



## 7. Region F

The selected counties in the Region F RWPA include Crockett, Ector, Glasscock, Kimble, Loving, Midland, Reagan, Reeves, Tom Green, Upton, and Ward Counties (Figure 30). The region is predominately rural; ranching, irrigated agriculture, and the oil and gas industry have historically dominated the regional economy and culture. The main cities in the region are Midland, Odessa, and San Angelo (Freese and Nichols, Inc. et al., 2001b).

### 7.1 Water Resources Overview

The largest water use in the region is irrigated agriculture, which accounts for nearly 75 percent of the total demand. The adopted regional water plan projects a decrease in the demand for irrigation based on the assumed implementation of water-conserving irrigation technologies. Municipal, manufacturing, and steam electric demands are projected to increase in the more populous counties (Freese and Nichols, Inc. et al., 2001b). Water supply projections for Region F are shown in Table 10.

**Table 10. Projections for Selected Counties in Region F**

County	SSURGO Soil Data Available	Projected Water Supply <sup>a</sup> (ac-ft/yr)						Acreage Suitable for Recharge <sup>b</sup>
		2000	2010	2020	2030	2040	2050	
Crockett	Yes	666	---	-1,533	---	---	-1,530	63,182
Ector	No	-1,688	---	-4,099	---	---	-10,393	10,738
Glasscock	No	-47,853	---	-46,773	---	---	-45,145	522
Kimble	Yes	113	---	22	---	---	-218	13,938
Loving	No	-258	---	-250	---	---	-240	---
Midland	Yes	-29,072	---	-32,826	---	---	-43,490	29,765
Reagan	No	-20,155	---	-18,587	---	---	-16,478	6
Reeves	Yes	-39,210	---	-37,634	---	---	-35,134	7,596
Tom Green	No	-32,219	---	-38,154	---	---	-44,394	---
Upton	No	-6,822	---	-5,708	---	---	-4,871	4,877
Ward	No	-4,643	---	-5,781	---	---	-10,068	10,342

<sup>a</sup> Negative values indicate a deficit in supply

<sup>b</sup> Identified through site-specific analysis described in this report.

ac-ft/yr = Acre-feet per year

SSURGO = Soil Survey Geographic database

--- = Not available



Groundwater accounts for 66 percent of the total currently available supply in the region. Within Region F there are 12 groundwater conservation districts, which manage groundwater supplies, and 3 wholesale water providers.

As shown in Figure 31, six major rivers flow through the region. Some stretches of these rivers are designated as impaired.

Reservoirs account for 21 percent of the supply in Region F and provide most of the municipal supply. The region includes 17 reservoirs, 4 of which fall within the selected counties (Table 11). Figure 32 shows existing and planned conveyances within the region.

**Table 11. List of Major Reservoirs, Region F Site-Selected Counties**

County	Reservoir	Water Right Owner	Authorized Diversion (ac-ft/yr)
<i>Colorado Basin</i>			
Tom Green	O.C. Fisher Lake	Upper Colorado River Authority (contracted to the City of San Angelo)	---
	Twin Buttes Reservoir	City of San Angelo	---
	Lake Nasworthy		---
Loving and Reeves	Red Bluff Reservoir	Red Bluff Water Power Control District	---

Source: Freese and Nichols, Inc. et al., 2001b.

ac-ft/yr = Acre-feet per year  
 --- = Not available

## 7.2 Rate, Area and Time Period for Infiltration

In Region F, the scale difference between the SSURGO soils dataset and the STATSGO dataset are again evident. Because of the differences in resolution between the two data sources, soil permeability maps show artificial differences along the Crockett County line, where the more detailed SSURGO data join with the less detailed STATSGO data of surrounding counties.



The western and southwestern portions of Region F lie within the Rio Grande Basin. Because a WAM model is not yet completed in this area, WAM data are not available for Reeves, Loving, Ward, Crockett, and portions of Upton and Ector Counties (Figure 33).

Midland County has a number of potentially suitable banking locations near the City of Midland (Figure 30). Ector County has a 10,738-acre area within and around the City of Odessa that was identified as a potentially suitable location for groundwater recharge. The WAM model data show that 630 ac-ft/yr of excess surface water might be available for recharge along Monahans Draw. Ward County has a 10,342-acre area on the Pecos River, south of the City of Monahans, that was identified as a potentially suitable location for groundwater recharge. However, there is no WAM data available for Ward County.

Kimble County has several potential recharge locations along the Llano River and its tributaries (Figure 30). The WAM data show excess streamflows ranging from 10,000 ac-ft/yr to 35,000 ac-ft/yr along the main stem of the Llano River and more than 1,000 ac-ft/yr along some of the river's smaller tributaries (Figure 33). These areas tend to be agricultural with few population centers.

Reeves County, the example county for this region, has a total projected 2050 demand of 108,198 ac-ft/yr, of which 34,718 ac-ft/yr is for irrigation. Most of the irrigation demand is south and west of the City of Pecos (Figure 34). Many of the prime recharge areas are located in or near the southern part of this irrigated acreage and might provide local recharge for irrigated agriculture. The City of Pecos shows no prime sites for recharge in the initial analysis.

Soil permeability is low throughout most of Reeves County. Consequently, our site-specific analysis identified only a few small regions of potential recharge areas throughout the central and southeastern portions of the county (Figure 34). However, the existing soil surveys are for near-surface materials that extend no more than 80 inches below ground surface. Potentially, 80 inches is an economically acceptable depth for excavation of a recharge facility. Thus, if in-depth soil analyses of selected locations determines that soil permeability adequate for recharge is available at depths slightly deeper than those included in the SSURGO data, the top layer of these sites could potentially be excavated.



Figure 35 illustrates computations of banked water for two hydrographs. The top graph is for Gauge 8427500 at San Solomon Springs along Toyah Creek, and the bottom graph is for Gauge 8433000 along Barilla Draw. The San Solomon gauge is about 10 miles upstream of a number of potential recharge sites along or in the vicinity of Toyah Creek, and the Barilla Draw gauge is about 15 miles downstream of several potential recharge sites (Figure 34). Both sites overlie Cenozoic Pecos Alluvium Aquifer outcrop. The average soil permeability for potential recharge sites closest to the San Solomon Springs and Barilla Draw gauges was determined to be 8 ft/d for both locations.

Calculated cumulative recharge for the San Solomon Springs site is about 1,150 ac-ft over a 10-year period, while calculated cumulative recharge for the Barilla Draw gauge is about 5,000 ac-ft over about 8 years. As illustrated by the hydrographs in Figure 35, the source of flow at these two gauges is very different. Flow at the San Solomon Springs gauge is fed by flow from San Solomon Spring, which is the largest spring in Reeves County (Brune, 2000). This spring has a constant base flow of about 30 to 35 cubic feet per second (cfs), but spikes that occur in the spring's flow, presumably caused by greater than normal precipitation, could potentially be banked. The Barilla Draw hydrograph is typical for smaller tributaries in semiarid regions. This tributary is ephemeral and only flows after significant precipitation events within its drainage basin. The vast majority of calculated recharge for this gauge comes from two storm events (1979 and 1982) that occurred during the 8-year period of record.

In addition to the above infiltration calculations, which were made assuming a basin size of 100 acres, the two selected hydrographs were analyzed to determine the area required to infiltrate all available water (assumed to be one-half of the flow above the threshold values indicated on Figure 35) and the average time period for infiltration. The required area and average time period for infiltration is 0.5 acre and 57 days, respectively, for the San Solomon Springs site, and 22 acres and 2.4 days for the Barilla Draw site. Because the source of flow to the San Solomon Springs gauge is groundwater, the hydrologic record indicates that time periods for infiltration can be substantial following unusually wet periods. Along Barilla Draw and other similar tributaries, however, available time for infiltration, without engineered storage capacity, is very short.

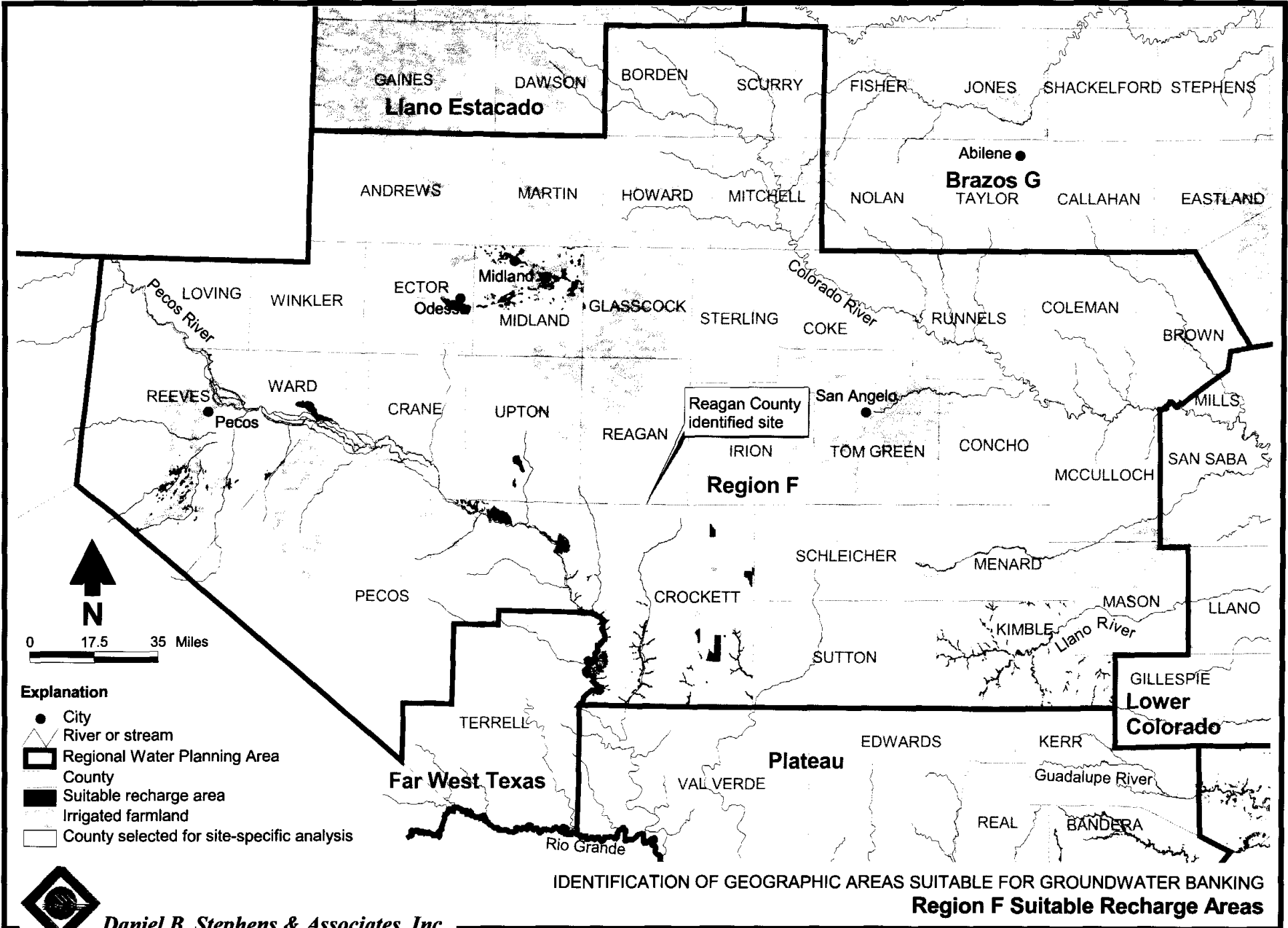


Figure 30



**IDENTIFICATION OF GEOGRAPHIC AREAS SUITABLE FOR GROUNDWATER BANKING  
Region F Suitable Recharge Areas**

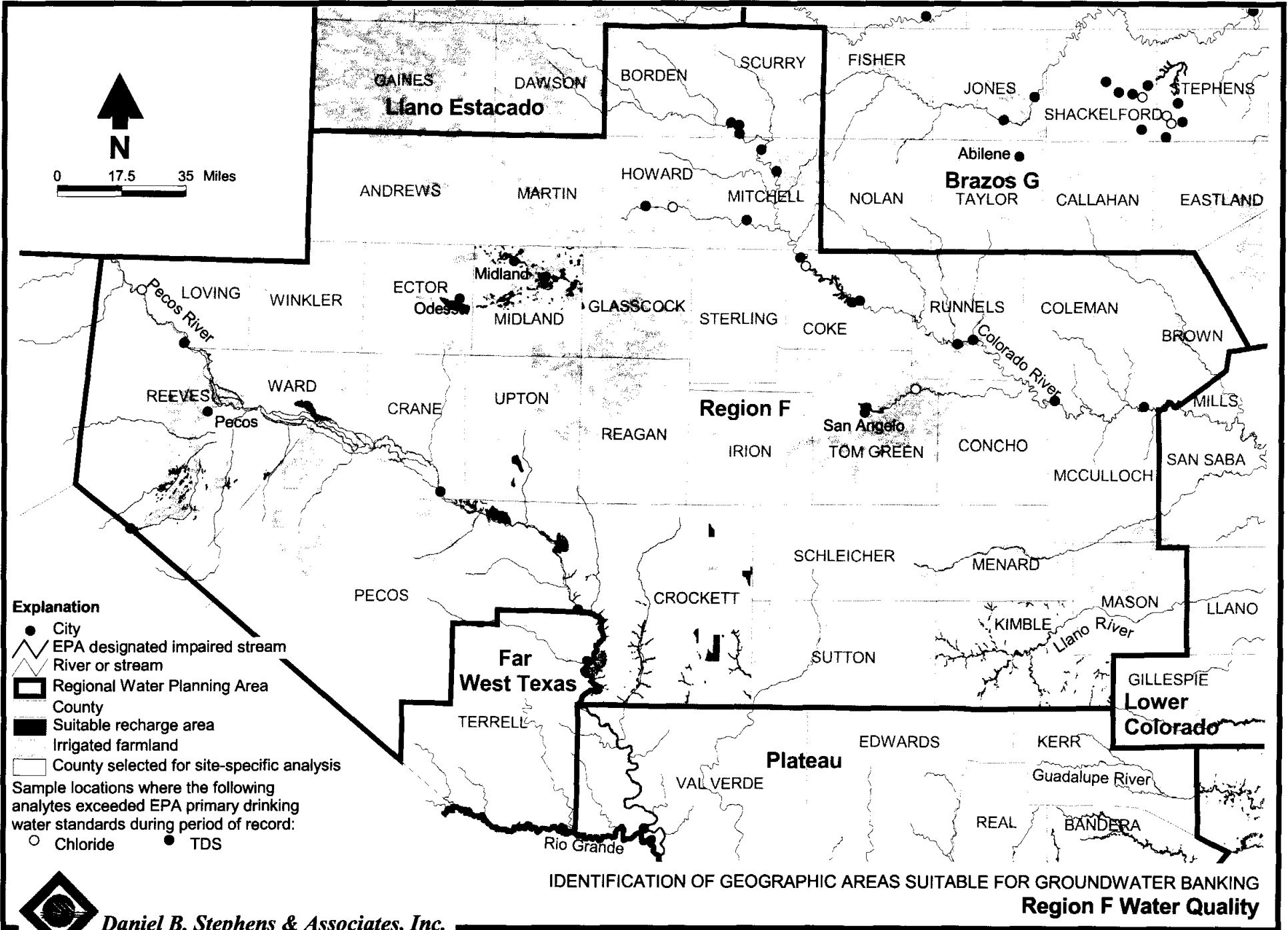
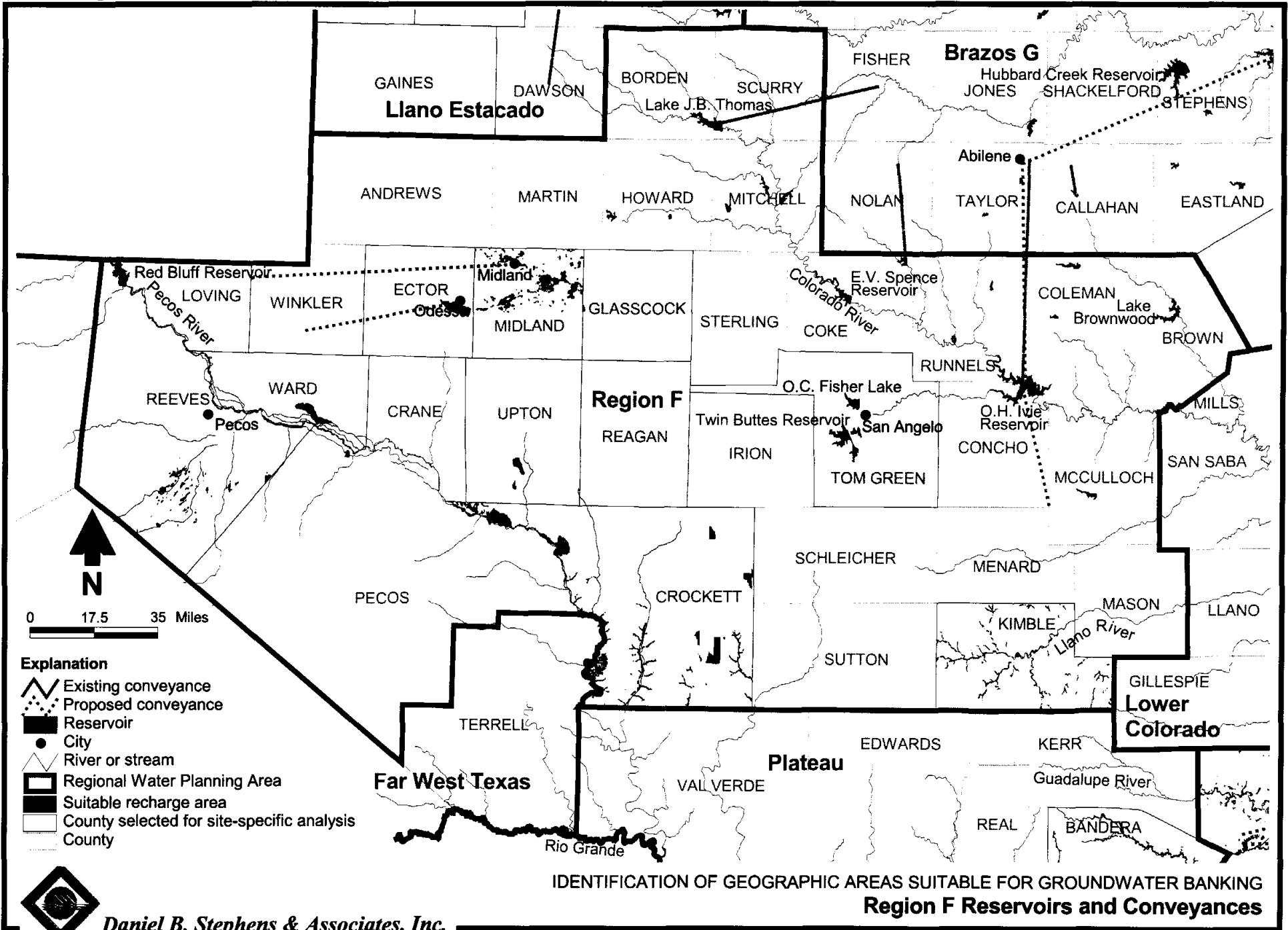


