Chapter 5

Hydrologic Relationships and Numerical Simulations of the Exchange of Water Between the Southern Ogallala and Edwards–Trinity Aquifers in Southwest Texas

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Introduction

The Edwards–Trinity aquifer is the most significant source of water on the Edwards Plateau, which covers approximately 23,000 square miles in southwest Texas. The aquifer is bounded to the northwest by the physical limit of the Cretaceous rocks, which occurs in the southern portions of Andrews, Martin, and Howard counties (Figure 5-1). The primary aquifer in these counties occurs in saturated sediments of the Ogallala Formation, but the Ogallala Formation sediments thin to the south and often occur above the water table in Ector, Midland, and Glasscock counties where saturated Cretaceous sediments form the predominant (Edwards–Trinity) aquifer. Where significant saturated thickness occurs in Cretaceous sediments, the Trinity Group Antlers sand is the dominant aquifer material. Within the study area, it is often difficult to differentiate between the two aquifers.

This paper provides an overview of the hydrogeology of the far southern portion of the Southern High Plains and the northwestern margin of the Edwards Plateau where the transition occurs between the Southern Ogallala and Edwards–Trinity aquifers. The boundary between the two aquifers is transitional and is not well defined within much of this area. The approaches used in previously published modeling studies to simulate the flow of water across this boundary are reviewed, and modifications made to the recently developed Southern Ogallala Groundwater Availability Model (GAM) to evaluate alternative conceptual models of inter-aquifer flow are presented.

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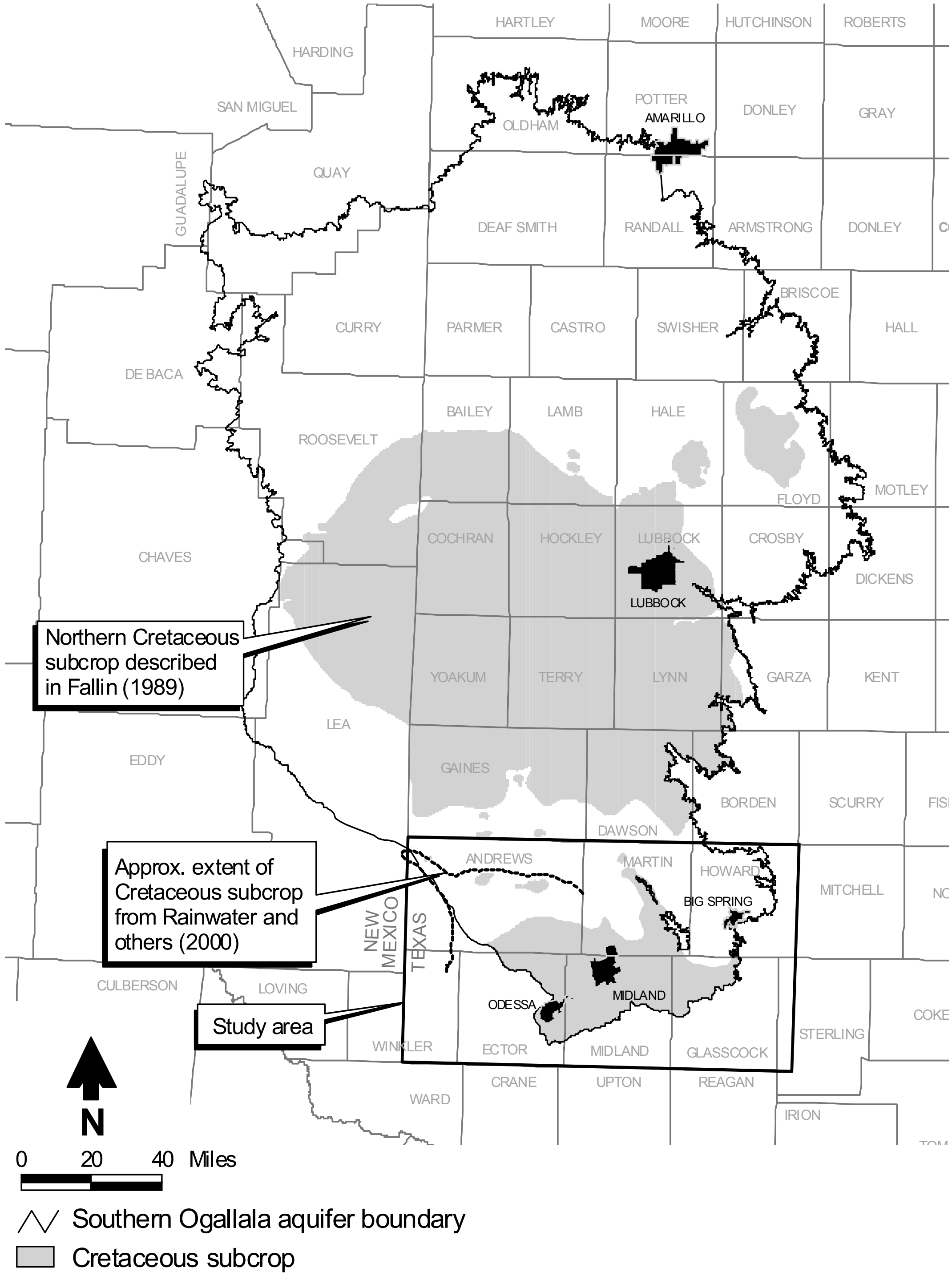

Figure 5-1: Extent of Cretaceous subcrop beneath Southern High Plains and location of study area (after Fallin 1989; Knowles and others 1984).

