 | 169-191 | 225-250 | 232-257 | 145-175 | 190-220 | 237-242 | 130-135 | 211-221 | 263-273 | 191-201 | 262-272 | 145-155 | 173-193 |
| TOP-BOTTOM SCREENED INTERVAL ELEVATIONS | 3262.72-3232.72 | 3307.55-3285.55 | 3214.93-3189.93 | 3241.07-3216.07 | 3294.56-3264.56 | 3249.68-3219.68 | 3202.11-3197.11 | 3330.17-3325.17 | 3248.99-3238.99 | 3197.02-3187.02 | 3295.66-3285.66 | 3220.26-3210.26 | 3312.28-3302.28 | 3307.94-3287.94 |
| **DATE: 11/30/92** | | | | | | | | | | | | | | |
| depth to water | 200.15 | 185.23 | — | — | — | — | — | — | — | — | — | — | — | — |
| water surface elevation | 3247.57 | 3291.32 | | | | | | | | | | | | |
| **DATE: 12/01/92** | | | | | | | | | | | | | | |
| depth to water | 200.15 | 187.67 | — | — | — | — | — | — | — | — | — | — | — | — |
| water surface elevation | 3247.57 | 3288.88 | | | | | | | | | | | | |
| **DATE: 12/03/92** | | | | | | | | | | | | | | |
| depth to water | 214.50 | 187.80 | — | — | — | — | — | — | — | — | — | — | — | — |
| water surface elevation | 3233.22 | 3288.75 | | | | | | | | | | | | |
| **DATE: 12/10/92** | | | | | | | | | | | | | | |
| depth to water | 172.10 | 186.30 | — | — | — | — | — | — | — | — | — | — | — | — |
| water surface elevation | 3274.62 | 3290.25 | | | | | | | | | | | | |
| **DATE: 12/15/92** | | | | | | | | | | | | | | |
| depth to water | 169.40 | 187.43 | — | — | — | — | — | — | — | — | — | — | — | — |
| water surface elevation | 3278.32 | 3289.12 | | | | | | | | | | | | |
| **DATE: 12/21/92** | | | | | | | | | | | | | | |
| depth to water | — | — | — | 248.00 | — | — | — | — | — | — | — | — | — | — |
| water surface elevation | | | | 3225.07 | | | | | | | | | | |
| **DATE: 12/29/92** | | | | | | | | | | | | | | |
| depth to water | 157.10 | 187.60 | 219.80 | 183.90 | — | — | — | — | — | — | — | — | 217.00 | — |
| water surface elevation | 3290.62 | 3288.95 | 3220.13 | 3289.17 | | | | | | | | | 3240.28 | |
| **DATE: 1/10/93** | | | | | | | | | | | | | | |
| depth to water | 151.45 | 187.85 | 181.10 | 164.40 | — | — | — | — | — | — | — | — | 183.90 | — |
| water surface elevation | 3296.27 | 3288.70 | 3258.83 | 3308.67 | | | | | | | | | 3273.38 | |
| **DATE: 1/14/93** | | | | | | | | | | | | | | |
| depth to water | 149.78 | 187.79 | 181.03 | 161.82 | — | — | — | — | — | — | — | — | 176.15 | — |
| water surface elevation | 3297.94 | 3288.76 | 3258.90 | 3311.25 | | | | | | | | | 3281.13 | |

| WELL NO./ GRID LOC. | 7-G | 4-C | 2-G | 11-0 | 4-G1 | 4-G2 | 4-G3 | 9-G1 | 9-G2 | 9-G3 | 6-B1 | 6-B2 | 5-E | 5-C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T.O.C. ELEV. (FT) | 3447.72 | 3476.55 | 3439.93 | 3473.07 | 3439.56 | 3439.68 | 3439.11 | 3460.17 | 3459.99 | 3460.02 | 3486.66 | 3482.26 | 3457.28 | 3480.94 |
| DATE: 1/17/93 | | | | | | | | | | | | | | |
| depth to water | 148.88 | 187.51 | 181.05 | 158.58 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 172.00 | ----- |
| water surface elevation | 3298.84 | 3289.04 | 3258.88 | 3314.49 | | | | | | | | | 3285.28 | |
| DATE: 1/20/93 | | | | | | | | | | | | | | |
| depth to water | 148.00 | 187.72 | 181.08 | 154.72 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 167.80 | ----- |