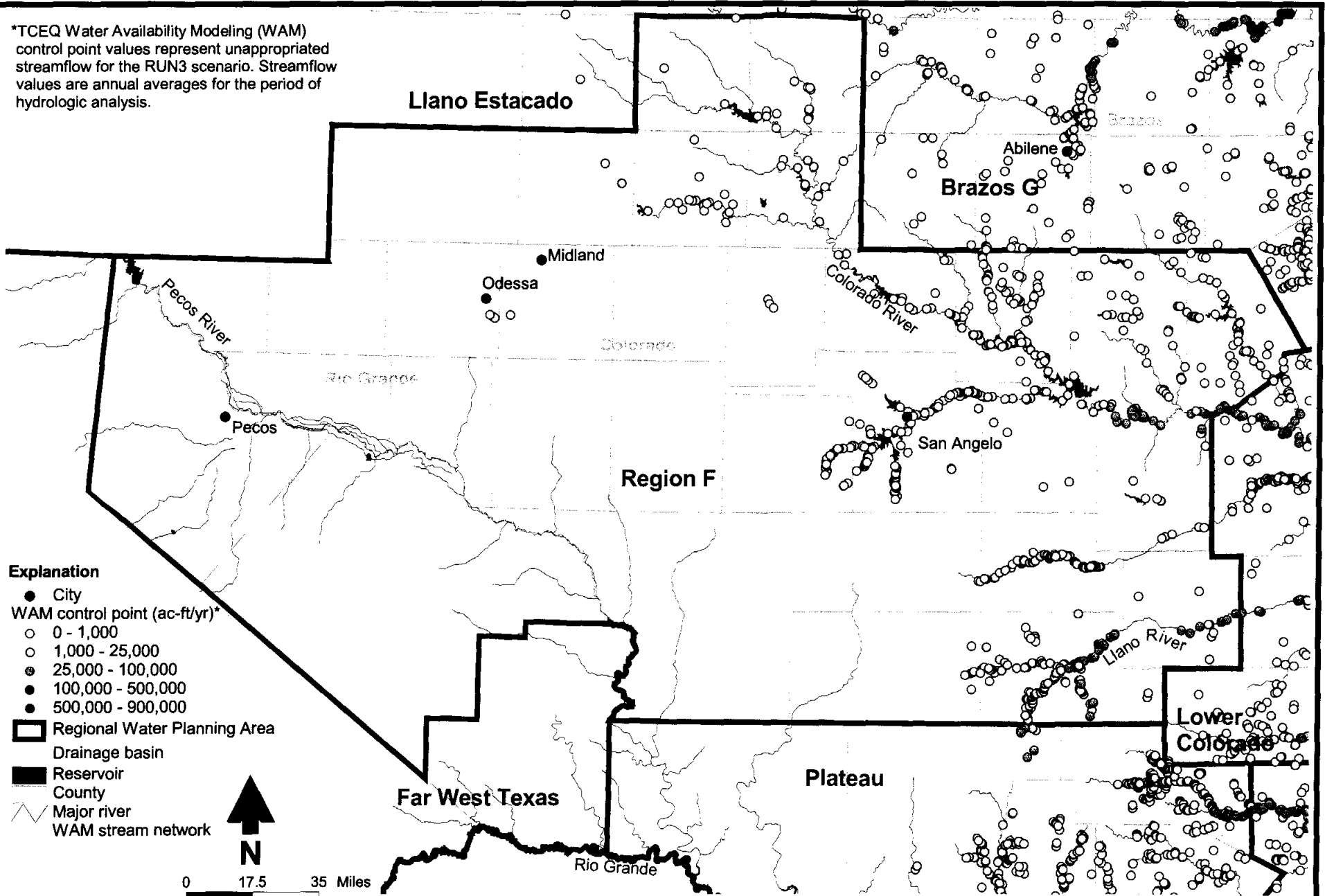
Figure 31





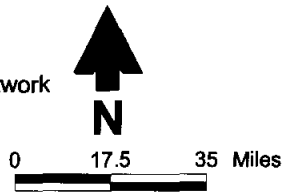
IDENTIFICATION OF GEOGRAPHIC AREAS SUITABLE FOR GROUNDWATER BANKING  
**Region F Reservoirs and Conveyances**

\*TCEQ Water Availability Modeling (WAM)  
control point values represent unappropriated  
streamflow for the RUN3 scenario. Streamflow  
values are annual averages for the period of  
hydrologic analysis.



**Explanation**

- City
- WAM control point (ac-ft/yr)\*
  - 0 - 1,000
  - 1,000 - 25,000
  - 25,000 - 100,000
  - 100,000 - 500,000
  - 500,000 - 900,000
- ▭ Regional Water Planning Area
- ▭ Drainage basin
- ▭ Reservoir
- ▭ County
- ▭ Major river
- ▭ WAM stream network



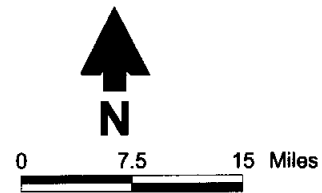
**IDENTIFICATION OF GEOGRAPHIC AREAS SUITABLE FOR GROUNDWATER BANKING  
Region F Surface Water Availability**

Figure 33



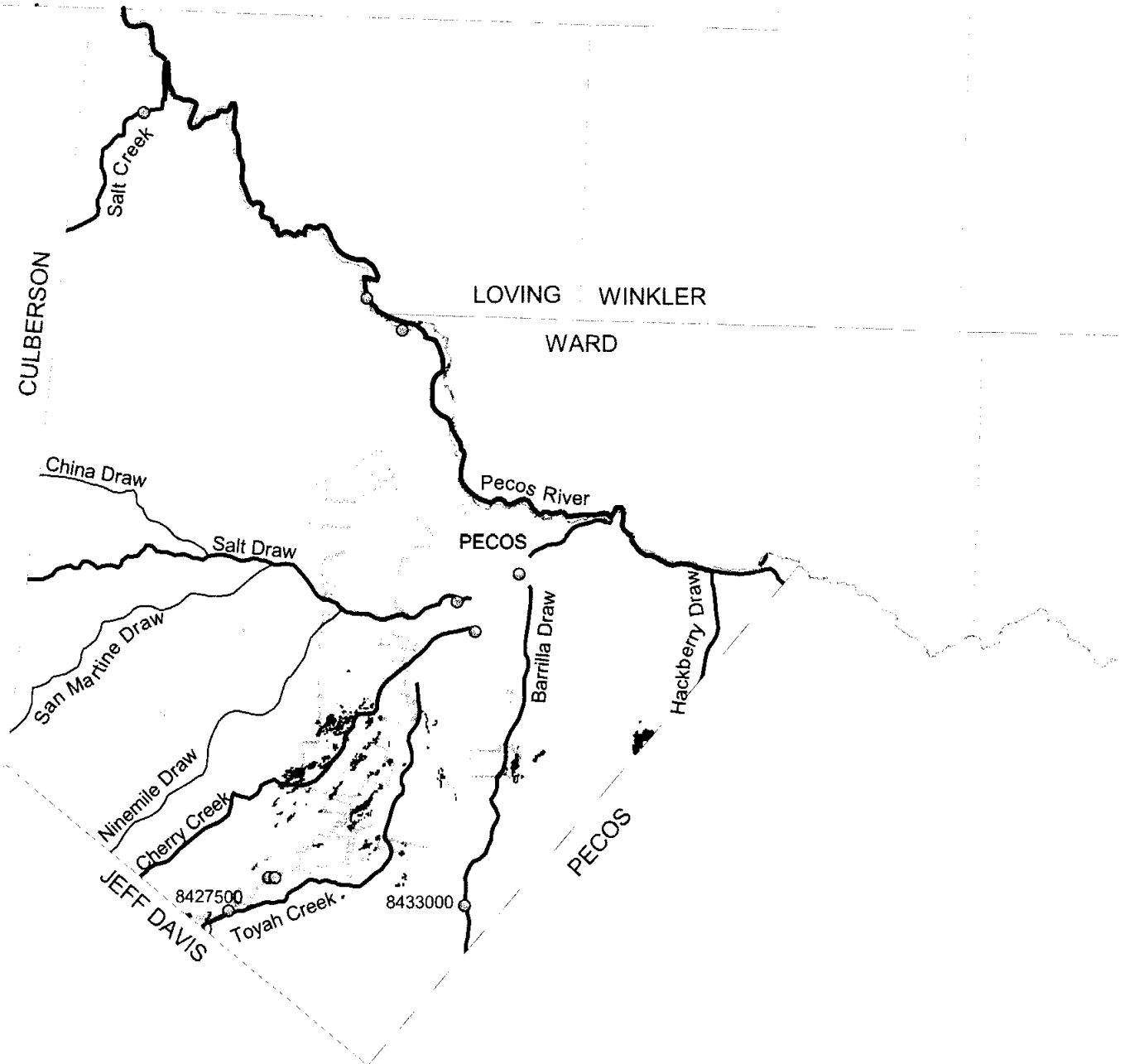


Note: Suitable recharge areas defined as:  
 - Areas within 3 miles of a stream  
 - Soil permeability  $\geq 2$  inches per hour  
 - Topographic slope  $\leq 5$  degrees



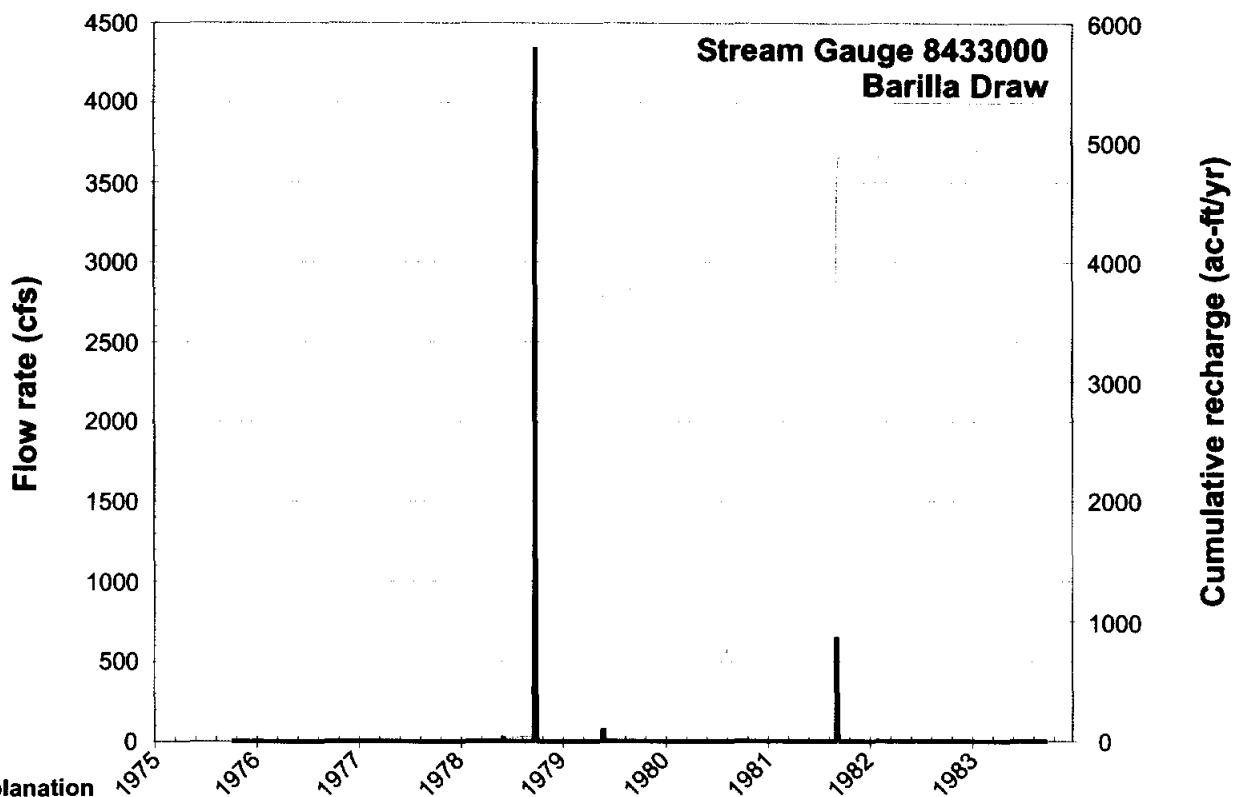
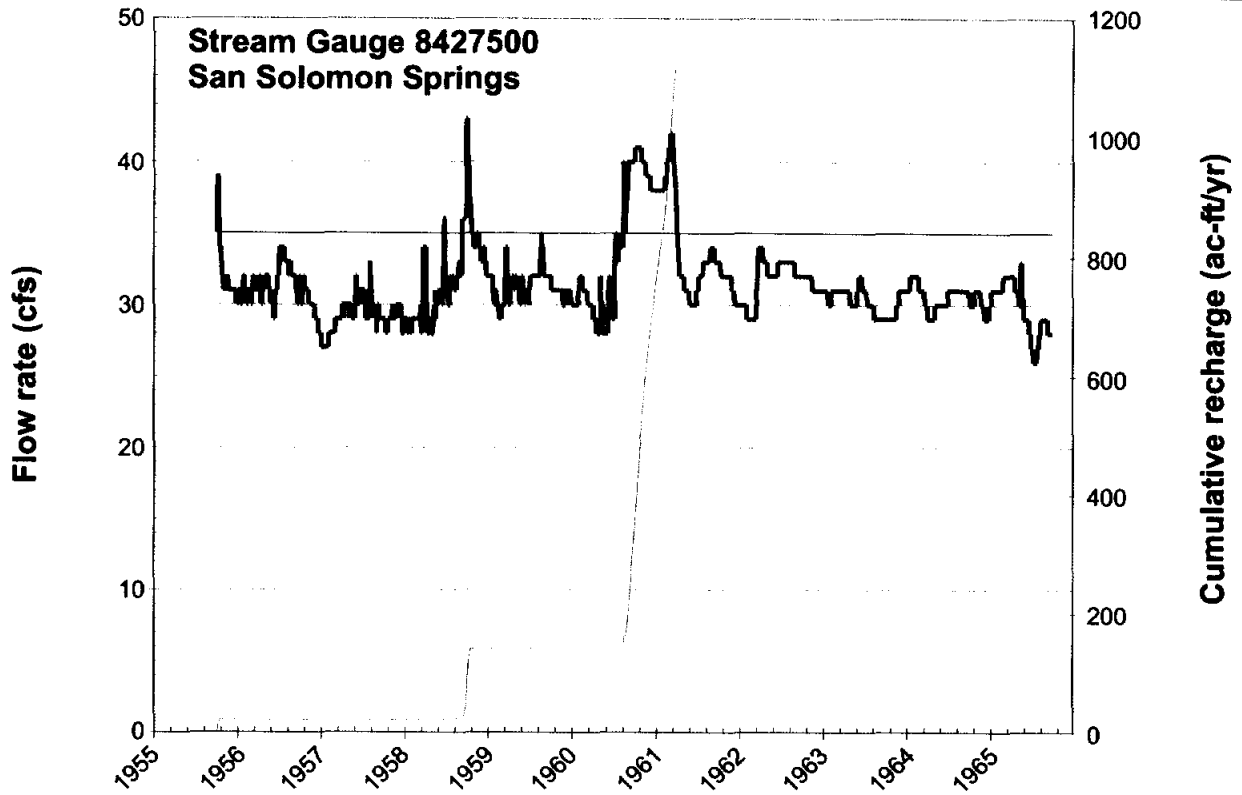
**Explanation**

- USGS stream gauge
- 7297500 Gauge used in site-specific analysis
- River or stream
- ▲ 1st order stream
- ▲ 2nd order stream
- ▲ 3rd order stream
- ▲ 4th or 5th order stream
- Suitable recharge area
- ▨ Irrigated farmland
- City - urban area
- ▭ County






**IDENTIFICATION OF GEOGRAPHIC AREAS SUITABLE FOR GROUNDWATER BANKING  
 Reeves County Suitable Recharge Areas**





**Explanation**

-  Observed stream flow
-  Threshold
-  Calculated cumulative recharge

**Notes:**

Recharge area: This scenario calculates the cumulative infiltration of water based on a hypothetical recharge basin of 100 acres.

**IDENTIFICATION OF GEOGRAPHIC AREAS  
SUITABLE FOR GROUNDWATER BANKING  
Available Recharge Hydrograph for  
USGS Stream Gauges, Reeves County**

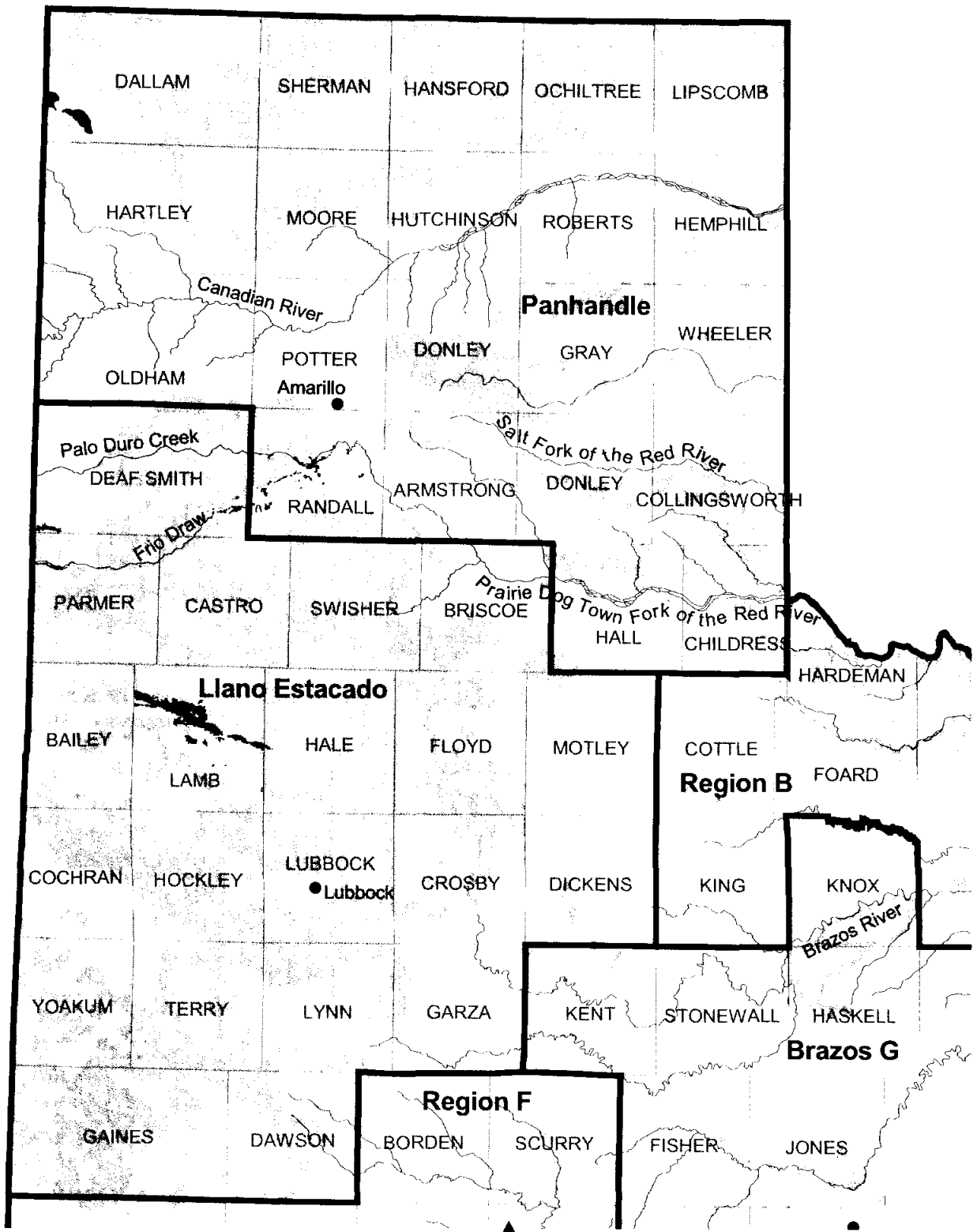
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Figure 35

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**Explanation**

- City
- △ River or stream
- ▭ Regional Water Planning Area
- ▭ County
- ▨ Suitable recharge area
- ▨ Irrigated farm land
- ▭ County selected for site-specific analysis