Geology

The geologic units within and adjacent to the study area are summarized in Figure 5-2. Where the Cretaceous subcrop beneath the Southern High Plains (Figure 5-1) is absent, Triassic sediments (Chinle Formation "red beds") generally occur immediately beneath the Ogallala Formation. Within the study area, many of the mapped Cretaceous outcrops consist of the Trinity Group Antlers Formation (Bureau of Economic Geology, 1976, 1994), which is equivalent to the Paluxy sand of central Texas (Knowles and others, 1984). The contacts between the different systems are unconformable.

Aquifer Terminology

Prior to proceeding with a discussion of the hydrogeology of the study area, it is important to understand the distinctions in terminology used in various reports to describe the aquifers of this region. The term Ogallala (or Southern Ogallala) aquifer is the standard Texas Water Development Board (TWDB) term for the major aquifer that exists primarily within sediments of the Ogallala Formation. However, the term High Plains aquifer is commonly applied to the same aquifer system (Gutentag and others, 1984; Knowles and others, 1984), implicitly recognizing that in some areas saturated Ogallala Formation sediments are hydraulically connected to underlying permeable Cretaceous rocks. In this paper, the term Southern Ogallala aquifer is used for consistency with TWDB terminology, although portions of the aquifer (substantial portions within the study area discussed here) actually exist within Cretaceous sediments rather than within the Ogallala Formation. To avoid confusion, where a clear distinction between groundwater in each geologic unit is necessary, the terms "saturated Ogallala sediments" and "saturated Cretaceous sediments" are used.

Hydrogeology

Relatively little has been published about the hydrogeology of the Edwards–Trinity aquifer beneath the Southern High Plains. Fallin (1989) provides what is probably the most detailed description of the hydrogeology of the lower Cretaceous rocks that lie below the Ogallala Formation over an area of approximately 10,000 square miles stretching from New Mexico to the eastern caprock escarpment (Figure 5-1) (north of the area of interest for this paper). Rettman and Leggat (1966) and Cooper (1960) provide detailed discussions of the Cretaceous hydrogeology in subregions of the larger northern area. Nativ (1988) and Nativ and Gutierrez (1988) also provide detailed analyses of the hydrogeology and hydrochemistry of the Cretaceous aquifers that exist beneath the Southern High Plains. A comparison of the base of the Southern Ogallala aquifer maps from Knowles and others (1984) and McReynolds (1996) with the elevation of the top of the Cretaceous section provided by Fallin (1989) indicates that, in general, large (more than several tens of feet) thicknesses of Cretaceous rocks are not included within the aquifer as defined by these maps.

System	Series	Group	Formation	Description of Rocks	Hydrogeologic Units
Quaternary	Pleistocene to Recent		Alluvium, eolian and lacustrine deposits	Sand, clay, silt, caliche, and gravel.	Generally yields small amounts of water to wells; may yield large amounts of water along stream valleys of Edwards Plateau.
Tertiary	Late Miocene to Pliocene		Ogallala	Tan, yellow, and reddish brown silt, clay, sand, and gravel. Caliche layers common near the surface.	Yields moderate to large amounts of water to wells across Southern High Plains. Yields small to moderate amounts of water in Andrews, Martin, Howard, Ector, Midland and Glasscock Counties.
Cretaceous	Comanche	Washita	Duck Creek	Yellow, sandy shale and thin gray to yellowish brown argillaceous limestone beds.	Yields small amounts of water locally to wells.
		Fredericksburg	Kiamichi	Gray to yellowish brown shale with thin interbeds of gray argillaceous limestone and yellow sandstone.	Yields small amounts of water locally to wells.
			Edwards	Light gray to yellowish gray, thick to massive bedded, fine- to coarse-grained limestone.	Generally yields fairly small amounts of water to wells beneath Southern High Plains, but may yield large amounts of water locally due to fractures and solution cavities.
			Comanche Peak	Light gray to yellowish brown, irregularly bedded argillaceous limestone with thin interbeds of light gray shale.	
			Walnut	Light gray to yellowish brown argillaceous sandstone; thin-bedded gray shale; light gray to grayish yellow argillaceous limestone.	Not known to yield water to wells.
		Trinity	Antlers	White, gray, yellowish brown to purple, argillaceous, loosely cemented sand, sandstone, and conglomerate with interbeds of siltstone and clay.	Yields small to moderate amounts of water to wells. Primary aquifer of Cretaceous system within the study area.
Triassic		Dockum	Chinle	Red, maroon to purple shale. Thin, discontinuous beds of sand and silt.	May yield small amounts of water to wells. Commonly known as the "red beds" that form the base of the High Plains aquifer.
			Santa Rosa	Multi-colored fine- to coarse-grained micaceous sandstone with some claystone and shale interbeds.	Yields moderate amounts of water to wells.
			Tecovas	Red to red-brown shale with fine-grained micaceous sand.	Not known to yield water to wells.

Figure 5-2: Summary of geologic and hydrogeologic units (after Walker, 1979; Knowles and others, 1984; Fallin, 1989).

Within the study area, the Trinity Group Antlers Formation (commonly called the Antlers or Trinity sand) forms the predominant water-bearing unit of the Cretaceous rocks (Knowles, 1952; Walker, 1979; Knowles and others, 1984; Ashworth, 1986; Bureau of Economic Geology, 1976, 1994). For the most part, therefore, the Edwards–Trinity aquifer within the southernmost counties of the Southern High Plains can be considered to be coincident with the saturated portion of the Antlers Formation. Although the Antlers Formation lies below the Ogallala Formation stratigraphically (Figure 5-2), the Antlers sand is similar in appearance to Ogallala sediments, and the two are often not easily distinguishable (Mount and others, 1967, p. 45, *in* Barker and others, 1994). Knowles and others (1984) state that although the Antlers sand is the primary water-bearing formation in Ector, Midland, and part of Glasscock counties, only moderate quantities of water can be obtained from individual wells due to relatively thin saturated thickness and low hydraulic conductivity.