| water surface elevation | 3299.72 | 3288.83 | 3258.85 | 3318.35 | | | | | | | | | 3289.48 | |
| DATE: 1/23/93 | | | | | | | | | | | | | | |
| depth to water | 147.10 | 187.60 | 188.01 | 151.61 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 164.55 | ----- |
| water surface elevation | 3300.62 | 3288.95 | 3251.92 | 3321.46 | | | | | | | | | 3292.73 | |
| DATE: 1/27/93 | | | | | | | | | | | | | | |
| depth to water | 148.92 | 187.97 | 184.10 | 153.47 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 160.80 | ----- |
| water surface elevation | 3298.80 | 3288.58 | 3255.83 | 3319.60 | | | | | | | | | 3296.48 | |
| DATE: 1/30/93 | | | | | | | | | | | | | | |
| depth to water | 152.05 | 188.23 | 186.45 | 156.15 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| water surface elevation | 3295.67 | 3288.32 | 3253.48 | 3316.92 | | | | | | | | | | |
| DATE: 2/3/93 | | | | | | | | | | | | | | |
| depth to water | 156.30 | 188.20 | 189.80 | 155.28 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| water surface elevation | 3291.42 | 3288.35 | 3250.13 | 3317.79 | | | | | | | | | | |
| DATE: 2/9/93 | | | | | | | | | | | | | | |
| depth to water | 159.60 | 187.20 | 191.10 | 156.23 | 179.15 | DRY | DRY | DRY | 224.40 | 271.70 | 162.70 | DRY | DRY | DRY |
| water surface elevation | 3288.12 | 3289.35 | 3248.83 | 3316.84 | 3260.41 | | | | 3235.59 | 3188.32 | 3323.96 | | | |
| DATE: 2/12/93 | | | | | | | | | | | | | | |
| depth to water | 157.90 | 187.75 | 187.70 | 153.90 | 179.10 | DRY | 245.20 | DRY | 224.20 | 270.30 | 158.15 | DRY | DRY | DRY |
| water surface elevation | 3289.82 | 3288.80 | 3252.23 | 3319.17 | 3260.46 | | 3193.91 | | 3235.79 | 3189.72 | 3328.51 | | | |
| DATE: 2/17/93 | | | | | | | | | | | | | | |
| depth to water | 154.21 | 187.95 | 181.10 | 150.23 | 179.15 | DRY | 245.45 | DRY | 224.10 | 270.17 | 154.77 | 232.90 | DRY | DRY |
| water surface elevation | 3293.51 | 3288.60 | 3258.83 | 3322.84 | 3260.41 | | 3193.66 | | 3235.89 | 3189.85 | 3331.89 | 3249.36 | | |
| DATE: 2/24/93 | | | | | | | | | | | | | | |
| depth to water | 152.18 | 187.46 | 179.52 | 146.02 | DRY | DRY | 245.35 | DRY | 223.70 | 269.91 | 152.69 | 218.20 | DRY | DRY |
| water surface elevation | 3295.54 | 3289.09 | 3260.41 | 3327.05 | | | 3193.76 | | 3236.29 | 3190.11 | 3333.97 | 3264.06 | | |
| DATE: 3/3/93 | | | | | | | | | | | | | | |
| depth to water | 149.85 | 187.65 | 176.98 | 142.96 | DRY | DRY | 245.37 | DRY | 223.43 | 269.75 | 151.75 | 207.00 | DRY | DRY |
| water surface elevation | 3297.87 | 3288.90 | 3262.95 | 3330.11 | | | 3193.74 | | 3236.56 | 3190.27 | 3334.91 | 3275.26 | | |
| DATE: 3/10/93 | | | | | | | | | | | | | | |
| depth to water | 148.50 | 187.80 | 174.70 | 139.90 | 179.20 | DRY | 245.36 | DRY | 223.13 | 269.73 | 151.25 | 188.80 | DRY | DRY |
| water surface elevation | 3299.22 | 3288.75 | 3265.23 | 3333.17 | 3260.36 | | 3193.75 | | 3236.86 | 3190.29 | 3335.41 | 3293.46 | | |

| WELL NO./ GRID LOC. | 7-G | 4-C | 2-G | 11-D | 4-G1 | 4-G2 | 4-G3 | 9-G1 | 9-G2 | 9-G3 | 6-B1 | 6-B2 | 5-B | 5-C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T.O.C. ELEV. (FT) | 3447.72 | 3476.55 | 3439.93 | 3473.07 | 3439.56 | 3439.68 | 3439.11 | 3460.17 | 3459.99 | 3460.02 | 3486.66 | 3482.26 | 3457.28 | 3480.94 |