0 17.5 35 Miles

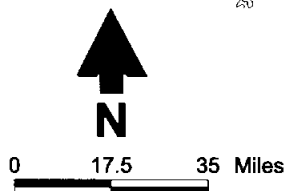
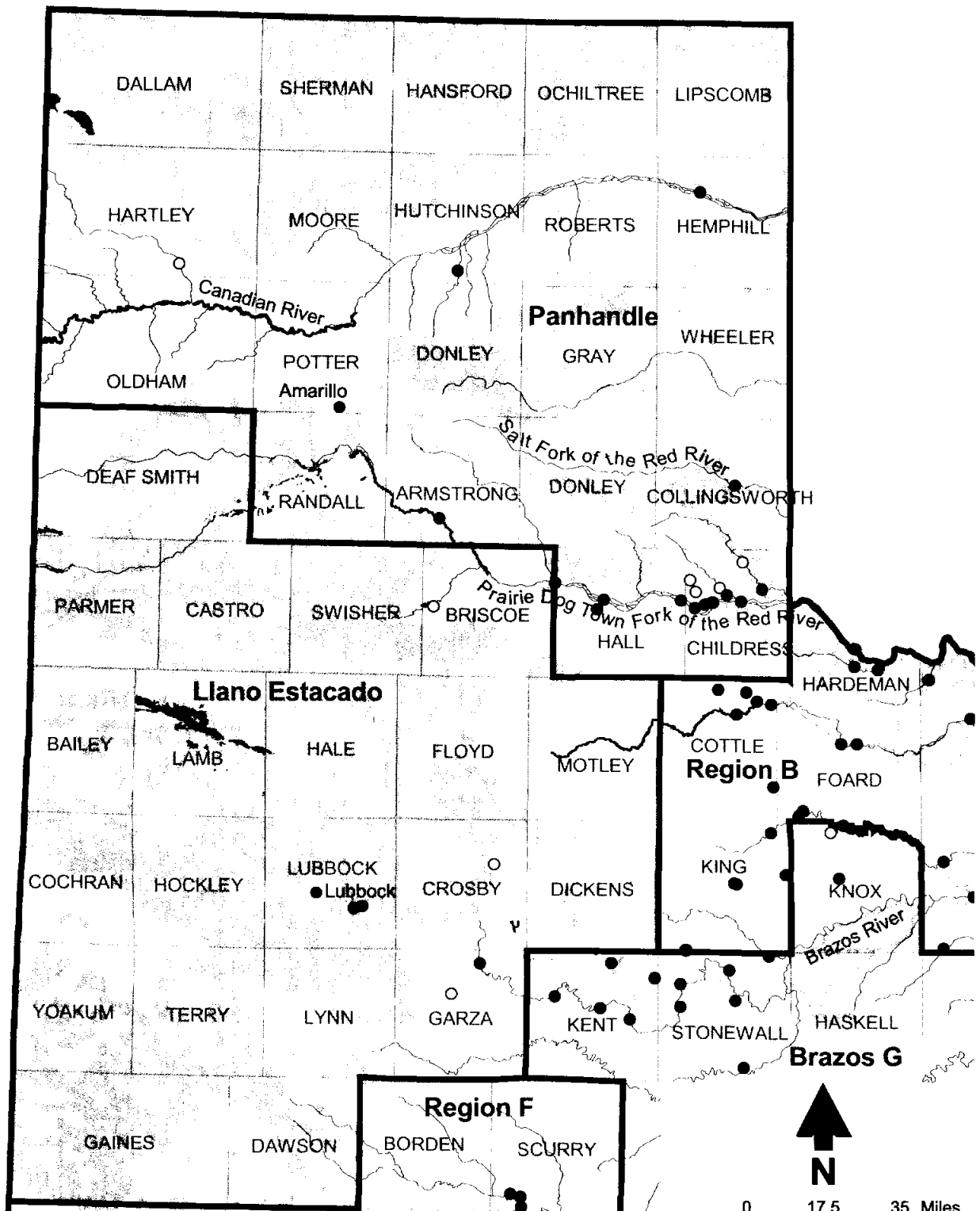
**IDENTIFICATION OF GEOGRAPHIC AREAS  
SUITABLE FOR GROUNDWATER BANKING  
Ogallala Suitable Recharge Areas**



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Figure 36

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**Explanation**

- City
- EPA designated impaired stream
- River or stream
- ▭ Regional Water Planning Area
- ▭ County
- ▭ Suitable recharge area
- ▭ Irrigated farmland
- ▭ County selected for site-specific analysis

- Sample locations where the following analytes exceeded EPA primary drinking water standards during period of record:
- Fluoride
  - Chloride
  - TDS



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**IDENTIFICATION OF GEOGRAPHIC AREAS  
 SUITABLE FOR GROUNDWATER BANKING  
 Ogallala Water Quality**

Figure 37



## **8. Ogallala Region**

For the purposes of this analysis, the Ogallala Region includes counties from both the Panhandle (Region A) and Llano Estacado (Region O) RWPAs (Figure 36). These counties were grouped into one region because all of them overlie the Ogallala Aquifer (Figure 5), which is unconfined.

### **8.1 Water Resources Overview**

The primary use of water in regions that overlie the Ogallala Aquifer is for irrigated agriculture. In the Panhandle region of the aquifer, especially north of Amarillo and the Canadian River Valley, approximately 85 percent of the total water use is for irrigated agriculture. In the southern counties of the Ogallala region, approximately 95 percent of the total water use is for irrigated agriculture.

Most of the region that overlies the Ogallala Aquifer drains internally to thousands of playas, each of which has its own drainage area. Thus, any large-scale recharge program would need to incorporate some type of playa modification or enhancement. It is probable that the benefits of such a program could be significant, as recent studies have demonstrated that a significant portion of recharge to groundwater on the High Plains occurs through playas. The playas are not addressed specifically in this report due to their unique hydrologic aspects. In addition, playas did not make it through our screening process because they (1) are generally not within 3 miles of a significant watercourse and (2) generally have bottoms that are covered by low-permeability soils. A more detailed overview of enhanced recharge at playas is provided in Section 1.2.1.

Tributaries to the Red, Brazos, and Colorado Rivers cross the southern plains of this region, but these tributaries are ephemeral. When they flow after storm events, most or all of the water typically infiltrates or is lost to evaporation before it flows off the caprock into the central plains. To a certain extent, therefore, these stream courses already act as natural recharge facilities. However, there could be some opportunity for capturing storm flows from these tributaries before they flow off the escarpment.



Table 12 shows the water supply projections and Figure 37 shows selected water quality data for the region.

**Table 12. Projections for Selected Counties in Ogallala Region (Llano Estacado and Panhandle Regional Water Planning Areas)**

County	SSURGO Soil Data Available	Projected Water Supply* (ac-ft/yr)						Acreage Suitable for Recharge <sup>b</sup>
		2000	2010	2020	2030	2040	2050	
Bailey	No	-7,278	-6,463	-5,350	-4,014	-2,431	-925	---
Briscoe	No	---	---	---	---	---	---	---
Castro	Yes	-39,261	-39,143	-38,621	-37,592	-36,449	-35,107	---
Cochran	No	-13,181	-12,046	-10,948	-9,868	-8,836	-7,856	---
Deaf Smith	Yes	---	---	---	-2,516	-2,596	-2,717	3,642
Floyd	No	-23,567	-23,949	-24,088	-23,855	-23,577	-23,199	---
Gaines	No	0	-581	-555	-547	-535	-533	---
Hale	Yes	-2,234	-2,183	-4,180	-7,998	-10,472	-13,442	362
Lamb	Yes	---	---	-918	-1,371	-1,368	-1,381	38,527
Parmer	Yes	-34,176	-42,245	-49,404	-56,597	-62,026	-66,840	1,518
Swisher	No	-45,349	-45,145	-42,545	-44,533	-44,228	-43,921	---
Terry	Yes	-961	-935	-891	-871	-846	-792	---
Yoakum	No	0	0	-457	-1,935	-2,030	-2,158	---
Dallam	No	---	---	-392,701	---	---	397,991	15,235
Moore	No	851	---	-218,773	---	---	224,415	---
Oldham	No	456	---	-28,291	---	---	-28,783	---
Potter	No	1,907	---	-35,776	---	---	-45,929	---
Randall	Yes	1	---	-60,150	---	---	-72,661	5,534
Sherman	No	0	---	2,154	---	---	0	---

\* Negative values indicate a deficit in supply

<sup>b</sup> Identified through site-specific analysis described in this report.

ac-ft/yr = Acre-feet per year

SSURGO = Soil Survey Geographic database

--- = Not available

Of the few counties in the region for which the high-resolution SSURGO soils data were available, Randall County was the only one for which hydrograph data also existed. Therefore, Randall County is the selected example county for the region.

Figure 38 shows the existing and proposed conveyances within the Ogallala region.



## **8.2 Rate, Area, and Time Period for Infiltration**

The WAM data show excess streamflows ranging from 2,470 ac-ft/yr to more than 32,000 ac-ft/yr along the Prairie Dog Town Fork of the Red River with 579 ac-ft/yr on Frio Draw and 23,422 ac-ft/yr on Palo Duro Creek in Deaf Smith County (Figure 39).

In Randall County, the total demand is 105,116 ac-ft/yr, of which 57,491 ac-ft/yr is for irrigation. Most of the prime acreage for recharge is along the Prairie Dog Town Fork of the Red River and its tributaries, while most of the irrigated agriculture is located well away from the watercourses (Figure 40).

Figure 41 illustrates computations of banked water for Gauge 7297500 on the Prairie Dog Town Fork of the Red River several miles downstream of Canyon. The average permeability for this site was determined to be about 8 ft/d. Calculated cumulative recharge for a 100-acre basin is about 15,800 ac-ft over a 10-year period from the 1940s, when data are available for this gauge. About 80 percent of this calculated recharge is due to two very large precipitation events that occurred during 1942 (Figure 41), which was a record year of precipitation across much of the Southern High Plains. Based on the same hydrograph record, the required area to bank all available water, as determined using the Prairie Dog Town Fork of the Red River gauge, is 75 acres, and the average time available for infiltration is 3.3 days.

The hydrograph record for this site illustrates that the draws that cross the High Plains only flow during storm events. In addition, the volume of water that can be practically captured for banking is small compared to the major demand in the region, which is irrigated agriculture. For example, the site-specific analysis for the Prairie Dog Town Fork of the Red River gauge in Randall County indicated that 15,800 ac-ft of water could have been banked over a 10-year period, yet the estimated 2050 deficit in Randall County is more than 72,661 ac-ft/yr. Therefore, groundwater banking of water from the Prairie Dog Town Fork site, and likely from other stream courses on the High Plains that overlie the Ogallala Aquifer, is probably not an efficient approach to take in general, although some applications for municipal uses (such as Canyon and Amarillo in our example) could be worthwhile. The greatest benefit from artificial recharge



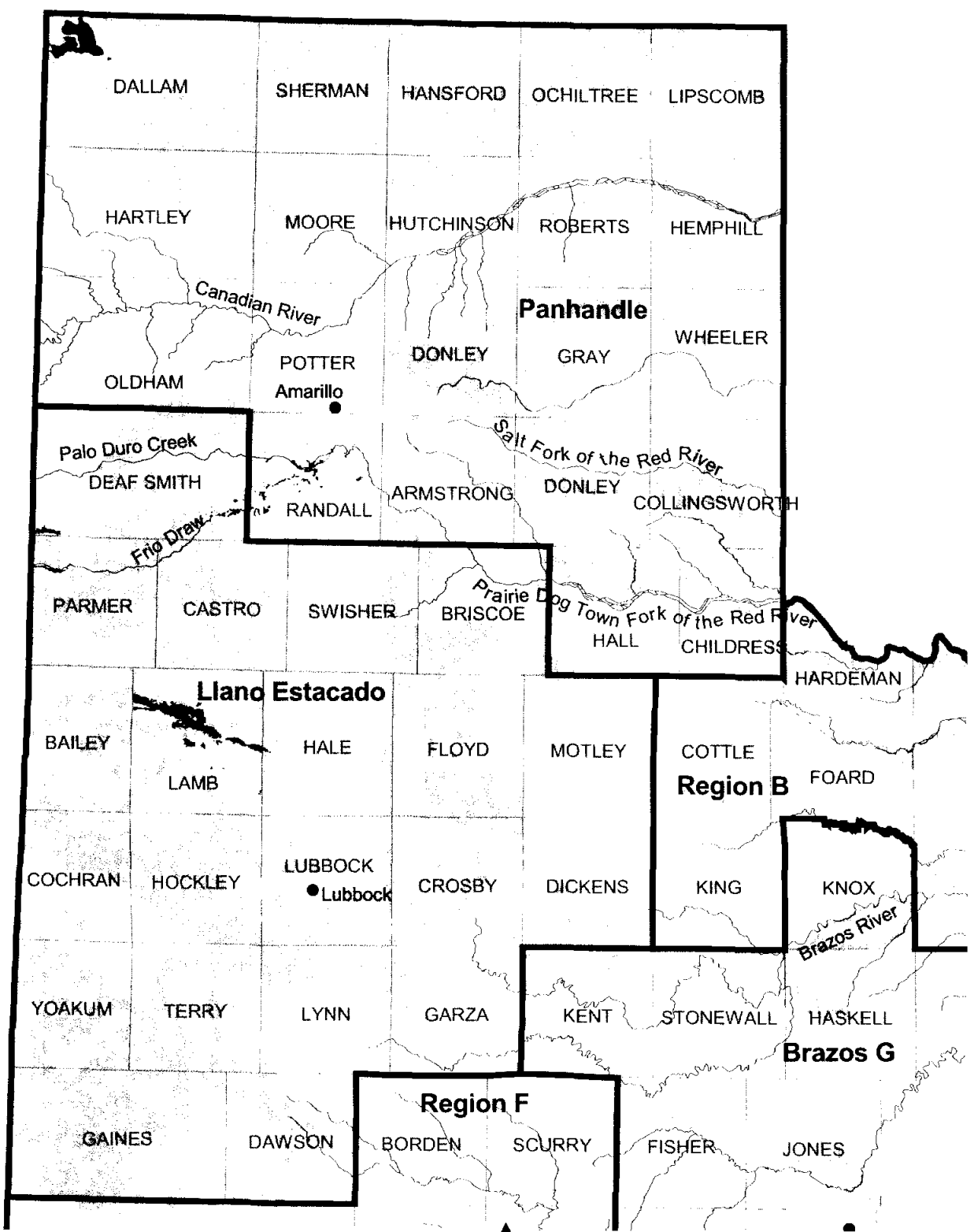
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on the High Plains would probably be obtained from enhanced recharge at playas in or immediately adjacent to regions of irrigated agriculture.



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**Explanation**

- City
- △ River or stream
- ▭ Regional Water Planning Area
- ▭ County
- ▨ Suitable recharge area
- ▨ Irrigated farm land
- ▭ County selected for site-specific analysis



0 17.5 35 Miles

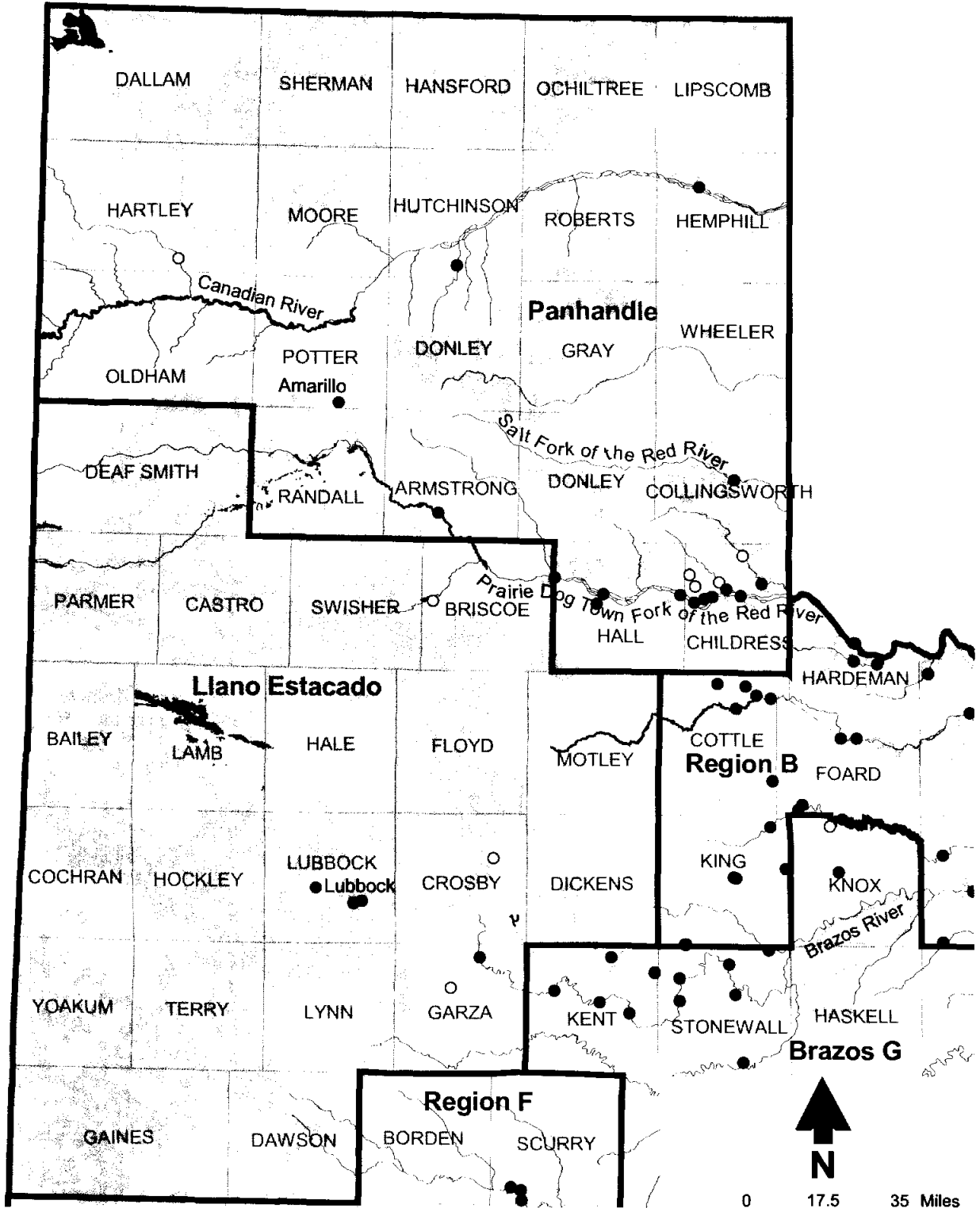
**IDENTIFICATION OF GEOGRAPHIC AREAS  
SUITABLE FOR GROUNDWATER BANKING  
Ogallala Suitable Recharge Areas**



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Figure 36

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**Explanation**

- City
- ⚡ EPA designated impaired stream
- ⚡ River or stream
- ▭ Regional Water Planning Area
- ▭ County
- ▭ Suitable recharge area
- ▭ Irrigated farmland
- ▭ County selected for site-specific analysis

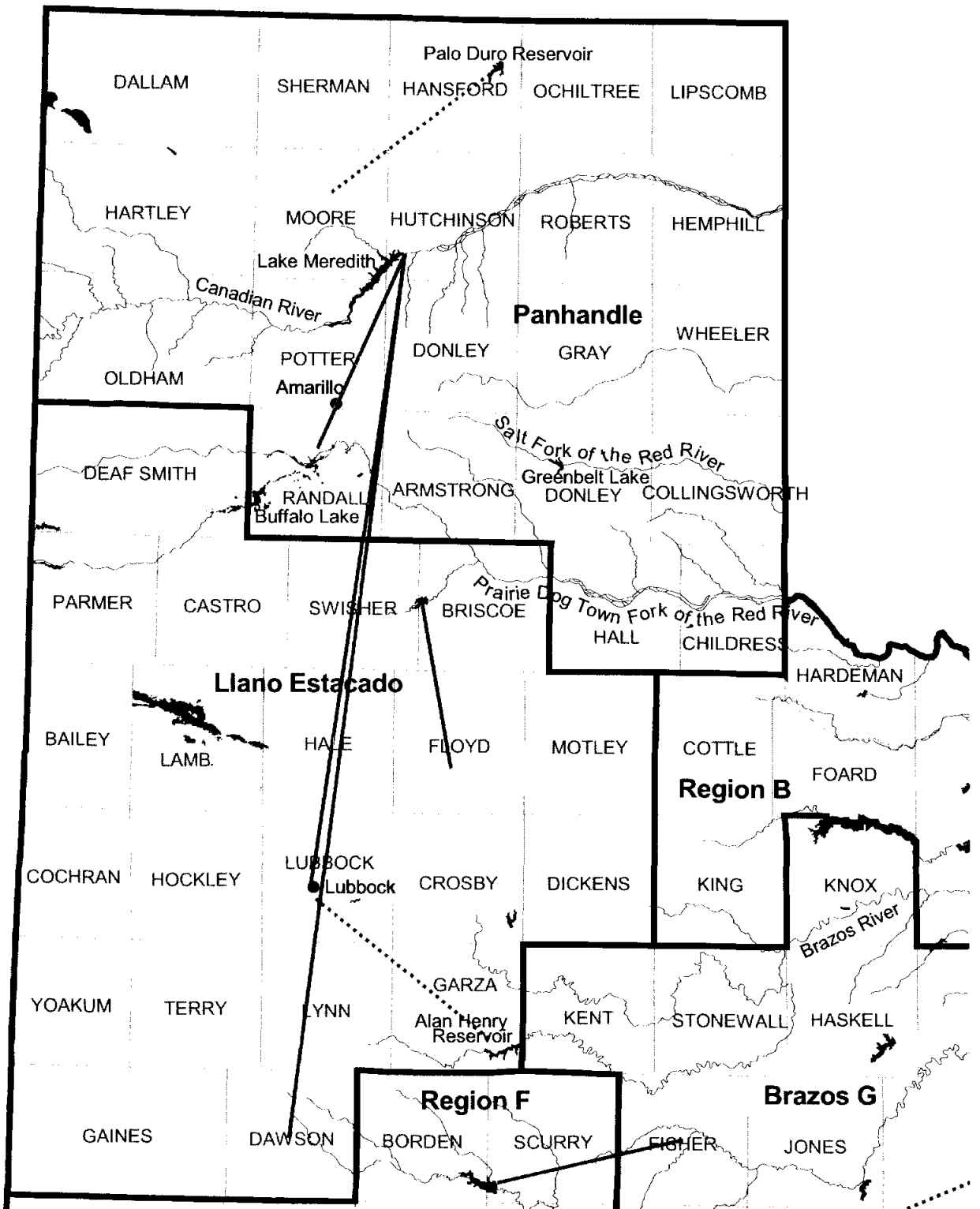
Sample locations where the following analytes exceeded EPA primary drinking water standards during period of record:

- Fluoride
- Chloride
- TDS

**IDENTIFICATION OF GEOGRAPHIC AREAS  
SUITABLE FOR GROUNDWATER BANKING  
Ogallala Water Quality**

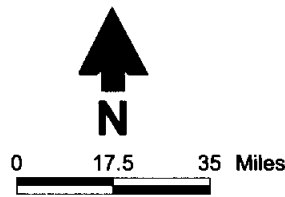


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**Explanation**

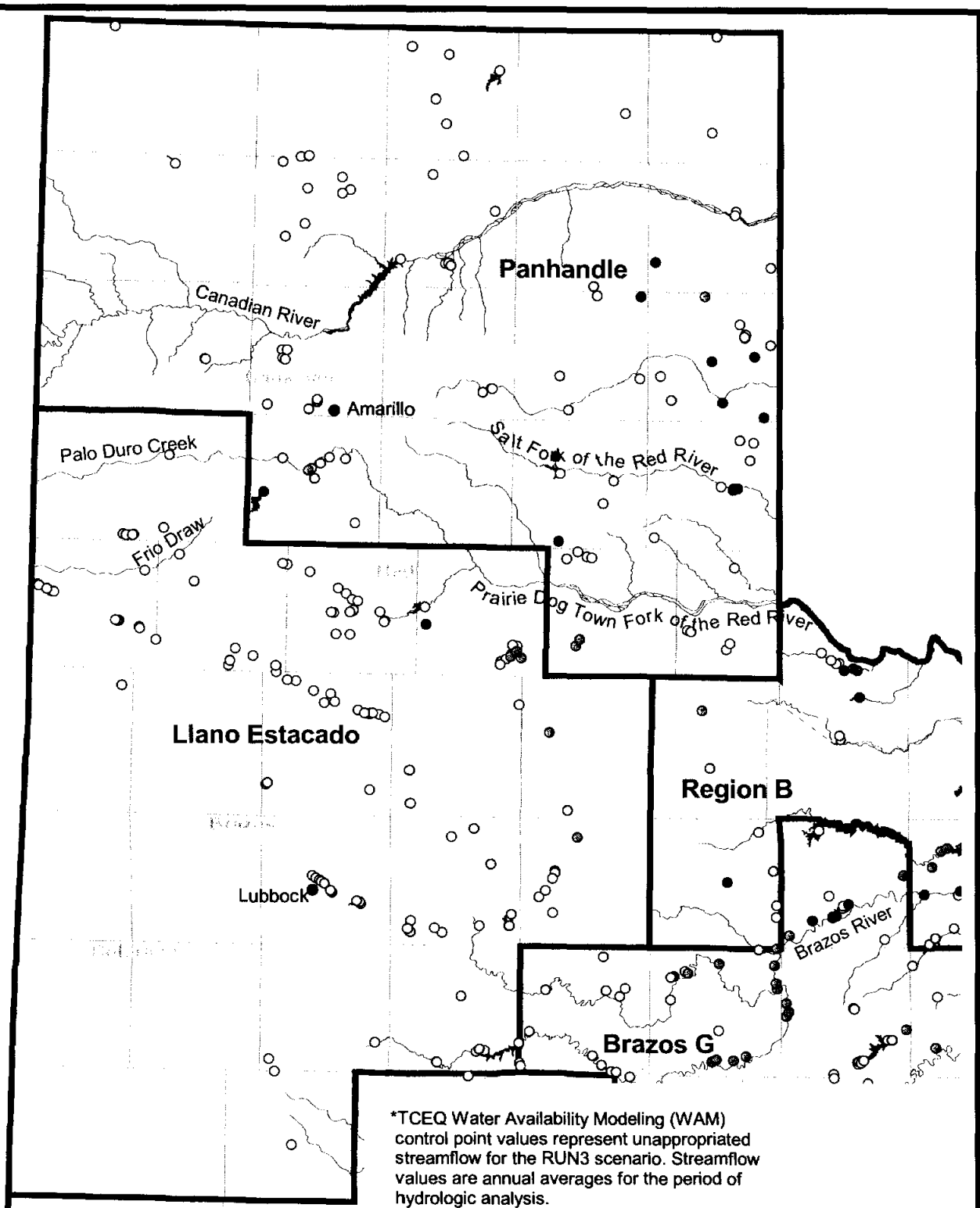
- Existing conveyance
- Proposed conveyance
- Reservoir
- Suitable recharge area
- City
- River or stream
- Regional Water Planning Area
- County



**IDENTIFICATION OF GEOGRAPHIC AREAS SUITABLE FOR GROUNDWATER BANKING Ogallala Reservoirs and Conveyances**



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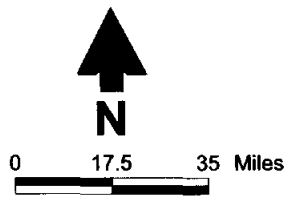


\*TCEQ Water Availability Modeling (WAM) control point values represent unappropriated streamflow for the RUN3 scenario. Streamflow values are annual averages for the period of hydrologic analysis.

**Explanation**

- City
- WAM control point (ac-ft/yr)\*
  - 0 - 1,000
  - 1,000 - 25,000
  - ⊙ 25,000 - 100,000
  - 100,000 - 500,000
  - 500,000 - 900,000

- Regional Water Planning Area
- ▭ Drainage basin
- Reservoir
- ▭ County
- ~ Major river
- WAM stream network



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**IDENTIFICATION OF GEOGRAPHIC AREAS  
 SUITABLE FOR GROUNDWATER BANKING  
 Ogallala Surface Water Availability**

Figure 39

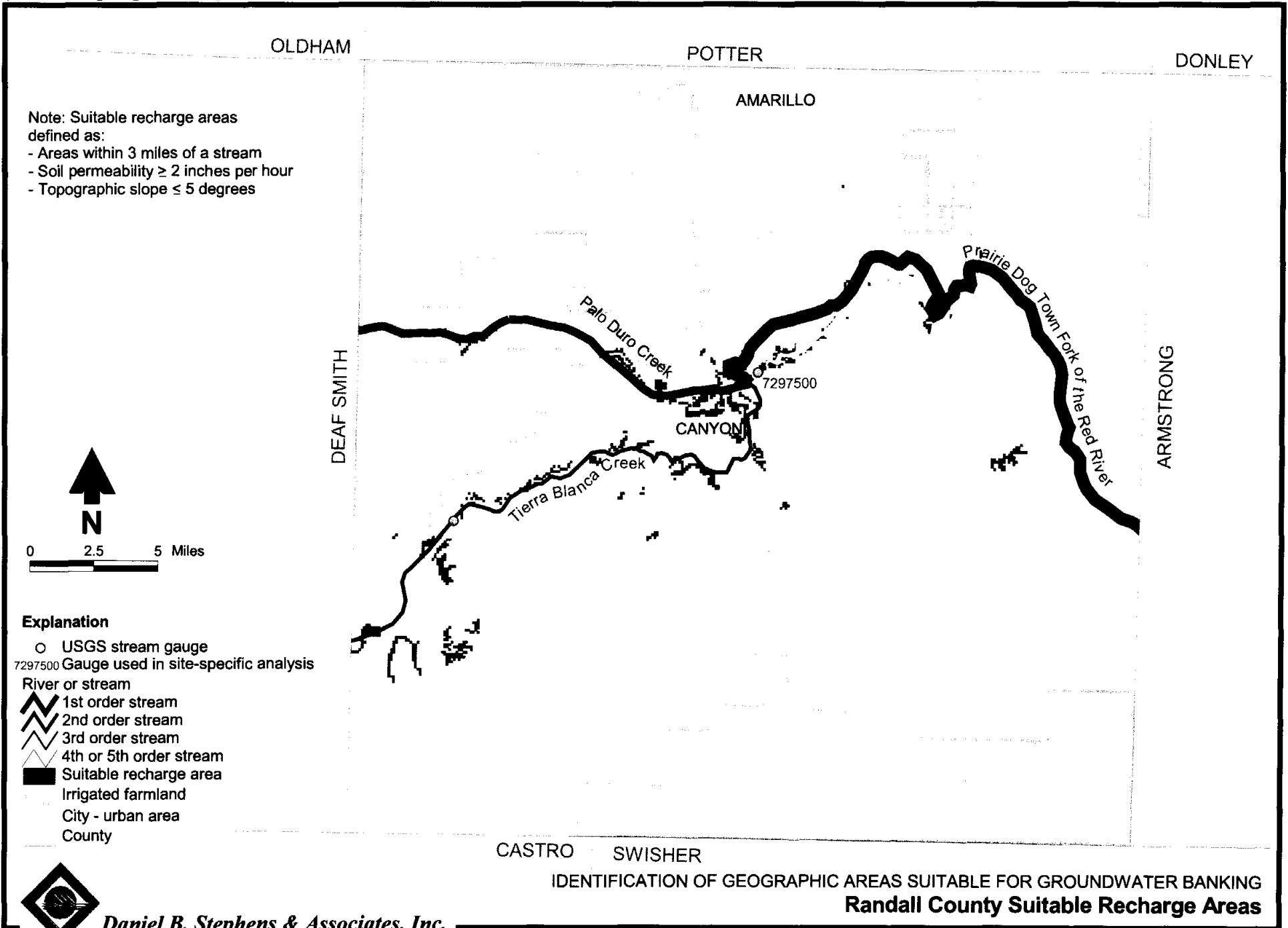
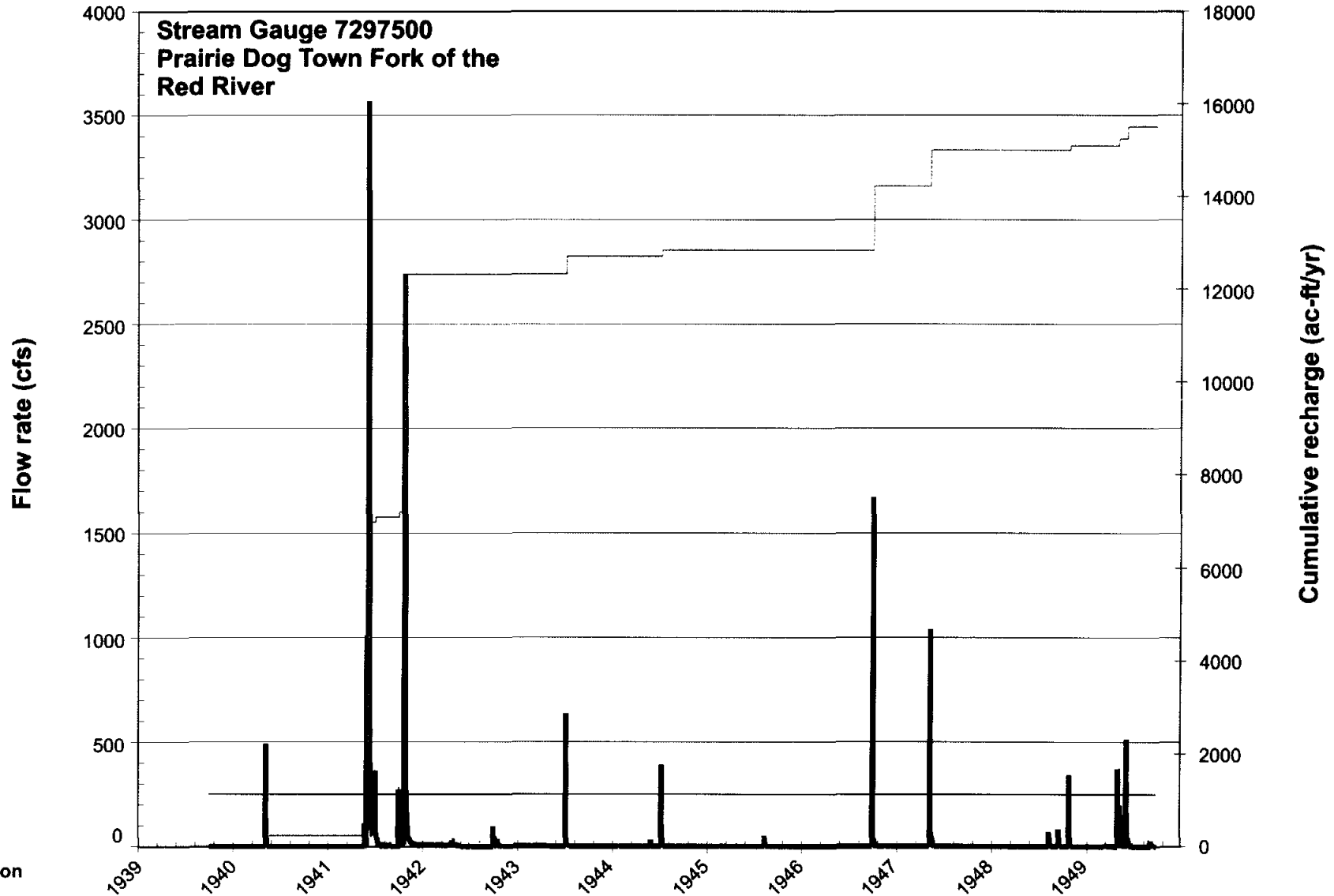





Figure 40





**Explanation**

-  Observed stream flow
-  Threshold
-  Calculated cumulative recharge

**Notes:**

Recharge area: This scenario calculates the cumulative infiltration of water based on a hypothetical recharge basin of 100 acres.

Figure 4.1





## 9. Far West Texas Region

El Paso County was the only selected county from the Far West Texas RWPA (Region E) (Figure 42). Most of the population (96 percent) of the region resides in El Paso County.

### 9.1 Water Resources Overview

El Paso and Hudspeth Counties account for the majority of irrigation demand (Figure 42) in the Far West Texas Region, although irrigation demand in El Paso County is projected to decrease from 179,842 ac-ft in 2000 to 152,014 ac-ft in 2050. El Paso County is responsible for 66 percent of the current 509,426 ac-ft of water used each year. Municipal water use in El Paso County is expected to nearly double in the next 50 years, from 101,928 ac-ft in 2000 to 199,097 ac-ft in 2050. Water supply projections for the region are shown in Table 13. Surface water quality data are summarized on Figure 43.

**Table 13. Projections for El Paso County in the Far West Texas Region**

County	SSURGO Soil Data Available	Projected Water Supply <sup>a</sup> (ac-ft/yr)						Acreage Suitable for Recharge <sup>b</sup>
		2000	2010	2020	2030	2040	2050	
El Paso	Yes	-118,727	-87,908	-67,526	-376,072	-392,139	-412,237	44,658

<sup>a</sup> Negative values indicate a deficit in supply

ac-ft/yr = Acre-feet per year

<sup>b</sup> Identified through site-specific analysis described in this report.

SSURGO = Soil Survey Geographic database

The Rio Grande is the major surface water source in the region. Below the El Paso-Hudspeth County line, river flow is primarily irrigation return flow and storm runoff. Groundwater is the major source of water in the region, and the Hueco-Mesilla Bolson is the major aquifer. Large-scale groundwater withdrawals by the cities of El Paso and Juarez have led to severe declines in the aquifer.

Figure 44 shows the existing and proposed conveyances in the region. The Rio Grande Compact provides for the distribution of the waters of the Rio Grande among Colorado, New



Mexico, and Texas above Fort Quitman, Texas. The Compact sets out a schedule of the water-delivery obligation of Colorado at the Colorado-New Mexico state line and requires New Mexico to deliver water to Elephant Butte and Caballo Reservoirs as the deliveries to Texas. Releases from the reservoirs are measured downstream of Caballo Reservoir in south-central New Mexico.

The Rio Grande Project is an irrigation storage and flood control federal reclamation project administered by the U.S. Bureau of Reclamation. The El Paso County Water Improvement District (EPCWID) No. 1 encompasses the project lands in El Paso County, Texas (LBG-Guyton Associates et al., undated). The only viable surface water resource in El Paso County is the Rio Grande. The EPCWID irrigation ditch network is a potential surface water conveyance resource for potential groundwater banking.

## **9.2 Rate, Area, and Time Period for Infiltration**

El Paso County has large areas suitable for recharge (Figure 45), but although the Rio Grande is a first-order stream, very little, if any, water is currently available due to prior appropriations. The TCEQ has not completed the WAM study for the Rio Grande Basin. However, Figure 45 can be used to suggest areas to reserve for recharge of existing well fields should water be made available.

In the El Paso area, there are virtually no opportunities for constructing surface reservoirs; therefore, aquifer storage is the only alternative. Aquifer storage recharge has been considered by the El Paso Water Utility as a method to provide seasonal storage of surplus treated wastewater effluent and to help restore the Hueco Bolson (Basin) in northeast El Paso. The Hueco Basin is the primary source of water for the City of El Paso, Fort Bliss, Biggs Air Force Base, Ciudad Juarez, and private industries in the area. As a result of long-term pumping to supply this water, groundwater levels in the basin have declined as much as 150 feet since 1903 (Ashworth, 1990). Low-cost recharge provides a method of extending the life of existing well fields in El Paso and elsewhere.





Since the mid-1980s the Hueco Basin has been successfully recharged at modest rates (up to about 10,000 ac-ft/yr) through deep injection wells. The concept of subsurface storage of water as a means of sustaining and/or increasing the water supply available in the area northeast of El Paso was presented in a report prepared by Boyle Engineering Corporation and Parsons Engineering Science, Inc. (1995). This report concluded that the northeast El Paso area appears to have conditions suitable for implementation of large-scale recharge. The area affords ample underground storage space and reasonably high assurances of long-term recovery of stored water. The lowering of water levels in the Hueco Basin has created a substantial depression in the water table into which the recharge water can be placed. The report also concluded that large-scale recharge provides an opportunity to mitigate aquifer overdraft and potentially restore groundwater supplies for continued use (Boyle and Parsons, 1995).

DBS&A and Boyle Engineering have performed a recharge study for the City of El Paso and the American Water Works Association Research Foundation (Hahn et al., 2002) that aims to locate and optimize recharge basin performance for the City of El Paso. The area of investigation, in the northern portion of a cone of depression that has developed around a major pumping center serving the City of El Paso, is well suited for both short-term and long-term groundwater storage. In July 2001, a recharge basin was excavated below a surface caliche layer, and recharge has averaged more than 8 ft/d since construction.

This high-performing site provides an example of how a Boolean query using low-resolution data can miss an excellent recharge location that the same query using high-resolution data would find. The site was missed by our query because it is too far from a natural water source and the slope of the site was identified as too steep. Analysis of high-resolution DEM data at the site would show what field reconnaissance showed, that is, the slope is workable.