Groundwater flow within the saturated portions of the Ogallala and Cretaceous sediments is generally to the east or southeast (Figures 5-3 and 5-4). Contours of regional water levels within the study area are smooth and continuous and apparently indicate a smooth transition between portions of the aquifer composed primarily of Ogallala sediments and portions composed primarily of Cretaceous sediments. Groundwater from Ogallala sediments discharges at springs along the caprock escarpment, at the margins of salt lakes, along draws, and at wells under post-development conditions.

Water in saturated Cretaceous sediments flows east or southeast toward the Edwards Plateau, unless it is intercepted by wells or discharges at springs. In the past, many of the springs within the study area, particularly in the southern and eastern portions, have discharged groundwater from Cretaceous sediments. For example, Big Spring, at the caprock escarpment in Howard County, reportedly emitted from "lower Cretaceous limestones and sands in a collapse or sink area" before it ceased flowing due to nearby pumping (Brune, 2002, p. 238). Mulkey Springs in southeastern Martin County "poured from Ogallala sand on Antlers sandstone" until the 1950s (Brune, 2002, p. 304).

Recharge to the saturated Ogallala and Cretaceous sediments within the study area occurs primarily from precipitation and lateral inflow. Recharge applied in the Southern Ogallala GAM is about 0.03 inch per year (in/yr) for predevelopment conditions but was increased to a maximum of 0.5 in/yr for agricultural areas (Blandford and others, 2003). Because regional groundwater flow is generally to the southeast, mimicking the slope of the land surface, groundwater flows into the study area from portions of the aquifer to the north (Figure 5-3). As the Ogallala sediments thin and/or occur above the water table, groundwater flows directly into the Edwards–Trinity aquifer (Cretaceous sediments).

Portions of hydrogeologic cross section F-F' from Knowles and others (1984) and geologic cross section B-B' from Barker and Ardis (1996) are reproduced in Figure 5-5. The Knowles and others' (1984) cross section (F-F') indicates that the saturated sediments in Ector and southern Andrews counties are Cretaceous, with a relatively abrupt transition to saturated Ogallala sediments to the north. The transition from the predominance of saturated Ogallala sediments to saturated Cretaceous sediments is not reflected by observable changes in water-table elevations, at least at the regional scale. This is consistent

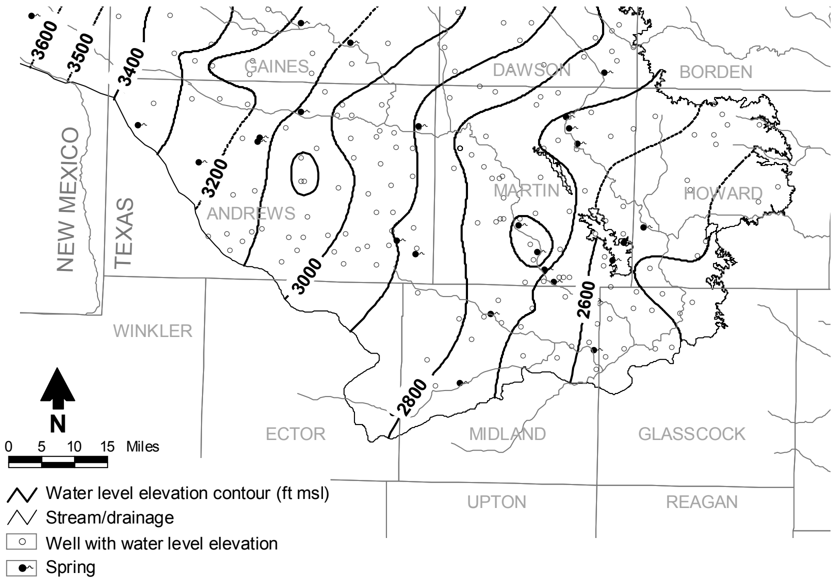

Figure 5-3: Observed water levels for Southern Ogallala aquifer for winter of 1989 and 1990, major drainages and historical spring locations (after Blandford and others, 2003).

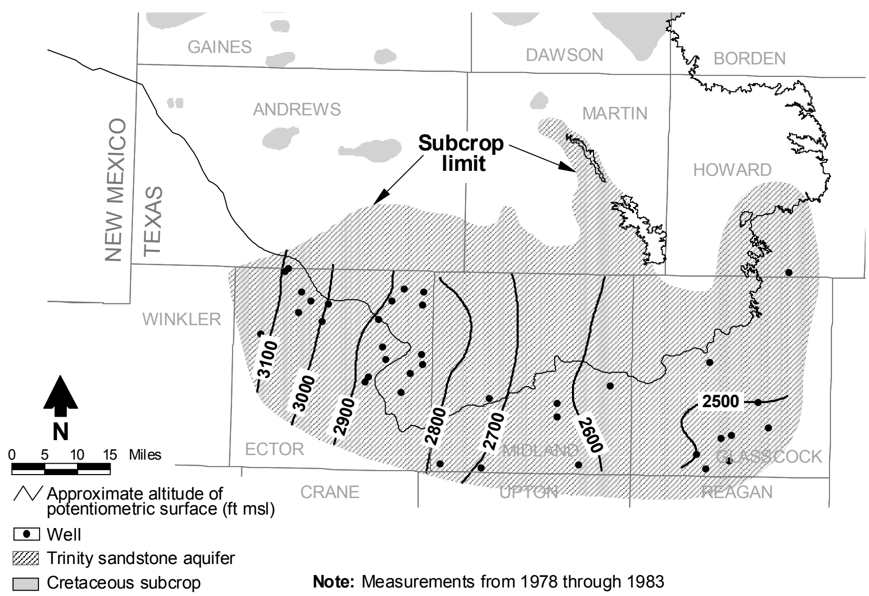

Figure 5-4: Observed water level in the Cretaceous sediments (Edwards–Trinity aquifer) in southern portion of the study area for 1978 through 1983 (after Nativ and Gutierrez, 1988).