| DATE: 3/18/93 | | | | | | | | | | | | | | |
| depth to water | 147.20 | 187.55 | 172.10 | 137.00 | 179.60 | DRY | 245.37 | DRY | 222.76 | 269.60 | 150.78 | 189.23 | DRY | DRY |
| water surface elevation | 3300.52 | 3289.00 | 3267.83 | 3336.07 | 3259.96 | | 3193.74 | | 3237.23 | 3190.42 | 3335.88 | 3293.03 | | |
| DATE: 3/30/93 | | | | | | | | | | | | | | |
| depth to water | 145.13 | 187.45 | 169.16 | 133.85 | 179.15 | 203.77 | 245.40 | DRY | 222.24 | 269.48 | 150.30 | 179.40 | DRY | DRY |
| water surface elevation | 3302.59 | 3289.10 | 3270.77 | 3339.22 | 3260.41 | 3235.91 | 3193.71 | | 3237.75 | 3190.54 | 3336.36 | 3302.86 | | |
| DATE: 4/13/93 | | | | | | | | | | | | | | |
| depth to water | 143.45 | 187.48 | 167.86 | 131.11 | 179.29 | 203.90 | 245.49 | DRY | 221.70 | 269.42 | 150.05 | 171.21 | DRY | 195.94 |
| water surface elevation | 3304.27 | 3289.07 | 3272.07 | 3341.96 | 3260.27 | 3235.78 | 3193.62 | | 3238.29 | 3190.60 | 3336.61 | 3311.05 | | 3285.00 |
| DATE: 4/28/93 | | | | | | | | | | | | | | |
| depth to water | 141.63 | 187.66 | 163.70 | 129.04 | 179.28 | 202.25 | 245.50 | DRY | 221.01 | 269.28 | 149.85 | 164.92 | DRY | 194.44 |
| water surface elevation | 3306.09 | 3288.89 | 3276.23 | 3344.03 | 3260.28 | 3237.43 | 3193.61 | | 3238.98 | 3190.74 | 3336.81 | 3317.34 | | 3286.50 |
| DATE: 5/24/93 | | | | | | | | | | | | | | |
| depth to water | 140.40 | 187.52 | 160.90 | 126.77 | 179.28 | 200.84 | 245.45 | DRY | 219.90 | 269.08 | 149.58 | 157.67 | DRY | 192.33 |
| water surface elevation | 3307.32 | 3289.03 | 3279.03 | 3346.30 | 3260.28 | 3238.84 | 3193.66 | | 3240.09 | 3190.94 | 3337.08 | 3324.59 | | 3288.61 |
| DATE: 6/10/93 | | | | | | | | | | | | | | |
| depth to water | 139.62 | 187.48 | 159.05 | 125.58 | 179.31 | 199.97 | 245.45 | DRY | 219.16 | 268.95 | 149.44 | 154.45 | DRY | 191.78 |
| water surface elevation | 3308.10 | 3289.07 | 3280.88 | 3347.49 | 3260.25 | 3239.71 | 3193.66 | | 3240.83 | 3191.07 | 3337.22 | 3327.81 | | 3289.16 |
| DATE: 7/14/93 | | | | | | | | | | | | | | |
| depth to water | 140.20 | 187.50 | 159.58 | 124.60 | 179.30 | 198.20 | 245.38 | DRY | 218.89 | 268.68 | 149.31 | 150.10 | DRY | 192.18 |
| water surface elevation | 3307.52 | 3289.05 | 3280.35 | 3348.47 | 3260.26 | 3241.48 | 3193.73 | | 3241.10 | 3191.34 | 3337.35 | 3332.16 | | 3288.76 |
| DATE: 7/15/93 | | | | | | | | | | | | | | |
| depth to water | | | 232.13 | | | | | | | | 181.34 | | | |
| water surface elevation | | | 3207.80 | | | | | | | | 3305.32 | | | |
| DATE: 7/16/93 | | | | | | | | | | | | | | |
| depth to water | 198.78 | | | 225.89 | | | | | | | | | | |
| water surface elevation | 3248.94 | | | 3247.18 | | | | | | | | | | |
| DATE: 7/23/93 | | | | | | | | | | | | | | |
| depth to water | 164.01 | | 178.56 | 149.54 | | | | | | | 151.74 | | | |
| water surface elevation | 3283.71 | | 3261.37 | 3323.53 | | | | | | | 3334.92 | | | |
| DATE: 8/9/93 | | | | | | | | | | | | | | |
| depth to water | 150.90 | 187.60 | 167.50 | 128.28 | 179.30 | 196.90 | 245.32 | DRY | 216.80 | 268.50 | 150.30 | 148.25 | DRY | 192.22 |