Figure 46 illustrates computations of banked water for Gauge 8363840 on the Rio Grande north of Canutillo (Figure 45). The average permeability for this site was determined to be 8 ft/d. Calculated cumulative recharge for a 100-acre basin is about 60,000 ac-ft over a 5-year period, which is appreciable. As indicated on Figure 46, this calculation assumes that one-half of the water greater than the 600-cfs threshold value is available for banking. Flow at this gauge is



clearly seasonal, with releases from upstream reservoirs, along with contributions to flow from late summer thunderstorms, accounting for peak flows during the growing season. Based on the hydrograph record, the required area to bank all available water as determined using the Rio Grande gauge is 24 acres, and the average time available for infiltration is 9.2 days.

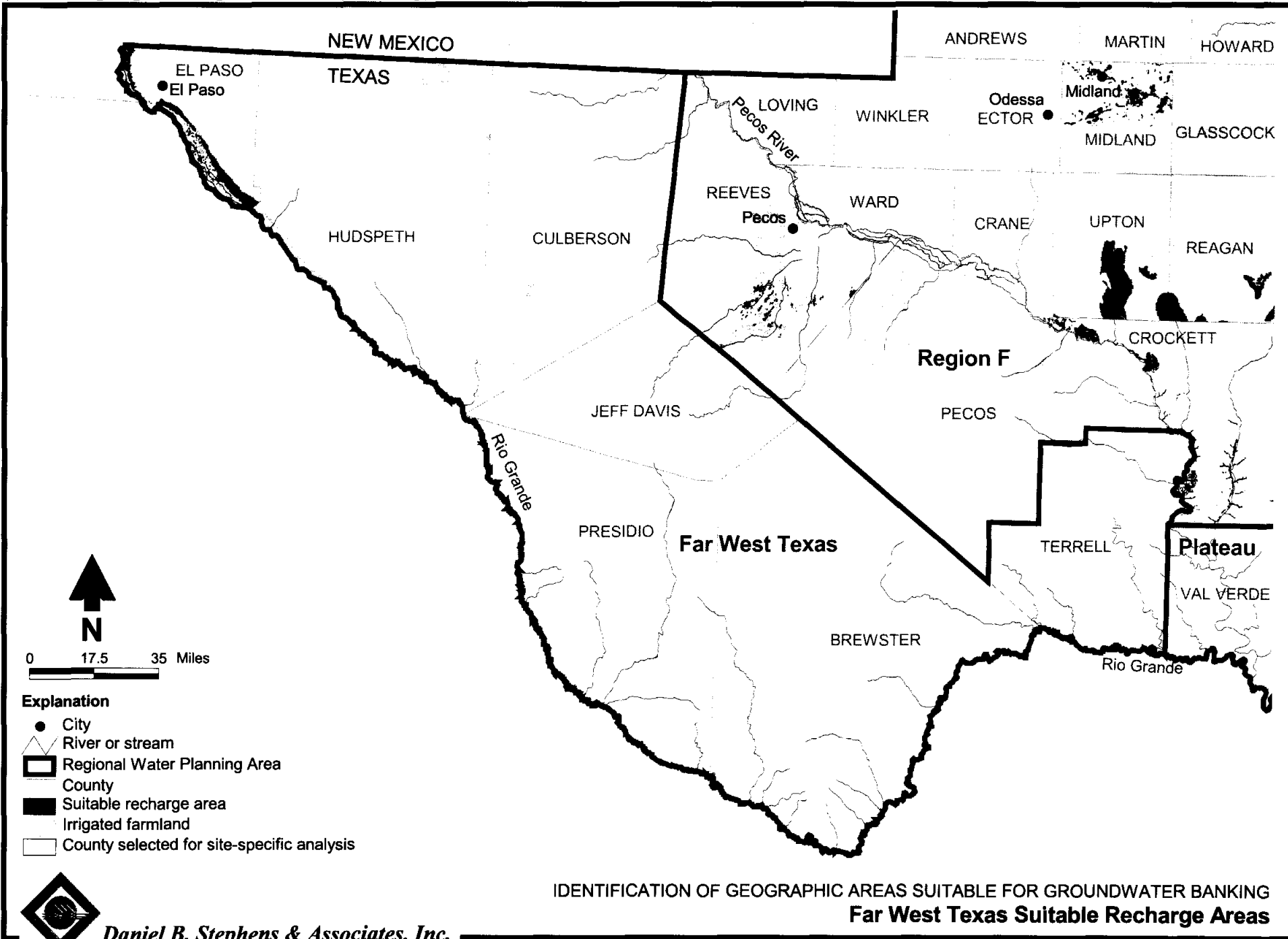
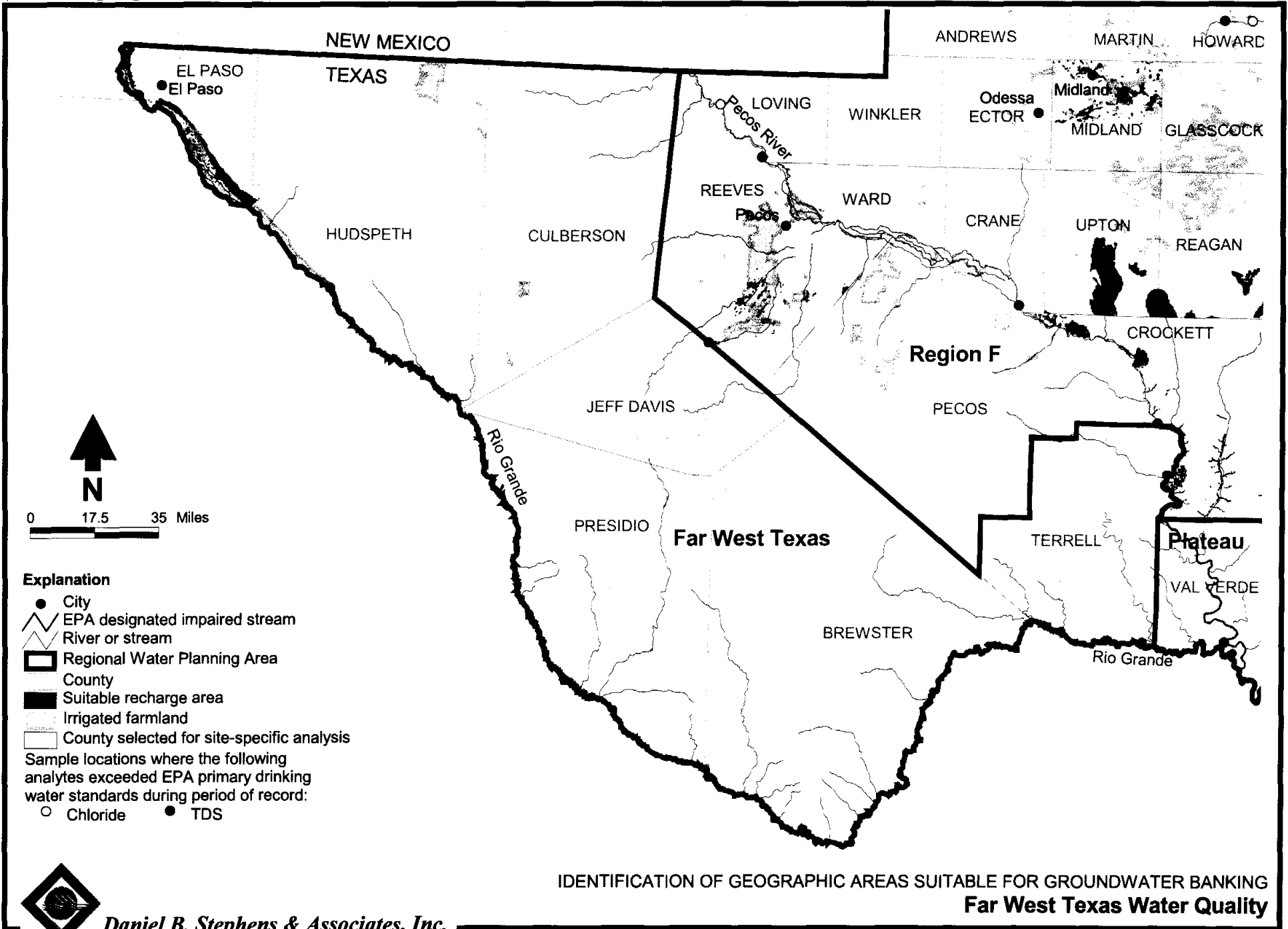


Figure 42





IDENTIFICATION OF GEOGRAPHIC AREAS SUITABLE FOR GROUNDWATER BANKING  
**Far West Texas Water Quality**

Figure 43

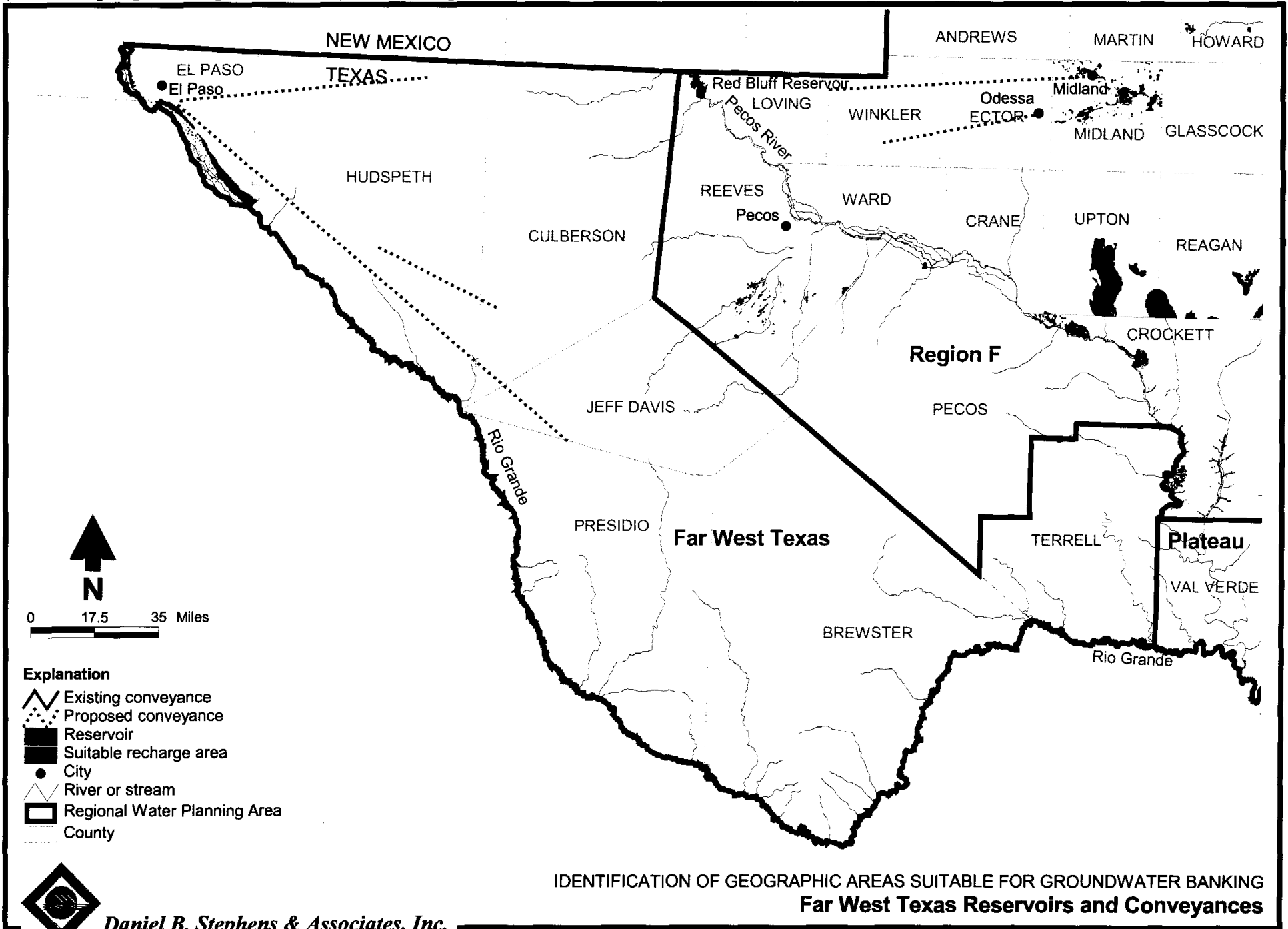


Figure 44



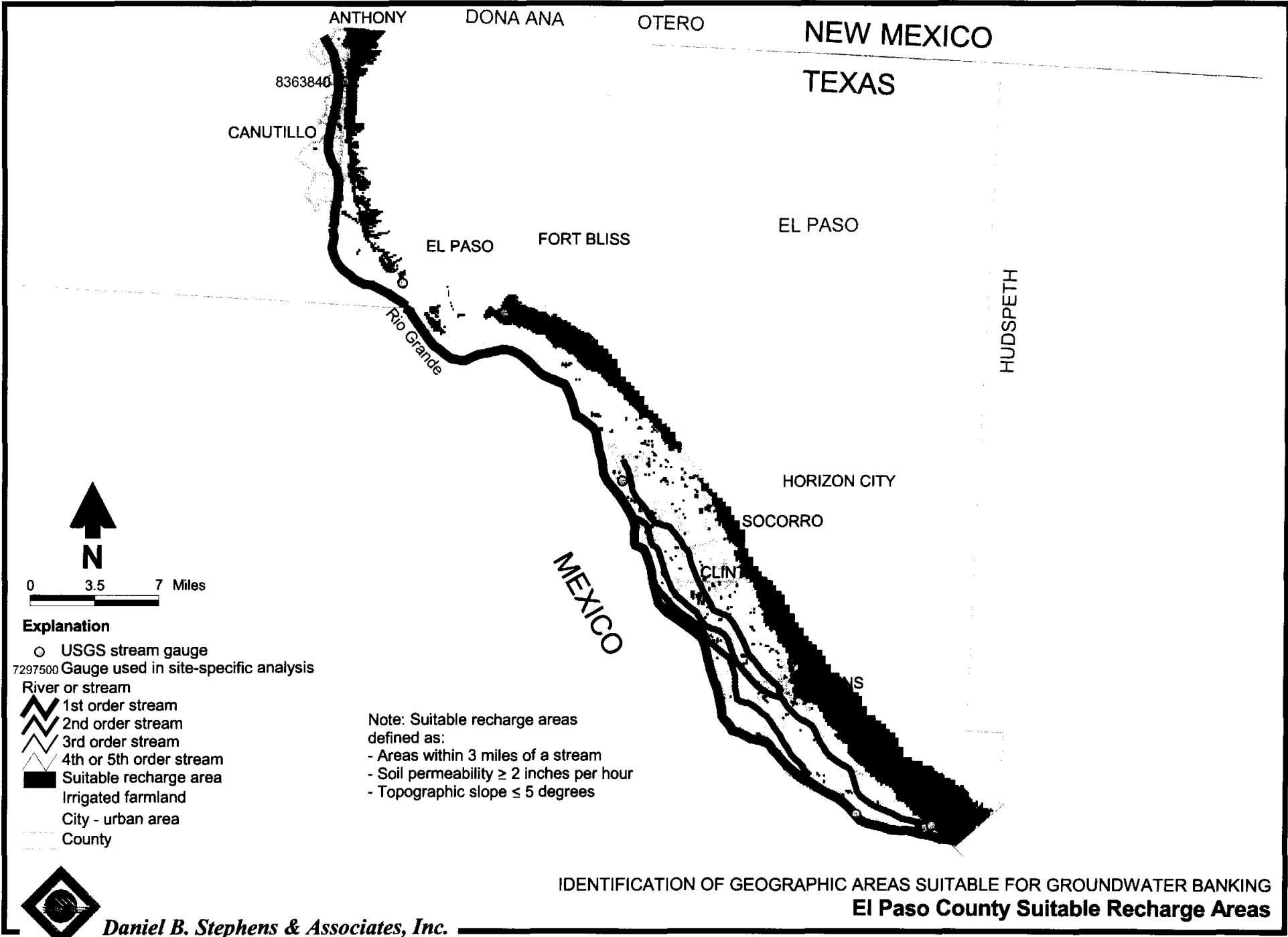
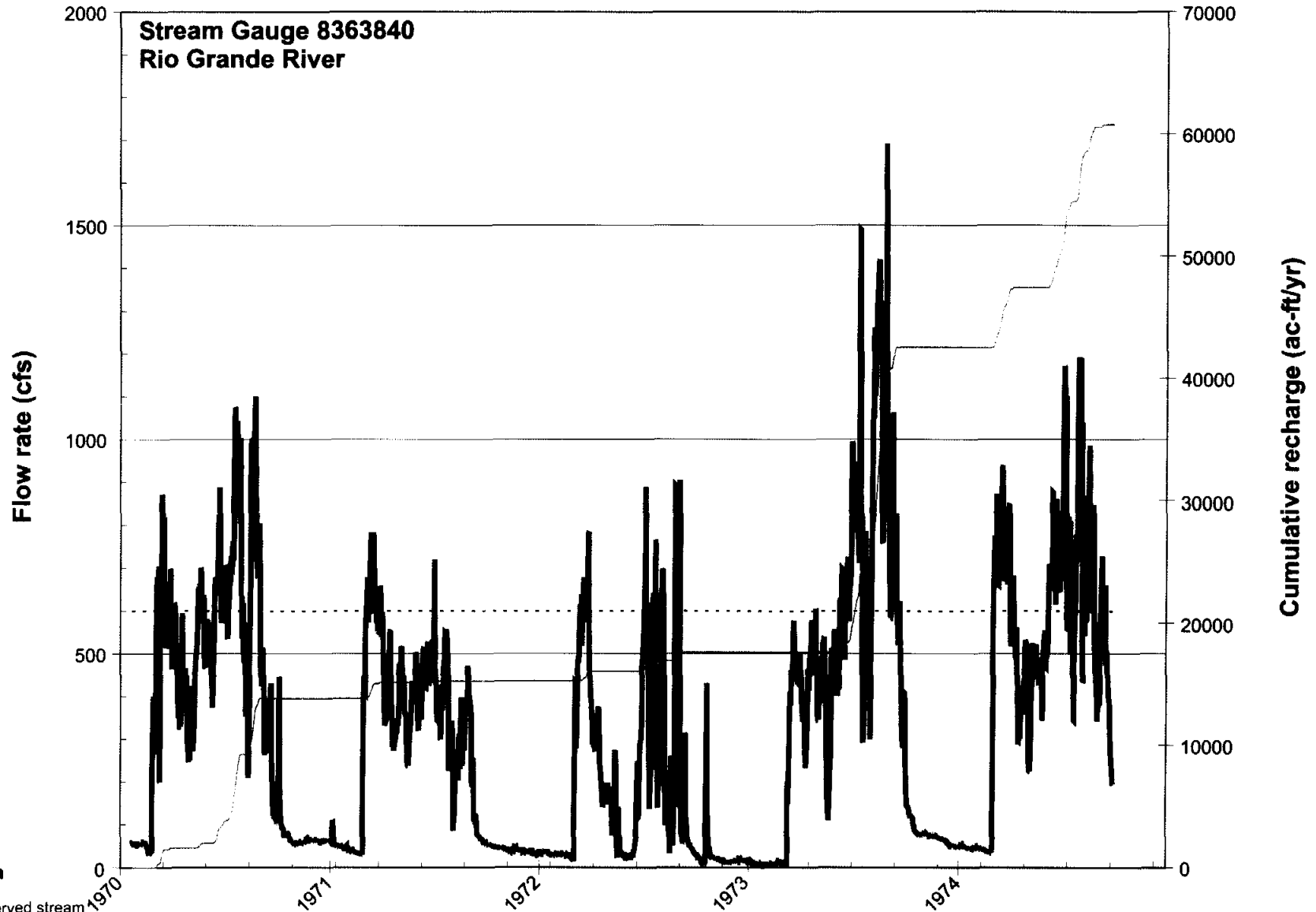


Figure 45



IDENTIFICATION OF GEOGRAPHIC AREAS SUITABLE FOR GROUNDWATER BANKING  
El Paso County Suitable Recharge Areas



**Notes:**  
Recharge area: This scenario calculates the cumulative infiltration of water based on a hypothetical recharge basin of 100 acre feet.