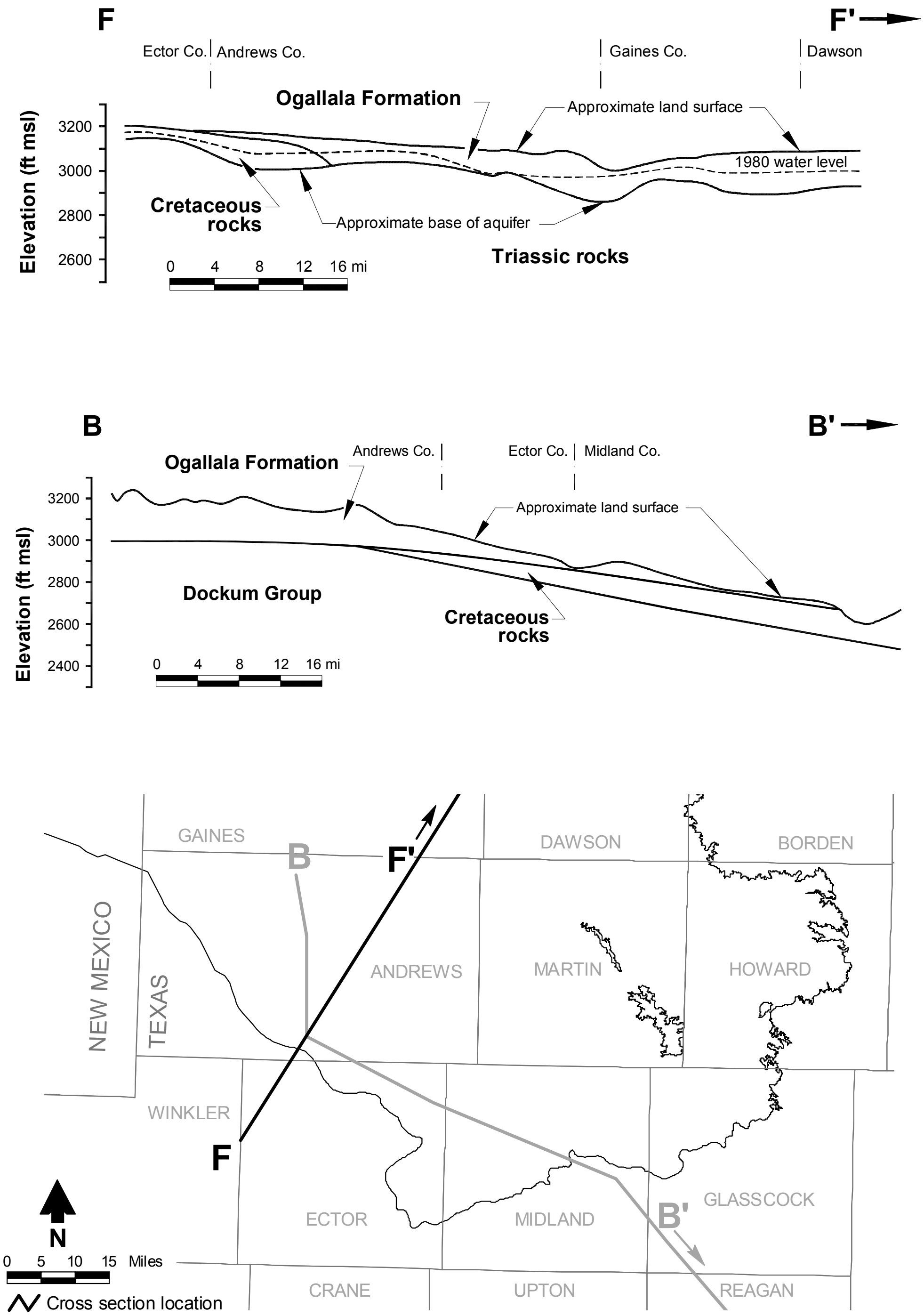

Figure 5-5: Portions of hydrogeologic cross sections (after Knowles and others, 1984; Barker and Ardis 1996).

with the observations that no apparent significant changes in aquifer thickness or hydraulic conductivity attributable to changes in saturated formation lithology occur within the study area (Blandford and others, 2003). The Barker and Ardis (1996) cross section (B-B') indicates a significant thickness of Ogallala Formation in Andrews and Ector counties, with a thin underlying wedge of Cretaceous sediments beginning in southern Andrews County and thickening to the southeast in Ector and Midland counties.

The base of aquifer map for the study area from Blandford and others (2003), assembled from maps presented by Knowles and others (1984), is provided in Figure 5-6. The map illustrates that the base of the High Plains (Southern Ogallala) aquifer is complex with numerous paleochannels evident throughout the study area. Note that the mapped paleochannels represent the base of the High Plains aquifer and therefore include the saturated thickness of the permeable Cretaceous units (primarily Antlers sand) where they form an important part of the aquifer.

Nativ (1988) presents a map of the difference in hydraulic head between the Ogallala aquifer and the underlying Edwards–Trinity aquifer within the six counties of interest (Figure 5-7). Although details of the construction of Figure 5-7 are not provided by Nativ (1988) or Nativ and Gutierrez (1988), observed water levels from wells completed in the Edwards–Trinity aquifer in Ector, southern Midland, and Glasscock counties for the time period 1978 through 1983 were apparently used by Nativ and Gutierrez (1988) to determine a potentiometric surface (Figure 5-4) that was extrapolated beneath the remainder of the study area. This surface could then be compared to Ogallala aquifer water levels from the same general time period provided by Gutentag and Weeks (1980) (Nativ, 1988; Nativ and Gutierrez, 1988).