| water surface elevation | 3296.82 | 3288.95 | 3272.43 | 3344.79 | 3260.26 | 3242.78 | 3193.79 | | 3243.19 | 3191.52 | 3336.36 | 3334.01 | | 3288.72 |

| WELL NO./ GRID LOC. | 7-G | 4-C | 2-G | 11-D | 4-G1 | 4-G2 | 4-G3 | 9-G1 | 9-G2 | 9-G3 | 6-B1 | 6-B2 | 5-E | 5-C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T.O.C. ELEV. (FT) | 3447.72 | 3476.55 | 3439.93 | 3473.07 | 3439.56 | 3439.68 | 3439.11 | 3460.17 | 3459.99 | 3460.02 | 3486.66 | 3482.26 | 3457.28 | 3480.94 |
| DATE: 9/21/93 | | | | | | | | | | | | | | |
| depth to water | 147.29 | 187.90 | 164.28 | 130.15 | 179.27 | 197.40 | 245.31 | DRY | 215.30 | 168.18 | 149.90 | 166.32 | DRY | 192.29 |
| water surface elevation | 3300.43 | 3288.65 | 3275.65 | 3342.92 | 3260.29 | 3242.28 | 3193.80 | | 3244.69 | 3291.84 | 3336.76 | 3315.94 | | 3288.65 |
| DATE: 10/18/93 | | | | | | | | | | | | | | |
| depth to water | 144.78 | 187.85 | 162.40 | 129.10 | 179.30 | 193.20 | 245.30 | DRY | 214.20 | 267.90 | 151.14 | 154.65 | DRY | 192.81 |
| water surface elevation | 3302.94 | 3288.70 | 3277.53 | 3343.97 | 3260.26 | 3246.48 | 3193.81 | | 3245.79 | 3192.12 | 3335.52 | 3327.61 | | 3288.13 |
| DATE: 10/18/93 | | | | | | | | | | | | | | |
| depth to water | 144.78 | 187.85 | 162.40 | 129.10 | 179.30 | 193.20 | 245.30 | DRY | 214.20 | 267.90 | 151.14 | 154.65 | DRY | 192.81 |
| water surface elevation | 3302.94 | 3288.70 | 3277.53 | 3343.97 | 3260.26 | 3246.48 | 3193.81 | | 3245.79 | 3192.12 | 3335.52 | 3327.61 | | 3288.13 |
| DATE: 3/16/94 | | | | | | | | | | | | | | |
| depth to water | 141.25 | 187.65 | 158.05 | 125.06 | 179.30 | 194.99 | 244.95 | DRY | 217.78 | 267.05 | 149.50 | 163.20 | DRY | 192.80 |
| water surface elevation | 3306.47 | 3288.90 | 3281.88 | 3348.01 | 3260.26 | 3244.69 | 3194.16 | | 3242.21 | 3192.97 | 3337.16 | 3319.06 | | 3288.14 |
| DATE: 1/17/95 | | | | | | | | | | | | | | |
| depth to water | 140.76 | 187.80 | 158.30 | 124.90 | 179.30 | 194.45 | 245.01 | DRY | 217.68 | 266.98 | 149.43 | 163.21 | DRY | 192.79 |
| water surface elevation | 3306.96 | 3288.75 | 3281.63 | 3348.17 | 3260.26 | 3245.23 | 3194.10 | | 3242.31 | 3193.04 | 3337.23 | 3319.05 | | 3288.15 |
| DATE: 4/19/95 | | | | | | | | | | | | | | |
| depth to water | 140.57 | 187.76 | 157.60 | 124.87 | 179.31 | 194.52 | 245.01 | DRY | 217.63 | 266.96 | 149.30 | 163.25 | DRY | 192.82 |
| water surface elevation | 3307.15 | 3288.79 | 3282.33 | 3348.20 | 3260.25 | 3245.16 | 3194.10 | | 3242.36 | 3193.06 | 3337.36 | 3319.01 | | 3288.12 |
| Current thickness of water | 74.43 | 3.24 | 92.40 | 132.13 | 0.00 | 25.48 | 0.00 | 0.00 | 3.37 | 6.04 | 51.70 | 108.75 | 0.00 | 0.18 |

——— AM ENVIRONMENTAL RESPONSIBLE FOR WATER LEVEL MEASUREMENTS

[ ] depth to water FROM OPEN BORE HOLE

Monitor wells 6-B1 and 2-G were developed to dryness on 7/14/93
Monitor wells 7-G and 11-D were developed to dryness on 7/15/93
Monitor wells 6-B1 and 6-B2 were developed to dryness on 8/9/93
Monitor wells 7-G and 11-D were developed to dryness on 8/10/93
Monitor well 2-G was developed to dryness on 8/11/93
Monitor wells 6B-1, 6B-2, 11-D, 4-C, and 5-C were developed to dryness on 10/18/93
Monitor wells 9G-2, 7-G, 4G-2, and 2-G were developed to dryness on 10/19/93
Approximate site elevation 3484.75 ft