IDENTIFICATION OF GEOGRAPHIC AREAS SUITABLE FOR GROUNDWATER BANKING  
**Available Recharge Hydrograph for USGS Stream Gauge, El Paso County**

Figure 46





## **10. Conclusions and Recommendations**

The primary goal for this study was to identify areas suitable for groundwater banking (recharge of excess surface water to an aquifer from surface or near-surface infiltration for use at a later date) within the state of Texas. An additional goal was to develop and provide a tool that would allow other users to select potentially suitable sites based on their unique circumstances.

Using a statewide screening analysis, we concluded that 48 counties fit the criteria for preliminary site-specific evaluation of recharge basin suitability (Table 1, Figure 8). The 48 counties were grouped into 6 regions, and one county from each region was selected for more detailed, site-specific analysis. Because the statewide screen for high-demand regions was performed at the county level, potentially suitable sites in counties with lower demand were excluded from further analysis. Initially, the statewide screen included water quality, regional water demand, aquifer characteristics (recharge areas and depth to water), distance from surface water, and topographic slope. However, once available data sets were evaluated, it was concluded that the water quality, distance from surface water, and topographic slope screens were more appropriately applied at the site level.

Users can conduct a screening analysis similar to that documented in this report using the ArcView GIS 3.2 Screening Analysis Tool developed as part of this project, described in Appendix C. The GIS tool was developed to assist users with application of custom screening criteria for site selection.

Within each selected region, we used the GIS Screening Analysis Tool to identify areas with soil permeability greater than or equal to 2 inches per hour, slopes of less than 5 degrees, and locations within 3 miles of a designated stream. Other factors, including surface water quality, water availability, and time period in which recharge could occur, were considered in the site-specific analysis but were not applied directly to include or exclude potential water banking sites. Water availability was estimated using TCEQ WAM model results along with one or more hydrographs selected from available stream gauges near potentially suitable sites.





Detailed site-specific screening was conducted for an example county from each region, selected on the basis of data availability including the higher-resolution SSURGO soil data and the presence of at least one surface water gauging station reasonably near potential recharge sites. In addition to the detailed screening, infiltration was calculated for one or two hypothetical basins in each example county; the results of these sample calculations are summarized in Table 14.

Specific findings and conclusions related to each region are provided in Sections 10.1 through 10.6. Additional recommendations and conclusions are provided in Section 10.7.

## **10.1 South Central Texas Region**

The South Central Texas region is perhaps the most suitable region in Texas for groundwater banking. Water deficits are projected to occur by 2050 for a large number of counties in the region. The unconfined sections of the Edwards and Edwards-Trinity Aquifers are well suited in many areas as potential recharge sites. Due to the dynamic nature of groundwater flow in the Edwards Aquifer, recharge to this aquifer is likely not recoverable near the source, but should be viewed as an additional recharge component to the regional aquifer system. A number of potential recharge sites also overlie the Carrizo-Wilcox aquifer outcrop area.

Bandera, Medina, and Bexar Counties all have potential banking locations along stretches of the Medina and San Antonio Rivers. However, because stretches of both these rivers are impaired, potential water quality impacts should be evaluated as part of any further consideration of these sites for groundwater banking. Zavala and Dimmit Counties, both of which have projected water deficits, have several small potential sites along the headwaters of the Nueces River, including El Morro, Comanche, and Capote Creeks. WAM data show significant water availability along these streams.

Uvalde County, which was selected for more in-depth screening because of the available SSURGO soil and streamflow hydrograph data, has many potential recharge locations along the river valleys and tributary reaches of the Nueces and Frio Rivers, as well as a lesser number of



**Table 14. Summary of Site-Specific Infiltration Calculations for Selected Counties**

Region	Example County	Gauge	Available Time Period for Infiltration (days)	Sample Infiltration Calculations <sup>a</sup>		
				Threshold Flow (cfs) <sup>b</sup>	Period	Cumulative Volume (ac-ft)
South Central Texas	Uvalde	Nueces River	5	850	1990-1999	50,000
		Frio River	8	450	1990-1999	75,000
Brazos	Coryell	Leon River	5	2,000	1991-2001	34,000
Region C	Parker	Brazos River	6	3,250	1991-2001	225,000
		Clear Fork of the Trinity River	6	100	1991-2000	22,500
Region F	Reeves	San Solomon Springs	57	35	1956-1966	1,150
		Barilla Draw	2	0	1976-1984	5,000
Ogallala	Randall	Prairie Dog Town Fork of the Red River	3	250	1940-1950	15,800
Far West Texas	El Paso	Rio Grande	9	600	1970-1975	60,000

<sup>a</sup> Infiltration calculations assumed a basin area of 100 acres except for Coryell County where 50 acres was used.

<sup>b</sup> Water available for infiltration assumed to be one-half the streamflow above the threshold value.

cfs = Cubic feet per second  
ac-ft = Acre-feet



areas along the Sabinal River. These locations are primarily upstream from Uvalde and Sabinal, the major towns in the county.

Recharge computations were conducted using two observed hydrographs, one from a gauge on the Nueces River in the southern part of the county and the other from a gauge on the Frio River in the northern part of the county. Both gauges are close to potentially suitable recharge sites. The Nueces River site overlies the Carrizo-Wilcox Aquifer outcrop area, and the Frio River overlies the Edwards-Trinity Aquifer. Assuming 100 acres of infiltration basin area at each site, calculated cumulative recharge over 10 years is about 50,000 ac-ft for the Nueces River gauge and about 75,000 ac-ft for the Frio River site. Computed time periods for infiltration are about 5 days for the Nueces gauge and 8 days for the Frio River gauge.

## **10.2 Brazos Region**

The site-specific analysis identified only one potential recharge location in the three counties in the Brazos region selected by the statewide screening. This 80-acre site is in Coryell County, on the Leon River upstream from Gatesville and Belton Lake. Analysis using a hydrograph from the gauge at Gatesville indicated potential infiltration of about 34,000 ac-ft over a 10-year period for a 50-acre basin. The average time period for infiltration at this site was determined to be about 5 days.

This location could be ideal for groundwater banking as it is upstream from the major population center of the county and it meets all initial screening criteria. Because of the limited available acreage, such a site might be reserved as a future recharge facility. However, since this stretch of the Leon River has been designated as an impaired stream, potential water quality impacts should be evaluated as part of any further consideration of this site for groundwater banking.

Williamson County should be analyzed further, as it is one of the fastest growing counties in the nation (HDR Engineering, Inc., 2001). In our analysis, no suitable locations were identified because of the criteria for distance from streams and rate of infiltration. However, the rate of infiltration should be evaluated in greater detail, because some of the sites excluded on this basis might be acceptable recharge locations if the uppermost layers of soil are excavated.



### **10.3 Region C**

Of the two counties selected for site-specific analysis in Region C, high-resolution SSURGO soil data are available for only one, Parker County. While the site-specific analysis identified many potential groundwater banking locations in Parker County, the soil infiltration characteristics derived from the STATSGO data in Wise County did not meet the screening criteria.

Parker County recharge sites are scattered along the Brazos River in the southwestern portion of the county, along Rock Creek in the northwestern portion of the county, and along Willow Creek and the Clear Fork of the Trinity River in the central and north-central portions of the county. Many of the potential banking sites identified in Parker County are well situated because they are near and upstream of population centers; however, the availability of good-quality recharge water limits the usefulness of some of these sites.

WAM model data indicate up to 8,500 ac-ft/yr of available water on Rock Creek near Mineral Wells, although the smaller tributaries in this region have available flows of less than 100 ac-ft/yr. The WAM model data show excess flows of more than 400,000 ac-ft/yr along the Brazos River above Lake Granbury. Site-specific recharge analysis using a Brazos River hydrograph in the southeastern portion of the county, very close to several potential recharge sites, indicated potential infiltration of 225,000 ac-ft over a 10-year period.

Sites along Willow Creek could be potentially viable recharge sites for meeting the future needs of Weatherford, Texas. Willow Creek WAM data indicate excess flows of about 1,800 ac-ft/yr.

Recharge sites along the Clear Fork of the Trinity River are likely unsuitable for banking due to the amount and water quality of flows in the Clear Fork of the Trinity River above Lake Weatherford.

### **10.4 Region F**

The primary need for future water development in Region F will be near the population centers of Midland, Odessa, Pecos, and San Angelo in Midland, Ector, Reeves, and Tom Green



Counties, respectively. Potentially suitable locations exist in three of these counties as well as in some of the rural agricultural counties in the region. Tom Green County failed to meet the final screening criteria of the site-specific analysis; however, no SSURGO data are available for this county, and potential recharge locations might be missed due to lack of data.

Based on our site-specific screening, Midland County has a large area of potentially suitable locations near the City of Midland. Ector County has a fairly large site in the eastern portion of the county, in and around the City of Odessa. However, potentially available surface water for banking in these areas is very small (less than 630 ac-ft/yr on average, according to WAM model data in Midland and Ector Counties). Kimble County has several potential locations along the Llano River and its tributaries. WAM model data from the Llano River show excess surface water of more than 46,000 ac-ft/yr on the river and more than 1,000 ac-ft/yr on some of the river's smaller tributaries.

Reeves County was selected for detailed infiltration calculations; only a few small potential recharge areas throughout the central and southeastern portions of the county were identified. As illustrated by the Barilla Draw gauge, water available for banking along most of the area's streams originates in short-duration, infrequent storm events and the capture of this water may be difficult. According to calculations, about 5,000 ac-ft of water might have been banked over an 8-year period at the Barilla Draw gauge. However, the average duration of flow at this gauge is about two days, and most of the 5,000 ac-ft would have come from only two storm events.

Opportunities for efficient banking of water from springs may exist, particularly following wet periods where spring flows are higher than normal. This water would be ideal for banking because it is potentially available over extended time periods and, unlike tributary storm flows, would not be laden with suspended sediment. However, volumes of water available for banking from springs is likely to be small, as indicated by analysis of the San Solomon Springs gauge data, which indicated that only 1,150 ac-ft of water might be banked over a period of 10 years. Ward County has a large site identified as potentially suitable near the Pecos River, south of the City of Monahans. Additional suitable locations may exist in this region along the northern side of the Pecos River that were not identified because only low-resolution STATSGO data are available for Loving County.



## **10.5 Ogallala Region**

The primary use of water in counties that overlie the Ogallala Aquifer is for irrigated agriculture. Most of the region that overlies the Ogallala Aquifer drains internally to thousands of playas, each of which has its own drainage area. Therefore, any large-scale recharge program should incorporate some type of playa modification or enhancement within or adjacent to irrigated areas, the benefits of which could be significant.

The site-specific screening analysis indicates that potentially suitable recharge sites are present along several of the draws that cross the High Plains. However, these draws flow only during large storm events, and the volume of water that can be practically captured for banking is small compared to demand in the region. For example, the site-specific analysis for the Prairie Dog Town Fork of the Red River gauge in Randall County, where the estimated 2050 deficit is more than 72,661 ac-ft/yr, indicated that only about 16,000 ac-ft of water could have been banked over a 10-year period, about 80 percent of which came from two storm events during one year of record precipitation.

In addition, previous studies have indicated that a significant portion of storm flows along the draws infiltrates and recharges the Ogallala Aquifer naturally. Therefore, groundwater banking of water from stream courses on the High Plains that overlie the Ogallala Aquifer is probably not an efficient approach to take in general, although there could be local applications, such as municipal use.

## **10.6 Far West Texas Region**

El Paso County, which was the only county selected for site-specific analysis in the Far West Texas Region, is the most populous in the region. The TCEQ has not yet completed the water availability study for the Rio Grande Basin, so WAM results were not available for review as part of this study. Although the Rio Grande is a first-order stream, probably very little if any water is currently available that is not already appropriated. Irrigation structures in the Rio Grande Valley, from the New Mexico-Texas state line to El Paso and from El Paso into Hudspeth County, could potentially serve as conveyance for groundwater banking projects.



Site-specific analysis indicates that a substantial area, primarily within and immediately adjacent to the Rio Grande Valley, is potentially suitable for groundwater banking if water is made available. Example calculations for a Rio Grande hydrograph record several miles upstream of El Paso indicated that 60,000 ac-ft of water could be banked using a 100-acre basin over 5 years.

Because of the 3-mile distance from surface water used as a criterion in the site-specific analysis, the only sites identified in El Paso County were along the Rio Grande. However, very permeable soil exists throughout the Far West Texas Region, and various methods for moving water longer distances should be explored before totally excluding an area for groundwater banking.

## **10.7 Recommendations and Additional Research**

The methods applied and the associated results documented in this report highlight (1) the effects of the various types of screening criteria applied to determine suitable regions for groundwater banking and (2) the utility of the GIS tool for conducting alternative queries and screens of the data. Clearly, users from different geographic areas will have different priorities regarding screening criteria. The methodology presented in this report is useful not only for the screening results documented herein, but also for its flexibility in allowing other users to manipulate the screens according to their own needs. Thus the report can be used as a template for identifying suitable sites for groundwater banking and a guide in determining some of the key factors that should be considered.

Evaluation of sites for the alternative recharge techniques discussed in Section 1 (e.g., infiltration through dry wells or aquifer storage and recovery) was beyond the scope of work for this project. However, the GIS tool used for this study is potentially useful in evaluating potential sites where some of these other recharge techniques might be applied.

Prior to implementation of an actual recharge basin or series of basins, a formal feasibility study should be conducted that addresses, at a minimum, the following factors:



- Evaluation of site-specific stream hydrographs (observed or synthetic) to determine water availability, including the frequency and duration of peak (storm) flows
- Evaluation of the amount of prior appropriations on a given stream course and other water requirements, such as requirements for in-stream flows and freshwater inflows to bays and estuaries
- Detailed characterization of site-specific permeability of near-surface soils and deeper geologic units
- Evaluation of topographic slope and potential pathways for conveying surface water to the recharge basin (for off-channel systems)
- Evaluation of sediment load and surface water quality as a function of stream discharge

Consideration of the above factors was outside the scope of work for this project. Acquisition of such data would facilitate better recharge facility design and better predictions of long-term facility performance. However, lack of such data should not unduly impede pilot projects. Stream gauges can provide data useful for evaluation of available water at particular stream locations and for scaling up pilot projects. Periodic sampling under changing flow conditions (which can dramatically affect the concentrations of many dissolved to suspended constituent chemical species) can provide useful background information on water quality.

High-resolution soil data such as the SSURGO soil database will be required, at a minimum, to analyze the rate of infiltration. However, soil survey data pertain only to near-surface soils, and more in-depth data from soil borings would be necessary for a site feasibility study. If more in-depth soil analysis determines that near-surface permeability adequate for recharge is available at depths slightly deeper than those analyzed in the SSURGO data, excavation of the top layer of soil is an option.

The WAM data are still preliminary and not entirely complete. The Rio Grande Basin WAM will not be completed until sometime in 2003. TCEQ will eventually make much of their final results





available as GIS files. Although the WAMs are valuable tools for evaluating water availability, model results should always be cross-checked with observed stream flow data available at or near a potential banking site.

The environmental effects of recharge basin development must also be considered. The Texas Parks and Wildlife's Biological and Conservation Database provides tracking information on federally listed endangered and threatened species and most plants and vertebrate animals considered rare in Texas, as well as many non-rare biological features and plant communities (TPWD, 2002).

Finally, those involved in water planning should keep an open mind and attempt to be as creative as possible in formulating solutions to existing or pending supply problems. Each region or county is unique in terms of its water availability, and workable solutions will likely be highly customized to individual regions. With creative approaches to managing each region's particular resources, groundwater banking can play an important role in comprehensive water plans developed in many regions of Texas over the coming years.



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## **Appendix A**

### **Scope of Work and Review Comments on Draft Report**

**Appendix A1**  
**Project Scope of Work**



## **Scope of Work for Identification of Geographic Areas Suitable for Groundwater Banking - March 16, 2001**

The scope of work for this project is divided into three main tasks. Task 1 involves identification of regions in the state that are clearly not suitable for groundwater banking. These areas will be excluded from further analysis once they are identified. Task 2 involves more detailed analyses for regions not screened out during Task 1 for suitability for groundwater banking. Task 3 involves reporting and submission of deliverables to the Texas Water Development Board (TWDB). Some aspects of the approach outlined below may be modified (with permission of the TWDB project manager) during the study as available data sources are obtained and analyzed. Each of these tasks are presented in detail in the following sections.

Due to the large-scale nature of this research (the entire state of Texas), analyses conducted will depend to a great extent on existing regional or state-wide studies (e.g. the regional water plans and regional U.S. Geological Survey or Bureau of Economic Geology reports) and data available in electronic format from standard sources on the world wide web. Some readily available sources of information on which we will rely heavily include TNRIS, the TWDB well database, and U.S. Geological Survey databases. If sufficient quantitative information is not available for certain regions, we will make a professional judgement as to the suitability of a given region for groundwater banking.

### **Task 1 - Screening Analysis**

The purpose of the screening analysis is to identify regions of the state that are not suitable for water banking so they can be eliminated from further study. The screening analysis will be conducted by looking at the following factors. Additional factors may be determined in conjunction with the TWDB.

- Areas of the state underlain by aquifers that currently reject recharge will not be considered for additional analysis, as their storage capacity and/or residence time is likely to be small.
- Regions underlain by aquifers that have a low available storage capacity as indicated by small depths to groundwater will be excluded from additional analysis.
- Areas where surface water quality is significantly poorer than groundwater quality will not be considered. This is based on the assumption that it is unacceptable to degrade groundwater by infiltrating surface water of significantly lower quality.
- Areas where groundwater quality is significantly poorer than surface water quality will not be considered. This is based on the assumption that it is undesirable to reduce recovery efficiencies by mixing higher quality surface water with more saline groundwater.





- Areas where there is no surplus surface water during non-drought periods will not be considered. These areas will be identified using SB-1 Regional Water Plans, Water Availability Models where they exist, and by consultation with River Authorities.
- High demand regions will be determined using the SB-1 Regional Water Plans. Any county that has a total demand that exceeds available supply as of 2050 will be considered a high demand region. Regions that are not within reasonable proximity to high demand regions will not be considered. A working definition for reasonable proximity will be developed in conjunction with the TWDB project manager. One approach may be to consider all counties adjacent to high demand counties.

## Task 2 – Site-Specific Analysis

Once the screening analysis has been completed, the next step will be to evaluate remaining regions of the state for their suitability for groundwater banking using surface or near-surface infiltration techniques. Suitability for groundwater banking will be assessed by estimating the potential water volume that might be infiltrated for a given region, the estimated recovery of that water, and the availability of existing water storage and conveyance infrastructure. Total volume infiltrated equals the rate of infiltration times infiltration area times the time period during which infiltration occurs. Each of these factors can be locally limiting. Our approach for assessing each of these factors is outlined below.

*Rate of Infiltration.* The rate of infiltration will be controlled primarily by the hydraulic conductivity of surface and near surface materials. Information on the hydraulic properties of soils in targeted regions will be obtained from the State Soil Geographic Database (STATSGO), which is a 1:250,000 scale generalization of the detailed soil survey. Regional reports will be examined to determine the presence of extensive near-surface impeding layers that might need to be breached for groundwater banking to be effective.

*Infiltration Area and Time Period for Infiltration.* Because most surplus water in Texas is likely to come from large hydrograph spikes caused by summer rainfall, an impracticably large spreading area might be required to rapidly infiltrate surplus surface water. Therefore, feasibility of groundwater banking may often be more dependent upon the time period a water surplus can be supplied to a basin than on the permeability of surface and near-surface materials. We will compute the total area required to capture identified surplus surface water within each region of evaluation during non-drought periods. These computations will be based on the hydraulic conductivity of surficial materials and available estimates (in terms of both volume and time period available) of surplus water. Comparison of these calculated areas with information about existing land



uses in given regions may be a useful tool for planners to consider the feasibility of groundwater banking.

*Calculation of Recovery Efficiency.* Basic analytical computations of recovery efficiency will be presented for various regions using average aquifer hydraulic parameters available in the literature or collected as part of the Groundwater Availability Modeling studies. If recovery is to be obtained at or near the point of infiltration, recovery efficiencies will primarily be a function of aquifer transmissivity, storage, ambient hydraulic gradient and feasible well pumping rates.

*Identification of Water Storage and Conveyance Systems.* The existence or non-existence of water storage and conveyance systems is also a useful piece of information for evaluation of the potential for water banking programs in Texas. Existing spreading basins in other southwestern states are typically connected to massive regulated surface storage and conveyance systems (canals, dams, pipelines, etc.). Regions of Texas that have pre-existing water storage and conveyance systems will be identified using the Regional Water Plans.