Nativ's (1988) conceptual model is clearly one in which saturated Ogallala sediments and saturated Cretaceous sediments form distinct aquifer units with observable differences in hydraulic head between them. Although applicable to the northern section of Cretaceous subcrop beneath the Southern High Plains, it is not clear that this conceptual model is accurate within some portions of the study area discussed in this paper.

Assuming that the interpretation of Nativ (1988) and Nativ and Gutierrez (1988) is correct, Figure 5-7 illustrates that the observed difference between hydraulic head in saturated Ogallala and Cretaceous sediments ranges from 0 to 50 feet with downward flow from the Ogallala sediments into Cretaceous sediments prevalent throughout most of the study area. Although zones of upward flow are depicted in Figure 5-7, no direct water-level measurements are available to confirm the largest mapped region of potentially upward flow from the Cretaceous sediments to saturated Ogallala sediments in western Martin and northwestern Glasscock counties. In addition, recently constructed potentiometric surface maps for the study area (Blandford and others, 2003) differ markedly in some places from that presented by Gutentag and Weeks (1980), the map presumably used by Nativ (1988) to construct the hydraulic-head difference map that is reproduced here as Figure 5-7. Inherent uncertainty in the regional potentiometric surface maps leaves some question regarding the interpreted magnitude and location of vertical hydraulic head gradients between saturated Ogallala and Cretaceous sediments.

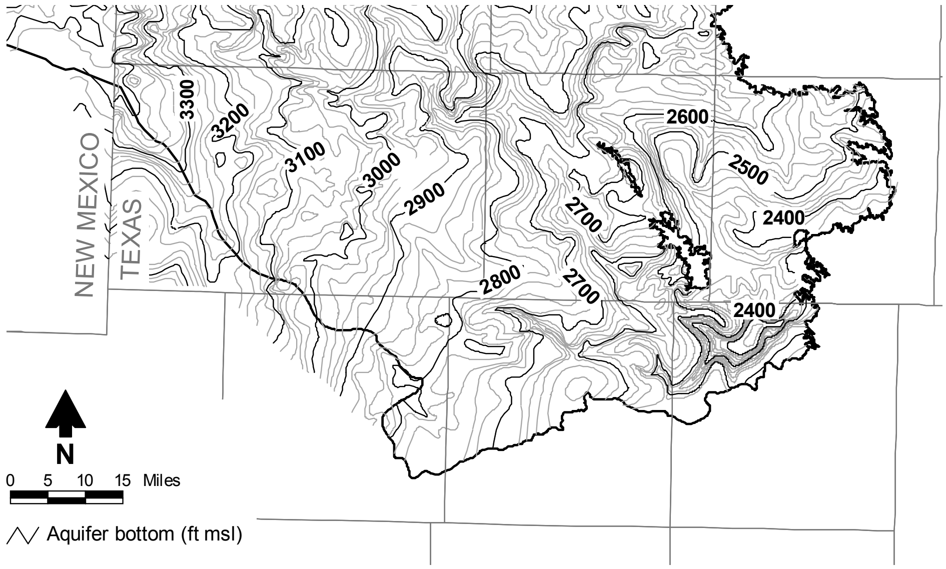

Figure 5-6: Base of High Plains (Southern Ogallala) aquifer within the study area (adapted from Knowles and others, 1984).

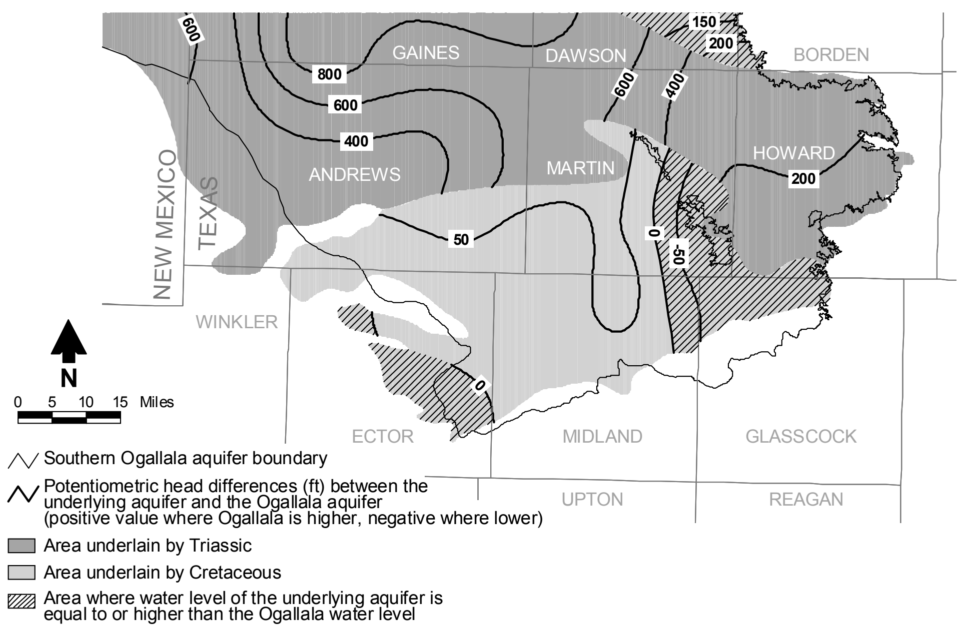

Figure 5-7: Difference in hydraulic head between saturated Ogallala sediments and underlying aquifer units (after Nativ, 1988).

The difference in hydraulic head between the saturated Ogallala sediments and the underlying Triassic Dockum Group immediately to the north of the Cretaceous subcrop are substantially larger (up to 800 feet), indicating a much higher degree of resistance to groundwater flow in the vertical direction caused by the upper Triassic units (the low-permeability Chinle Formation or "red beds"), as would be expected (Figure 5-7).