### **Task 3 - Reporting**

The final report will include the details of the technical approach and methodology used to identify geographic areas suitable for groundwater banking. The report will also include general suggestions for efficient approaches to groundwater banking for various site conditions, and will be suitable for use by water planners as a primer on artificial recharge of surface water.

At the end of the study, DBS&A will provide to TWDB:

1. 10 copies of the final report (more if requested)
2. A digital copy of the final report and all figures
3. An *Adobe Acrobat* PDF file of the final report for posting on the TWDB web site
4. Individual digital copies of each figure from the final report, per format guidelines consistent with the GAM studies
5. All source data and output data in digital format

Electronic files will be transmitted to the TWDB in a ready-to-use format. All file formats will be 100 percent PC-compatible and physically reside on either ZIP discs or ISO 9600 compact disks. Two copies of all electronic files and two hard copies of each file list, file description printout, and metadata file will be provided to TWDB.

Electronic deliverables shall be provided to TWDB in the following formats:

<u>Deliverable Type</u>	<u>Format/Software</u>
GIS shapefiles	ArcView 3.2
Database files	MS Access 97



Spreadsheet files	MS Excel 97
Graphs and charts	MS Excel 97
Internet-ready reports	Adobe Acrobat 4.0 PDF

All drawings and graphs will be provided to TWDB in EPS format with a TIFF preview using Pantone Process Colors that can be separated into cyan, yellow, magenta, and black.

### **Schedule**

This schedule for completion of this work will be negotiated with the TWDB. We suggest a time frame of 18 months after contract execution, which corresponds to a completion date around October 2002. This would allow ample time for some existing studies (e.g. the GAM studies) to progress to a stage where useful information should be available for this groundwater banking study.

**Appendix A2**

**Review Comments on  
*Draft Identification of  
Geographic Areas Suitable for  
Groundwater Banking***

**Review Comments on Water Research**  
**“Identification of Geographic Areas Suitable for Groundwater Banking”**  
**Contract No. 2001-483-388**

**Report Comments**

- Page 2, second bullet: Infiltration galleries - please provide an explanation of what these are.
- Page 12, 4th paragraph:2.3.8,sentence 3, states”this could be an overlay to add,” please provide one.
- Page 13, first sentence - please insert tables immediately after making reference to them in the text or make clearer how to find the table referenced in the text. For example, Table 1 is not near text references made to it and there is no reference to a separate tables appendix.
- Page 24, 1st paragraph, 3rd sentence: there are two commas in a row, perhaps something was left out, please correct to reflect the intended thought.
- Page 28, paragraph 1, 2nd sentence: “beyond the scope of this project” is listed twice in this sentence. Perhaps it only needs to be referred to once.
- Discuss the magnitude and effects of evaporation on water intended to be recharged over large areas.
- Suggest showing maps showing coverages of where certain data is available.

Volume/Titles  
Executive summary  
Table of contents  
List of figures  
List of tables  
Page numbers-sections/Consecutive page numbering  
Context-Intro-Purpose  
Methodology  
Graph numbers  
Conclusions  
Bibliography  
Appendices/reference  
Scope of work  
Includes input/comment from public scoping/hearings ect

- Regarding the map projection: projecting all GIS data layers into UTN 13 may not be the best choice. Any data outside a certain UTM zone is not appropriate to be included in a different zone because of geometric distortion (there are 3 UTM zones in Texas: 13, 14, and 15). Using a statewide map projection standard like TSMS (Texas State Mapping System) or TCMS (Texas Centric Mapping System) is recommended.
- Information on GIS data sources and quality are not clear. Metadata (data about data) should be provided along with all GIS layers.
- Explanation on methodologies are mostly very subjective lacking appropriate examples/references. Also using equations and/or flow charts would be more helpful for some GIS procedures instead of using descriptive methods.
- This report lacks references that could be used for validation or more information.
- Overall this report gave me an impression of ‘briefing’ on the topic rather than a technical report.
- Figure 3 - Please revise spelling to provide correct and full names of the aquifers.
- Figure 4 - The color code used for <40 ft. and >500 is the same (reddish brown). Use separate colors for each of the categories (<40) and (>500), and reprint the map.

- Figure 5 - This figure seems misleading because the line thickness of the area around the rivers seems large compared to the actual 3 miles. If this is true, maybe a thinner line would be more realistic.
- Figure 6 - Slope units are not given. If it is a percentage, that should be indicated in the legend.
- Figure 9 - Conveyance structures? What are they? Describe or explain.
- Figure 10 - It appears that the first and second order stream color codes or references are switched.
- Figure 10 - 13 - Why is 40+ year old data used (from 1960)? Replace this data with recent data (late 1990s or preferably 2000 streamflow hydrographs).
- Figures 12 and 13 - Suggest using the same y-scale for both right hand axis to better convey the impact of variations in acreage.
- Figure 12 and 13 - The legend shows some lines with dots, but those cannot be found on the hydrographs. The legend and the lines on the hydrographs should match. Redraw those graphs correctly.
- Figure 17 - No recharge area (dark green) is shown at all in Region G. Is that correct? Some recharge areas may be present in Region G, if so, such areas should be shown in dark green.
- Figure 18 -Flouride should be flouride.
- Figures 18 and 21 - There is no legend reference for why some streams are highlighted in yellow.
- Figure 20 - Same question as above, but for region C. Please explain.
- Figures 23,24,30: The suitable recharge area crossing from Upton and Reagan Counties to Crockett seem to disappear. Perhaps this is an artifact of the screening that could be corrected.
- Figure 26 and 27 -In Figure 27, recharge areas are shown in Lamb, Dallam and other counties but those are not shown as such in figure 26. Please change figure 26 to show the suitable recharge areas (in dark green).
- Table 1 - Comanche is misspelled, please correct.
- Page A-2 - 1st paragraph, 2nd sentence: Hucco-Mesilla is misspelled, please correct.
- Page A-3 - 2nd paragraph, 2nd sentence: “no” should be “not”.

### **Task 2 - Site Specific Analysis**

- The site specific analysis in the various regions did not include all of the areas identified in the screening as suitable for groundwater banking.

#### **3.7.1 South Central Region**

- The report section focuses on portions of Uvalde County identified in the GIS based screening but ignores the portions of Uvalde, medina, and Bexar Counties where groundwater banking sites are currently operated by the Edwards Aquifer Authority or have been adopted as planned water management strategies by the South Central Texas Regional Water Planning Group.
- The reviewer was unable to locate the discussion of the rate of infiltration of the areas identified in the screening as suitable for groundwater banking as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the time period during which water would be available for infiltration as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the computation of the total area required to capture the identified surplus water during non-drought periods as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the calculation of recovery efficiency as required in SOW Task 2.
- The reviewer was unable to locate the discussion of identified existing water storage and conveyance systems (or lack thereof) as required in SOW Task 2.

### 3.7.2 Brazos G Region

- The reviewer was unable to locate the discussion of the time period during which water would be available for infiltration as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the computation of the total area required to capture the identified surplus water during non-drought periods as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the calculation of recovery efficiency as required in SOW Task 2.
- The reviewer was unable to locate the discussion of identified existing water storage and conveyance systems (or lack thereof) as required in SOW Task 2.

### 3.7.3 Region C

- The reviewer was unable to locate the discussion of the rate of infiltration of the areas identified in the screening as suitable for groundwater banking as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the time period during which water would be available for infiltration as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the computation of the total area required to capture the identified surplus water during non-drought periods as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the calculation of recovery efficiency as required in SOW Task 2.
- The reviewer was unable to locate the discussion of identified existing water storage and conveyance systems (or lack thereof) as required in SOW Task 2.

### 3.7.4 Region F

- The reviewer was unable to locate the discussion of the rate of infiltration of the areas identified in the screening as suitable for groundwater banking as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the time period during which water would be available for infiltration as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the computation of the total area required to capture the identified surplus water during non-drought periods as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the calculation of recovery efficiency as required in SOW Task 2.
- The reviewer was unable to locate the discussion of identified existing water storage and conveyance systems (or lack thereof) as required in SOW Task 2.

### 3.7.5 Ogallala Region

- The reviewer was unable to locate the discussion of the rate of infiltration of the areas identified in the screening as suitable for groundwater banking as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the time period during which water would be available for infiltration as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the computation of the total area required to capture the identified surplus water during non-drought periods as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the calculation of recovery efficiency as required in SOW Task 2.
- The reviewer was unable to locate the discussion of identified existing water storage and conveyance systems (or lack thereof) as required in SOW Task 2.

### 3.7.6 West Texas Region

- The reviewer was unable to locate the discussion of the rate of infiltration of the areas identified in the screening as suitable for groundwater banking as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the time period during which water would be available for infiltration as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the computation of the total area required to capture the identified surplus water during non-drought periods as required in SOW Task 2.
- The reviewer was unable to locate the discussion of the calculation of recovery efficiency as required in SOW Task 2.
- The reviewer was unable to locate the discussion of identified existing water storage and conveyance systems (or lack thereof) as required in SOW Task 2.

### Task 3 - Reporting

- **Conclusions and Recommendations** - The conclusions given in this section contain no comments on the suitability of any sites considered for groundwater banking. The report would benefit greatly as an aid to regional water planning groups with the inclusion of comments on the suitability of sites for groundwater banking as a water management strategy.

### Comments from Texas Parks and Wildlife Department (TPWD)

- Although the draft report mentions Endangered Species Act requirements as possible limiting factors to groundwater banking projects, there is no discussion of how wildlife habitat value would be included in the analysis. At a minimum, TPWD's Biological Conservation Database (BCD) should be queried on a county by county basis to screen for potential threatened or endangered species habitat. Other, more detailed, habitat analysis should be performed on candidate sites as they are selected.

The "Conclusions and Recommendations" section makes the following statement, "Factors in basin siting beyond the scope of this project include hydrographs, water availability, water rights, and a detailed field evaluation are beyond the scope of this project." I would argue that this analysis should include water availability as a preliminary step. The surface water availability models (WAMs) are now complete (except for the Rio Grande) and should be used to at least screen to exclude fully appropriated sub-basins. The WAMs could also be used to identify underutilized water rights that could be candidates for sources of surface water. Finally, environmental flow needs are not addressed anywhere. Environmental Planning Criteria should be used to estimate how much water should be set aside for instream flows and freshwater inflows to bays and estuaries.



**Appendix B**  
**GIS Data Guide**



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## Appendix B. GIS Data Guide

### B.1 GIS layers

All GIS data layers are projected in the Texas Water Development Board (TWDB) Groundwater Availability Modeling (GAM) Texas Centric projection. The projection coordinate details are as follows:

#### Map\_Projection:

- Map\_Projection\_Name: Albers Equal-Area Conic
- Albers\_Equal-Area\_Conic:
- Standard\_Parallel: 27.500000
- Standard\_Parallel: 35.000000
- Longitude\_of\_Central\_Meridian: -100.000000
- Latitude\_of\_Projection\_Origin: 31.250000
- False\_Easting: 4921250.005939
- False\_Northing: 19685000.023755

#### ***B.1.1 Texas 2050 Water Demand***

Supply and demand values were derived from the various Regional Water Planning Groups (RWPGs). Each group's water plan was downloaded and imported into a Microsoft Access database (see Section B.2.3). Water plan attribute data were joined to the Texas counties GIS shapefile, which could then be displayed graphically on the GIS base map.

The database file containing this information is *counties\_site\_specific.shp*.

#### ***B.1.2 Depth to Groundwater***

The depth-to-water map is a GIS grid file with cells matching the digital elevation model (DEM) grid file cells and values representing the depth to groundwater in feet. The



maps were created using monitoring well data from the TWDB water level database and the ground surface DEM. The general approach to generating the maps began with the creation of a water table elevation map. Water level data are frequently sparse in many of the aquifer outcrop areas and monitored locations often exhibited irregular or discontinuous records.

To obtain as much information as possible, the latest water level records for all monitored locations within the outcrop areas for the period 1995 to 2001 were used. To supplement the limited point measurements, the water table elevations in the unmonitored areas of the Gulf Coast, Carrizo-Wilcox, Edwards-Trinity Plateau, Cenozoic-Pecos Alluvium, and Ogallala aquifer outcrop areas were generated as subdued reflections of the ground surface topography while honoring the existing measurement locations. The resulting water table elevation maps were then subtracted from the ground surface DEM to generate the depth-to-water maps for these aquifers. For the Trinity aquifer outcrop area, the use of surface elevation data was limited to imposing values at the up-dip outcrop limits and in some stream and river locations. For the Seymour and Hueco-Mesilla Bolson aquifers, monitoring data were particularly sparse and a depth-to-water value was imposed at all locations based upon trends indicated by the available data. There are limitations on the accuracy of the depth to water map. In areas removed from monitored locations, the water table surface is interpolated and may not be accurate.

### ***B.1.3 Distance to Surface Water***

The Texas Natural Resources Information System (TNRIS) Texas streams GIS coverage was used as the base file to determine a site's distance from a stream ([http://www.tnris.state.tx.us/DigitalData/data\\_cat.htm](http://www.tnris.state.tx.us/DigitalData/data_cat.htm)). The file has stream order designations that allow one to associate features in the GIS such as streamflow data with stream size. A stream order or class of 1 is a large river or stream, whereas a stream order or class or 4 is a small tributary. A distance buffer was created from this stream file to delineate areas within a certain distance of a stream. This distance buffer is simply a distance value grid file. Each cell contains a value that represents that cell's



distance from the nearest stream. One can easily query different distances using this file.

The database file containing this information is *Tx\_streams\_z13.shp*.

#### **B.1.4 Surface Water Quality**

Water quality records for all of the monitored locations were analyzed in conjunction with the surface water flow data. The database was examined for concentrations of both the primary and secondary non-organic constituents listed in the U.S. Environmental Protection Agency (EPA) National Drinking Water Standards (Table B-1). Primary constituent concentrations are legally enforceable standards that apply to public water systems and are intended to protect public health by limiting the levels of certain contaminants in drinking water. Secondary constituent concentrations are non-enforceable guidelines for contaminants that may cause cosmetic or aesthetic effects in drinking water. State or local regulations may impose concentration limits that are more stringent or comprehensive than the EPA limits.

The EPA primary and secondary drinking water standard maximum contaminant level (MCL) for various contaminants provided in Table B-1 are shown in milligrams per liter (mg/L). Values for the primary standards for antimony, asbestos, cyanide, and thallium are not listed because the analysis results for these constituents were either limited or not in the database.

Over 450,000 individual analyses for most of the EPA primary and secondary concentration standards were analyzed for this report and individual GIS database files were generated for each of the constituents shown in Table B-1. The attributes, descriptions, and units for the water quality analyses files are given in Table B-2. Each water quality record in the source database that was associated with a flow record was analyzed. Constituent concentrations were converted to log base 10 values and the average concentration of all samples for a given location that were collected under the



**Table B-1. U.S. EPA Primary and Secondary Drinking Water Standards**

Contaminant	Concentration (mg/L)		Number of Locations	Number of Samples
	Maximum Contaminant Level	Recommended Concentration		
<i>Primary Standard</i>				
Arsenic	0.010	---	277	10,307
Barium	2	---	267	8,837
Beryllium	0.004	---	156	2,429
Cadmium	0.005	---	270	6,859
Chromium	0.1	---	266	7,586
Copper	1.3	---	283	10,533
Fluoride	4.0	---	571	41,714
Lead	0.015	---	273	8,180
Mercury	0.002	---	270	10,000
Nitrate	10	---	502	35,228
Nitrite	1	---	330	23,112
Selenium	0.05	---	266	9,835
<i>Secondary Standard</i>				
Aluminum	---	0.05 to 0.2 <sup>a</sup>	169	3,131
Chloride	---	250	595	63,273
Iron	---	0.3	297	10,812
Manganese	---	0.05	292	11,916
pH	---	6.5-8.5	599	60,786
Silver	---	0.10	233	6,525
Sulfate	---	250	585	62,350
Total Dissolved Solids	---	500	552	48,133
Zinc	---	5	282	10,563

<sup>a</sup> A value of 0.2 mg/L was used as the maximum concentration for aluminum.

mg/L = Milligrams per liter

--- = Not applicable



**Table B-2. Attributes for GIS Database Files for  
EPA Drinking Water Standard Data**

Attribute Name	Units	Description
site_no	---	USGS Site ID number
num_recs	---	Number of analysis records for this constituent
av_value	mg/L	Average concentration of all analyses for this constituent
av_20	mg/L	0th to 20th percentile flow interval average constituent concentration
av_40	mg/L	20th to 40th percentile flow interval average constituent concentration
av_60	mg/L	40th to 60th percentile flow interval average constituent concentration
av_80	mg/L	60th to 80th percentile flow interval average constituent concentration
av_100	mg/L	80th to 100th percentile flow interval average constituent concentration
cutoff_p	---	Flow percentile above which average concentration is below EPA standard
cutoff_q	cfs	Flow value above which average concentration is below EPA standard

USGS = U.S. Geological Survey  
 --- = Not applicable  
 mg/L = Milligrams per liter

EPA = U.S. Environmental Protection Agency  
 cfs = Cubic feet per second



same 20<sup>th</sup> percentile-increment flow condition was calculated. All average concentration values are reported in mg/L.

The following files are dBase IV® files of each constituent from the surface water quality analysis. Each of these files can be joined to the *wq\_flow.shp* shapefile in order to display the data geographically.

- EPA\_dws\_Aluminum.dbf
- EPA\_dws\_Arsenic.dbf
- EPA\_dws\_Barium.dbf
- EPA\_dws\_Beryllium.dbf
- EPA\_dws\_Cadmium.dbf
- EPA\_dws\_Chloride.dbf
- EPA\_dws\_Chromium.dbf
- EPA\_dws\_Copper.dbf
- EPA\_dws\_Fluoride.dbf
- EPA\_dws\_Iron.dbf
- EPA\_dws\_Lead.dbf
- EPA\_dws\_Manganese.dbf
- EPA\_dws\_Mercury.dbf
- EPA\_dws\_Nitrate.dbf
- EPA\_dws\_pH.dbf
- EPA\_dws\_Selenium.dbf
- EPA\_dws\_Silver.dbf
- EPA\_dws\_Sulphate.dbf
- EPA\_dws\_TDS.dbf
- EPA\_dws\_Zinc.dbf
- TDS\_1000.dbf (uses a total dissolved solids [TDS] concentration of 1,000 instead of 500 mg/L)





### ***B.1.5 Groundwater Quality***

Groundwater quality was derived from the TWDB Groundwater database and is available online ([http://www.twdb.state.tx.us/data/waterwell/well\\_info.html](http://www.twdb.state.tx.us/data/waterwell/well_info.html)). The file contains approximately 99,915 records for approximately 53,436 wells. There are multiple samples for most wells. The 15 constituents in this dataset include:

- Silica
- Calcium
- Magnesium
- Sodium
- Potassium
- Strontium
- Carbonate
- Bicarbonate
- Sulfate
- Chloride
- Fluoride
- Nitrate
- pH
- TDS
- Alkalinity
- Total hardness

The database file containing this information is *AllTxQuality.shp*.

### ***B.1.6 Soil Maps***

Both databases provide information on the spatial extent of mapped soil units. Each map unit is defined by a GIS polygon and contains a number of components and, for each component, a number of related attributes such as the component name, percentage, slope, etc. Delineation of the spatial distribution between multiple



components within a mapped unit is not possible. Both databases also provide attribute information on the vertical distribution of soil properties. From one to seven layers are identified within a given component. Attributes for each layer such as depth, thickness, texture, permeability, etc, are listed to depths generally varying from 60 to 80 inches. Thus, each map unit polygon contains a number of components, with each component having generally consistent attributes, both spatially and vertically.

The primary difference between the Soil Survey Geographic (SSURGO) and State Soil Geographic (STATSGO) databases is in the number of components represented by a single map unit. The SSURGO data for 26 counties were analyzed for this study. Approximately 79 percent of the SSURGO map units contain only 1 component and none contain more than 3 components. In contrast, for the entire state of Texas, the STATSGO map units contain as many as 21 components, with the middle 50 percent containing from 6 to 12 components. Thus, with regard to analysis at the county scale, most of the SSURGO map units provide sufficient detail with regard to individual soil component locations, while most of the STATSGO map units do not. However, caution must be exercised in the use of both of these maps. The user should be aware of the methods used to compile and the inherent limitations of these databases and is referred to the respective user manuals.