Previous Modeling Studies

The U.S. Geological Survey completed a modeling study of the entire Edwards–Trinity aquifer in west-central Texas as part of their Regional Aquifer Systems Analysis (RASA) Program (Kuniansky and Holligan, 1994). In this model, the location of the northwest boundary that adjoins the High Plains aquifer "is somewhat arbitrary," according to the authors, and was simulated as a "head-dependent source or sink boundary placed within the High Plains aquifer" (Kuniansky and Holligan, 1994, p. 23). Other related Edwards–Trinity RASA reports include Kuniansky (1990), Barker and Ardis (1992), Barker and others (1994), and Barker and Ardis (1996).

The TWDB is in the process of developing a GAM for the Edwards–Trinity (Plateau) aquifer. Currently, general-head boundary conditions are used along the northwestern margin of the model to represent downward leakage where saturated Ogallala Formation lies above the Edwards–Trinity aquifer. General-head boundaries are also used to represent lateral inflow from the Southern Ogallala aquifer to the Edwards–Trinity aquifer along the northwestern model boundary (Roberto Anaya, personal communication, October 2003).

Groundwater Flow Simulations

To investigate discrepancies identified during development of the Southern Ogallala GAM (Blandford and others, 2003), the GAM was modified to simulate the exchange of water between the Southern Ogallala and Edwards–Trinity aquifers. It was noted during development of the Southern Ogallala GAM that simulated water levels in the southern portion of the model domain in western Martin County, Howard County, and Glasscock County were significantly higher than observed values. The model calibration was not refined in this area because groundwater uses are small compared to other regions of the model, and it is far removed from areas with the largest observed historical drawdown. However, it was hypothesized during the development of the Southern Ogallala GAM that one reason for the high simulated water levels could be that downward or lateral leakage from the Southern Ogallala aquifer to the adjoining Edwards–Trinity aquifer was not explicitly accounted for in the southernmost portion of the model.

To investigate the discrepancy between observed and simulated water levels, two alternative conceptual models of the hydrogeologic relationship between the Southern Ogallala and Edwards–Trinity aquifers were evaluated using the model.

In the Southern Ogallala GAM, the southern model boundary is assumed to be a no-flow boundary, and all groundwater is assumed to discharge at springs and seeps along the draws, the margins of salt lakes, or the eastern escarpment. Lateral groundwater flow out of the model domain to the greater Edwards–Trinity aquifer on the Edwards Plateau is not simulated. The first conceptual model of groundwater flow between the Southern Ogallala and Edwards–Trinity aquifers, called the "laterally continuous" model, assumes that, within the existing Southern Ogallala GAM domain, the full thickness of the Edwards–Trinity aquifer, where it exists, is already incorporated in the model. This approach is consistent with the base of aquifer contours and hydrogeologic cross sections presented by Knowles and others (1984), which indicate that the southernmost portion of the Southern Ogallala (High Plains) aquifer consists entirely of Cretaceous sediments.

The originally developed Southern Ogallala GAM is a single layer model with no leakage components to other aquifer units. The second conceptual model of groundwater flow, called the vertical-leakage model, assumes that, throughout most of the study area, saturated Ogallala sediments overlie the Edwards–Trinity aquifer, and water in the Southern Ogallala aquifer flows vertically downward into the Edwards–Trinity aquifer. This conceptual model is consistent with that applied by Nativ (1988), Nativ and Gutierrez (1988), and the current model under development by the TWDB.

Although not an additional conceptual model per se, some model runs were also conducted where evapotranspiration was implemented in the model. It was hypothesized that evapotranspiration could be an additional physical process neglected in the southern portion of the model that led to simulated hydraulic heads that are greater than observed values.

Modifications to the Southern Ogallala GAM

The laterally continuous conceptual model was implemented by prescribing hydraulic head along the southern boundary of the Southern Ogallala GAM domain (Figure 5-8). In the unmodified model, this boundary was treated as a no-flow boundary because it represents the transition between the Southern Ogallala and Edwards–Trinity aquifers and because the direction of regional groundwater flow is approximately parallel to the boundary (Blandford and others, 2003). Changing the boundary condition from no-flow to prescribed hydraulic head allows groundwater to either exit or enter across the southern boundary, depending on the prescribed boundary head values and the simulated hydraulic head values at interior model cells. This approach is consistent with the conceptual model that the Southern Ogallala aquifer and the Edwards–Trinity aquifer are one and the same along the southern boundary of the model.

The vertical-leakage conceptual model was implemented using a general-head boundary condition (the GHB package of the MODFLOW code), where leakage out of or into the Southern Ogallala model is controlled by a leakage conductance and the difference in the simulated hydraulic head of a given model cell and a prescribed hydraulic head associated with that cell. Conceptually, the prescribed head represents an estimate of the hydraulic head in the Edwards–Trinity aquifer, which is assumed to exist beneath saturated Ogallala sediments. The conductance is equal to the area of the model cell times the average vertical hydraulic conductivity between the two aquifer units, divided by the

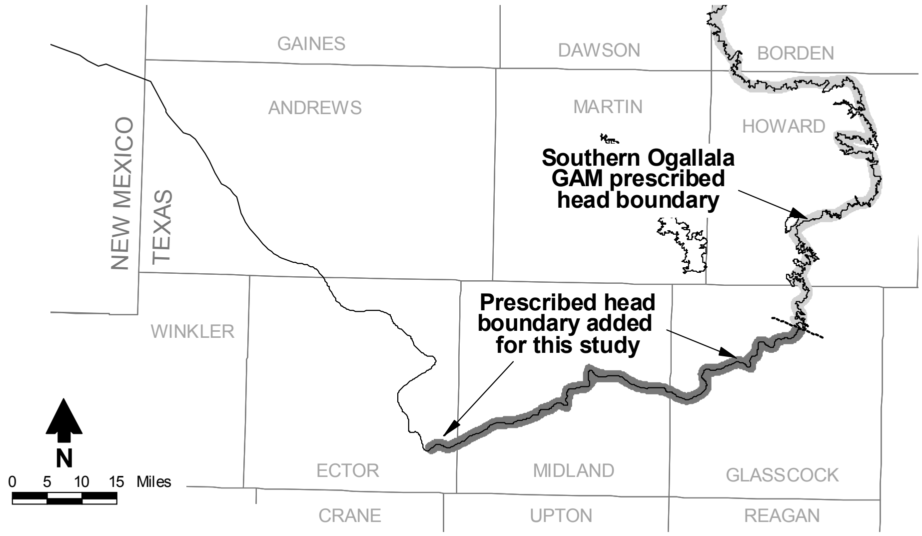

Figure 5-8: Prescribed hydraulic head boundaries used for Southern Ogallala GAM and current model.

average distance in the vertical dimension between the aquifer units. The general-head boundary condition was applied to all model cells that fall within the mapped extent of the southern region of Cretaceous subcrop as illustrated in Figure 5-1.Evapotranspiration was implemented using the ET package of the MODFLOW code. This boundary condition requires that a maximum rate of evapotranspiration and an extinction depth be assigned to a given node. When the simulated water table is at or above land surface, the maximum evapotranspiration rate will be applied. This maximum simulated rate will decline until it is zero (no evapotranspiration) at the prescribed extinction depth. As with the general-head boundary condition cells, evapotranspiration was applied to model cells that fall within the mapped extent of the southern region of Cretaceous subcrop as illustrated in Figure 5-1. However, there is no discharge from these cells unless the simulated water level lies above the assumed extinction depth.

Simulation Results

Simulations were conducted for each of the conceptual models presented above, as well as for various combinations of each approach (for example, prescribed hydraulic head and general-head boundaries). Sensitivity analyses for assumed boundary condition input parameters, such as general-head boundary conductance and evapotranspiration extinction depth, were also completed. As observed historical drawdown has not been extensive over much of the region of interest, most of the revised simulations were conducted using the steady-state Southern Ogallala GAM only, which was assumed to be indicative of average hydrologic conditions during and before 1940 (Blandford and others, 2003). However, hydrographs of simulated water levels for several of the revised

Table 5-1: Comparison of calibration statistics for Southern Ogallala GAM and modified models.

Model	RMSE (ft)	MAE (ft)	RME (ft)	% Error [1]
Southern Ogallala GAM	34	26	–8	1.5
Run 1: Vertical leakage [2]	32	24	–5	1.4
Run 2: Vertical leakage [3]	34	25	–7	1.5
Run 3: Vertical leakage [3] and evapotranspiration	33	24	–6	1.4
Run 4: Laterally continuous	34	25	–7	1.5
Run 5: Laterally continuous and vertical leakage [3]	33	25	–7	1.4

RMSE = Root-mean-squared error
MAE = Mean-absolute error
RME = Residual mean error

[1] RMSE divided by the maximum difference in observed hydraulic head values
[2] Prescribed head set to 15 feet below observed predevelopment hydraulic head
[3] Prescribed head set to 15 feet below simulated predevelopment hydraulic head from Southern Ogallala GAM

models were checked against those of observed water levels, to confirm that the general fit to water level changes was maintained in the revised models.

The calibration statistics for the Southern Ogallala GAM and the modified versions of the model are presented in Table 5-1. For the laterally continuous model runs, prescribed hydraulic head values along the southern model boundary (Figure 5-8) were obtained from the predevelopment potentiometric surface map in Blandford and others (2003). For the vertical leakage model runs, the prescribed general head boundary was assumed to be 15 feet below the bottom of the saturated Ogallala sediments, and the conductance was assumed to be 92.93 feet per day (ft/d), which corresponds to a vertical hydraulic conductivity of 0.0001 ft/d and a vertical flow distance of 30 feet.

During the sensitivity analyses conducted for both of these parameters, it was observed that the assumed leakance generally had to be increased to allow significant volumes of water to enter or leave the aquifer. The prescribed head for the leakance boundary was applied using two approaches. In the first approach, the prescribed head was assumed to be 15 feet less than the observed hydraulic head. In the second approach, the prescribed head was assumed to be 15 feet less than the simulated head from the Southern Ogallala GAM. The second approach was used to reduce simulated inflows to the model from the bottom that occurred in some regions, partially as an artifact of the simulated predevelopment hydraulic head field.

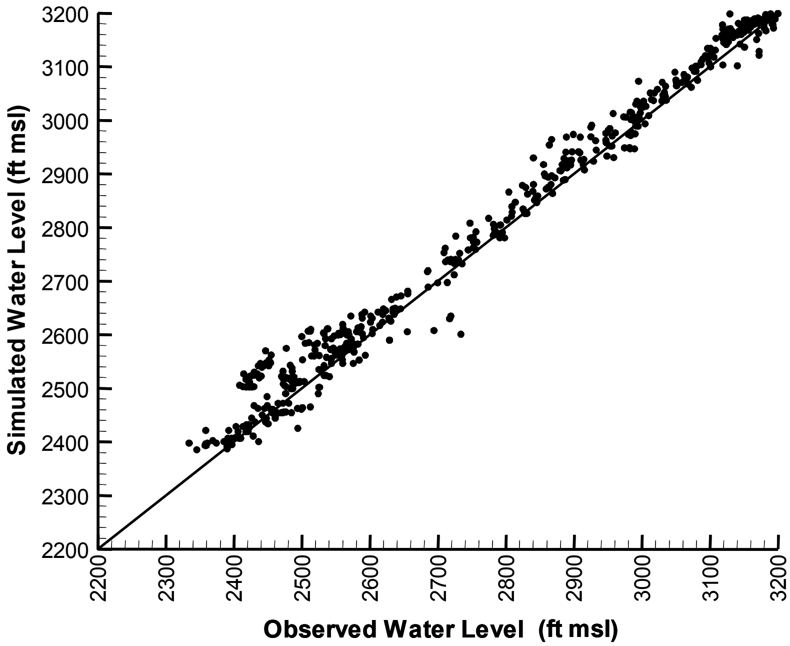

Figure 5-9: Simulated versus observed hydraulic head for Southern Ogallala GAM.

Where evapotranspiration was applied, an extinction depth of 10 feet was used with a maximum evapotranspiration rate of 1 foot per year at the land surface. The assumed rate of evapotranspiration is fairly low so that large volumes of water that could not be verified by field studies would not be removed from the model. Sensitivity runs conducted with higher maximum rates yielded similar results.

The calibration statistics for each of the modified simulations, except Run 4, improved significantly over the original GAM run, especially considering that the adjustments to the model only affect the southernmost points (lowest hydraulic heads) within the overall model domain. Scatter plots of observed versus simulated hydraulic heads for the Southern Ogallala GAM and for the modified model (Run 1) are provided in Figures 5-9 and 5-10, respectively. Comparison of the portion of these plots for the hydraulic heads less than about 2,700 ft-MSL illustrates the improvement in model calibration obtained from implementing the leakage boundary.

The largest improvements in the match between simulated and observed hydraulic heads were obtained through implementation of the vertical leakage model. Implementation of the laterally continuous model through the prescription of hydraulic heads along the southern model boundary did not yield significant improvements in the model calibration (Table 5-1, Run 4). Likewise, the combination of the two boundary approaches also yielded relatively small improvement in the model calibration statistics (compare Runs 2 and 5 in Table 5-1).

Because of data limitations and assumptions used in estimating the boundary condition parameters, it would not be appropriate to use the simulation results as quantitative

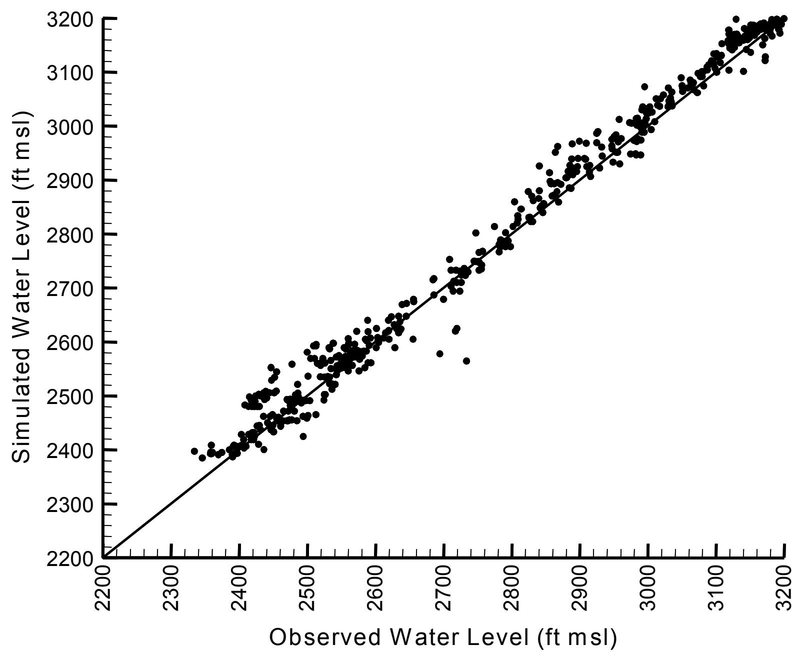

Figure 5-10: Simulated versus observed hydraulic head for modified model that incorporates vertical leakage (Run 1).

estimates of groundwater flow that occurs between the two aquifer systems. In addition, the hydraulic parameters (hydraulic conductivity and aquifer bottom elevation) in the Southern Ogallala GAM are representative of the High Plains aquifer, which includes both the saturated Ogallala sediments and Cretaceous sediments in at least the southernmost portion of the study area.

Conclusion

The Edwards–Trinity aquifer is hydraulically connected to saturated Ogallala Formation sediments within a six-county region of the far Southern High Plains. Within this area it is often difficult to distinguish between aquifer units because (1) the Cretaceous Antlers sand is similar to Ogallala sediments in appearance and (2) a smooth hydrologic transition occurs between aquifers. Some previous studies have considered the saturated Ogallala and Cretaceous sediments as distinct aquifer units, while others have grouped them into one aquifer unit called the High Plains aquifer.

A series of model runs were developed to evaluate alternative conceptual models of the exchange of water between aquifer units. The simulations were conducted using modified versions of the Southern Ogallala GAM. The simulations indicated an improved fit in simulation results when the exchange of water between aquifer units was explicitly accounted for, particularly using a vertical leakage conceptual model, where water flows vertically downward from saturated Ogallala sediments into the Edwards–Trinity aquifer.Although the simulation results best matched observed hydraulic heads when the vertical leakage conceptual model was employed, the possibility remains that the laterally continuous conceptual model may be appropriate for some regions within the study area. This opinion is based on review of the documents cited previously and the observation that aquifer bottom elevations used in the Southern Ogallala GAM, derived from Knowles and others (1984), apparently include the saturated portion of the Cretaceous Antlers sand. If this observation is correct, it is hypothesized that the component of groundwater flow that enters the greater Edwards–Trinity aquifer of the Edwards Plateau may be relatively small because (1) regional groundwater flow within saturated Ogallala and Cretaceous sediments generally parallels the approximate boundary between the two aquifer units, and (2) a portion of the water in the Antlers sand is discharged from wells and at springs that occur (or used to occur) along the far southeastern portion of the caprock escarpment, along draws, and at the margins of salt lakes within the study area.

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