For this study, the primary component for each map unit, defined as the component occupying the largest spatial percentage, was identified in both the SSURGO and STATSGO databases. The primary components for 26 counties in the SSURGO database resulted in an average of 83 percent coverage for all polygons. For the STATSGO database however, the results were only an average of 40 percent coverage for all polygons. The STATSGO database was additionally analyzed to identify the secondary component (i.e., the second-greatest spatial percentage) that, combined with the primary component, resulted in a total average of 62 percent coverage for all polygons. Finally, for each of the identified components, the deepest layer with the lowest permeability was identified. Note that the process used to identify the lowest permeability layer does not preclude the existence of a shallower layer having a similar



permeability value. Also, the shallow depth limitation of the databases is obvious and the presence of deeper impeding layers must be investigated locally.

Each attribute record included in the soil map GIS coverage files generated for this report represents the deepest layer having the lowest permeability within a given component within a given map unit. Attribute names, definitions, and units for each of the files are listed in Tables B-3 through B-5. Some of the attribute values were extracted directly from the respective databases, while other values were calculated.

There are two versions of the SSURGO database. Of the counties analyzed, six were in Version 1 format while the remaining used the Version 2 format. Version 1 is structured similar to the STATSGO database. Version 1 database values for layer properties such as clay content, carbonate content, and permeability are stored internally as high and low values. The values for this report were calculated as the average of the high and low values. The SSURGO Version 2 database stores representative values for the same layer properties in addition to high and low values. When available, these were deemed more appropriate for this report and were extracted directly from the database.

### ***B.1.7 Slope from Digital Elevation Model Data***

DEMs were derived from the U.S. Geological Survey (USGS) 1:250,000 DEM data. DEM data were joined into a single file for the purpose of evaluating the slope of potential recharge locations. The file was developed as a mosaic of 91 different DEM files that were pieced into one large file. The slope, which is expressed in degrees, was derived from the 303-foot grid cell size that contains the DEM data. Two files must be imported into ArcView:

- *Slope.flt*:— a binary-raster export file of the state wide slope grid
- *DEM.flt* — a binary-raster export file of the state wide DEM grid



**Table B-3. Attributes for Soil Survey Geographic (SSURGO) Version 1 Polygon Files**

Attribute Name	Units	Description
muid	---	Map unit key (unique identifier for map unit)
musym	---	Map unit symbol
muname	---	Map unit name
compname	---	Major component name
comp_pct	Percent	Percentage of map unit represented by major component
ave_slope	Percent	Average slope of ground surface where major component is found
layer	---	Soil layer number of lowest permeability layer within major component
ave_depth	Inches	Average depth to top of lowest permeability soil layer
ave_thick	Inches	Average thickness of lowest permeability soil layer
ave_clay	Percent	Average clay content of lowest permeability soil layer
ave_carb	Percent	Average carbonate content of lowest permeability soil layer
ave_perm	Inch/day	Average permeability of lowest permeability soil layer
shrinksw	---	Susceptibility of soil layer to shrink or swell

--- = Not applicable

Inch/day = Inches per day



**Table B-4. Attributes for Soil Survey Geographic (SSURGO) Version 2 Polygon Files**

Attribute Name	Units	Description
mukey	---	Map unit key (unique identifier for map unit)
compkey	---	Component key (unique identifier for component)
horkey	---	Horizon key (unique identifier for soil horizon)
musym	---	Map unit symbol
muname	---	Map unit name
compname	---	Major component name
comp_pct	Percent	Percentage of map unit represented by major component
rep_slope	Percent	Representative slope of ground surface where major component is found
horizon	---	Layer number of lowest permeability layer
rep_depth	Inches	Representative depth to top of lowest permeability layer
rep_thick	Inches	Representative thickness of lowest permeability layer
rep_clay	Percent	Representative clay content of lowest permeability layer
rep_carb	Percent	Representative carbonate content of lowest permeability layer
rep_perm	Inch/day	Representative permeability of lowest permeability layer

--- = Not applicable

Inch/day = Inches per day



**Table B-5. Attributes for State Soil Geographic (STATSGO) GIS Polygon Files**

Attribute Name	Units	Description
muid	---	Map unit identifier
muname	---	Map unit name
numseqs	---	Total number of sequences (components) in this map unit
totalpct	Percent	Total area represented by the combined primary and secondary components
seqnum	---	Sequence (component) number
seqname	---	Sequence (component) name
seqpct	Percent	Percentage of map unit represented by major sequence (component)
slope	Percent	Sequence (component) average slope
numlayers	---	Sequence (component) number of soil layers
layer	---	Layer number of lowest permeability layer
depth	Inches	Depth to top of lowest permeability layer
thickness	Inches	Thickness of lowest permeability layer
ave_clay	Percent	Average clay content of lowest permeability layer
ave_carb	Percent	Average carbonate content of lowest permeability layer
ave_perm	Inch/hr	Average permeability of lowest permeability layer
shrinksw	---	Shrink-swell characteristics of lowest permeability layer

--- = Not applicable

Inch/hr = Inches per hour



## **B.2 Tabular Data**

### ***B.2.1 Surface Water Flow***

The USGS maintains a network of stream gauging stations and water quality sampling locations throughout the state of Texas and the database is available online (<http://waterdata.usgs.gov/nwis/sw>). At present, the state has approximately 327 active gauging stations where average daily streamflows are monitored. The database also contains records for an additional 400 historical gauging stations that are no longer actively monitored. Water quality samples were generally obtained periodically from many of these locations and under different flow conditions. Water quality samples were also obtained at an additional 140 locations that did not have continuously monitored gauges, but for which limited flow data are available.

For this report, over 7.65 million individual flow records were analyzed. The daily average flow rates for the period of record for each of the 727 active and historical gauging locations were analyzed. Flow data from the water quality database were used at the 140 water quality locations that were not listed in the flow database and represent a mix of both daily average flow rates and instantaneous flow rates measured at the time of sampling. Flow rate analyses derived from the quality database locations were based on a limited number of flow measurements and may not be representative.

For each location, periods of zero flow were removed from the analysis and non-zero flow rates were converted to log base 10 values for percentile and average flow rate calculations. Percentile and average flow rates are reported in cubic foot per second (cfs). Percentile rankings of flow rates were determined at 5 percent intervals to produce 20 categories for each location. Average flow rates within each 20<sup>th</sup> percentile interval were calculated to produce 5 average flow rate categories for each station. The attributes, descriptions, and units for the streamflow rate analysis are provided in Table B-6. Each attribute record of the GIS file represents a point location at which the flow measurements were made.



**Table B-6. Attributes for Streamflow Analysis GIS Point Location Files**

Attribute Name	Units	Description
site_no	---	USGS Site ID number
station_nm	---	Site name
latitude	---	Latitude coordinate
longitude	---	Longitude coordinate
source	---	F for flow, Q for quality database
drainage_area	mi <sup>2</sup>	Drainage area
date_from	---	Date of first flow record
date_to	---	Date of last flow record
flow_recs	---	Number of flow records
cmplt	Days/days	Ratio of number of flow records to the total record length
non_zero	Days/days	Ratio of number of non-zero flow records to total number of flow records
av_nzflow	cfs	Average non-zero flow rate
p_5	cfs	5 <sup>th</sup> percentile flow rate
p_10	cfs	10 <sup>th</sup> percentile flow rate
p_100	cfs	100 <sup>th</sup> percentile flow rate
av_20	cfs	Average flow within the 0 <sup>th</sup> to 20 <sup>th</sup> percentile interval
av_40	cfs	Average flow within the 20 <sup>th</sup> to 40 <sup>th</sup> percentile interval
av_100	cfs	Average flow within the 80 <sup>th</sup> to 100 <sup>th</sup> percentile interval

--- = Not applicable  
 USGS = U.S. Geological Survey

mi<sup>2</sup> = Square miles  
 cfs = Cubic feet per second





Precautions should be used in applying the streamflow data at a given location. It is generally not valid to employ this data to determine whether a specific reach between measurement points may be gaining or losing. There may be withdrawals of water for municipal or irrigation use as well as inflows from non-gauged tributaries. Additionally there are limitations on the accuracy of the measurements themselves.

The database file containing this information is *wq\_flow.shp*.

### ***B.2.2 Surface Water Quality***

Over 450,000 individual analyses for most of the EPA primary and secondary concentration standards (Table B-1) were analyzed for this report, and individual GIS database files were generated for each of the constituents. The attributes, descriptions, and units for the water quality analyses files are given in Table B-2. Each water quality record in the source database that was associated with a flow record was analyzed. Constituent concentrations were converted to log base 10 values and the average concentration of all samples for a given location that were collected under the same 20<sup>th</sup> percentile-increment flow condition was calculated. All average concentration values are reported in mg/L. Values for the primary standards for antimony, asbestos, cyanide, and thallium are not listed because the analysis results for these constituents were either limited or nonexistent.

The average concentrations within each percentile increment for a given location were examined in order from high- to low-flow conditions. Concentrations were compared to the EPA concentration standards and appropriate cutoff flow percentile and flow rate values were reported. A reported cutoff value of zero percent indicates that the standard concentration was, on average, not exceeded during any flow condition. A reported cutoff value of 100 percent indicates that the standard concentration was, on average, exceeded during all flow conditions. Intermediate cutoff values of 20 percent to 80 percent indicate the flow percentile that, on average, must be exceeded before the average concentration is below the standard concentration.



Interpretation of the GIS database for pH values is an exception. Most of the pH values not in the range of 6.5 to 8.5 were below 6.5 and generally occurred at higher flow rates. Cutoff values in the pH file represent the percentile and flow values *below* which the pH, on average, is in the acceptable range. Thus, a reported pH cutoff value of zero percent indicates that the pH range was, on average, exceeded during all flow conditions and a reported cutoff value of 100 percent indicates that the pH range was, on average, acceptable during all flow conditions.

### ***B.2.3 County Surface Water Supply and Demand and Water Rights***

Data for the Texas Water Supply and Demand database were obtained from the regional water plans. The electronic formatting was performed in two steps. First, it was imported it from its native format into Microsoft Excel® 97. Once in Excel format, custom Microsoft VisualBasic® code was applied to format the data to the projection used in the database. When data were not available electronically, or were available in a format that could not be imported into Excel, they were entered by hand from available records.

The Texas Water Supply and Demand database consists of two related tables. The *Supply Demand* table offers yearly Supply and Demand data (in acre-feet) for each county within each region. County and region are both noted in separate fields and it is possible to sort or query them in any desired combination. For each record, supply and demand are given, as well as the net result (demand – supply). From these figures, maximums, minimums, averages, and other desired mathematical values can be calculated. The second table, *Water Rights*, ties the data provided in the *Supply Demand* table to their respective owners. The *Water Rights* table has information on permit holders, permit numbers, water use and other related information. Water rights were not evaluated for this analysis, however, the data are being made available. Any local site identification work will inevitably have to deal with the issue of water rights.

Table B-7 provides a detailed summary of the structure of database tables for supply and demand and water rights. Table B-8 contains water supply and demand data for Texas counties for the years 2000 through 2050 (in 10-year increments). These data were obtained from the SB-1 Regional Water Plans.



**Table B-7. Properties and Structure of the Supply Demand and Water Rights Tables**  
**Page 1 of 2**

<b>Table Name: Supply Demand</b>			
<b>Table Properties:</b>			
Date Created	1/8/02 4:58:58 PM		
Description	Supply/demand for each county by region. Surface and groundwater supply/demand split out separately where available.		
Last Updated	8/27/02 12:20:43 PM		
Order By On	True		
Def. Updateable:	True		
Filter:	([Supply Demand].Region="P")		
Order By	[Supply Demand].Supply_Ground		
Record Count	1647		
<b>Table Fields:</b>	Name	Type	Size
	Region	Text	255
	Partial	Yes/No	1
	County	Text	255
	Year	Number (Double)	8
	Demand	Number (Double)	8
	Supply_Ground	Text	255
	Supply_Surface	Text	255
	Supply	Number (Double)	8
	Net	Number (Double)	8
	UpperCounty	Text	50
<b>Table Name: Water Rights</b>			
<b>Table Properties:</b>			
Date Created	1/7/02 5:18:30 PM		
Description	Water rights information -- owners/permit numbers/status for a given water source		
Record Count	21486		
Def. Updateable:	True		
Last Updated	8/27/02 12:23:27 PM		
<b>Table Fields:</b>	Name	Type	Size
	Status	Text	255
	WR Number	Number (Double)	8
	Type	Text	255
	Sequence	Number (Double)	8
	Permit #	Text	255
	WR Issue Date	Date/Time	8
	Amendment	Text	255
	Status_Canc	Text	255
	Owner Name	Text	255
	Owner Type	Text	255
	Amount in Ac-Ft/Yr	Number (Double)	8
	Use	Text	255



**Table B-7. Properties and Structure of the Supply Demand and Water Rights Tables**  
**Page 2 of 2**

<b>Water Rights Table (continued)</b>			
Table Fields:	Name	Type	Size
	Priority	Number (Double)	8
	Class	Text	255
	Date Can	Text	255
	Expire	Text	255
	Acreage	Number (Double)	8
	Res Name	Text	255
	Res Cap (Ac-Ft)	Text	255
	Site Name	Text	255
	Basin	Number (Double)	8
	River Order	Text	255
	Reg Code	Text	255
	SWRA	Text	255
	Unnamed Trib Of (Y/N)	Text	255
	Stream Name	Text	255
	Other Stream	Text	255
	County	Text	255
	Latitude	Number (Double)	8
	Longitude	Number (Double)	8
	Remarks	Text	255
	Base WR #	Text	255



**Table B-8. Projected Water Demands in Acre-Feet**  
Page 1 of 7

Water supply and demand data were obtained from the SB-1 Regional Water Plans. Positive numbers reflect a projected water surplus and negative numbers represent a projected water deficit.

County	2000	2010	2020	2030	2040	2050
Anderson	12935	1733	1317	816	407	-228
Andrews	-1556	---	1256	---	---	2217
Angelina	16742	13570	9969	5496	507	-5044
Aransas	-46	-12	16	44	59	66
Archer	16355	1608	1491	1341	1193	1219
Armstrong	10833	---	10485	---	---	10333
Atascosa	-22689	-21569	-20734	-39922	-42501	-48830
Austin	1343	1173	954	672	376	1
Bailey	-7278	-6463	-5350	-4014	-2431	-925
Bandera	-2264	-3993	-3880	-4343	-4894	-5508
Bastrop	30436	28918	26523	24802	23824	22590
Baylor	1694	1796	1946	2037	2085	2124
Bee	9762	10118	10464	10715	10923	11072
Bell	57645	33693	20375	12739	8439	6946
Bexar	-119398	-151686	-199458	-271882	-332961	-379396
Blanco	13628	13501	13369	13244	13198	12907
Borden	-8446	---	-8184	---	---	-8115
Bosque	7935	2220	2042	1852	1630	1190
Bowie	-11382	-20730	-21420	-22348	-23051	-23877
Brazoria	52477	-31269	-46047	-84073	-114802	-158698
Brazos	34926	29681	24493	21023	16855	13182
Brewster	4821	4549	4300	4061	3830	3667
Briscoe	0	0	0	0	0	0
Brooks	-657	-364	-231	60	309	555
Brown	3469	---	3390	---	---	3464
Burleson	53495	53708	53915	54096	54272	54389
Burnet	19642	18951	16114	14637	10491	10372
Caldwell	2316	1908	1507	212	253	330
Calhoun	81534	69503	63840	56484	47651	37560
Callahan	2272	2348	2493	2591	2739	2788
Cameron	283404	257501	236391	196364	169119	138814
Camp	15653	13133	13096	13048	12997	12938
Carson	17532	---	17318	---	---	16569
Cass	4805	2384	2303	2199	2107	1990
Castro	-39261	-39143	-38621	-37592	-36449	-35107
Chambers	41879	46819	48061	37967	35383	30904

--- = Not analyzed



**Table B-8. Projected Water Demands in Acre-Feet**  
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County	2000	2010	2020	2030	2040	2050
Cherokee	446	-109	-5939	-11875	-12612	-18395
Childress	2095	---	2023	---	---	1926
Clay	3794	3221	3158	3027	2900	2848
Cochran	-13181	-12046	-10948	-9868	-8836	-7856
Coke	1929	---	2075	---	---	2178
Coleman	2039	---	2227	---	---	2339
Collin	23020	-29794	-80743	-124769	-174124	-210431
Collingsworth	8868	---	8745	---	---	8699
Colorado	106178	97717	98635	99683	101047	102637
Comal	-3506	-14287	-20401	-28685	-33755	-40613
Commanche	-11177	-11640	-11042	-10499	-9960	-9492
Concho	627	v	698			766
Cooke	-3008	-3087	-3192	-4034	-4311	-4609
Coryell	3894	1834	-597	-3337	-5333	-7732
Cottle	313	476	642	799	953	1098
Crane	342	---	1022	---	---	919
Crockett	666	---	-1533	---	---	-1530
Crosby	-179	-56	59	174	193	204
Culberson	2740	2925	3067	3195	3331	3450
Dallam	0	---	-392701	---	---	-397991
Dallas	-34250	-168112	-241696	-267472	-350525	-415879
Dawson	195	180	211	243	260	262
Deaf Smith	0	0	0	-2516	-2596	-2717
Delta	9991	10008	9966	9909	9936	9956
Denton	3108	-20744	-92987	-184125	-210954	-234983
Dewitt	2084	2228	2298	2163	2029	1893
Dickens	124	135	148	154	159	162
Dimmit	4103	3871	3555	-3952	-4041	-4187
Donley	1076	---	854	---	---	786
Duval	-6583	-5317	-4750	-4777	-4830	-4957
Eastland	2429	191	-137	40	185	340
Ector	-1688	---	-4099	---	---	-10393
Edwards	626	617	620	617	617	613
El Paso	-118727	-87908	-67526	-376072	-392139	-412237
Ellis	6935	-10542	-13252	-17304	-21678	-23346
Erath	12262	11892	11695	11504	11418	11341
Falls	28766	29018	29212	29323	29418	29465
Fannin	25663	24433	23263	22166	20701	19159
Fayette	57016	56711	56395	55992	55549	54957

--- = Not analyzed



**Table B-8. Projected Water Demands in Acre-Feet**  
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County	2000	2010	2020	2030	2040	2050
Fisher	4384	4534	4422	4171	4246	4295
Floyd	-23567	-23949	-24088	-23855	-23577	-23199
Foard	380	534	681	823	960	1098
Fort Bend	60112	31413	-14311	-47200	-163143	-198800
Franklin	10243	9987	9790	6514	2878	2706
Freestone	4057	-6927	-8868	-8903	-13126	-13155
Frio	-67724	-64349	-61123	-73406	-70540	-67774
Gaines	0	-581	-555	-547	-535	-533
Galveston	22943	14770	5803	-3946	-16342	-28214
Garza	-516	-40	79	119	164	189
Gillespie	9805	9496	9268	9080	8487	7987
Glasscock	-47853	---	-46773	---	---	-45145
Goliad	11457	11578	6684	6749	6791	6787
Gonzales	2328	4391	5154	5450	5604	5709
Gray	13696	---	12953	---	---	12307
Grayson	23778	23078	22596	21142	19981	18797
Gregg	28960	13394	11086	7672	-10538	-29613
Grimes	21160	20999	20837	20644	20715	20355
Guadalupe	6315	3704	741	-7045	-10860	-15635
Hale	-2234	-2183	-4180	-7998	-10472	-13442
Hall	3056	---	3048	---	---	3104
Hamilton	2242	2357	2461	2678	2751	2896
Hansford	116677	---	111836	---	---	108133
Hardeman	3074	3179	3265	3355	3438	3515
Hardin	1170	38	52	-193	-549	-1229
Harris	623989	477923	145560	62432	-26272	-119667
Harrison	145113	118937	112706	106390	93288	73356
Hartley	176378	---	174317	---	---	173312
Haskell	3350	2133	2565	2919	3243	3522
Hays	3364	2118	1214	-22	-1464	-2553
Hemphill	1213	---	261	---	---	-65
Henderson	-189	-227	-227	-210	-175	-244
Hidalgo	-300605	-294697	-280995	-272885	-331530	-400425
Hill	7494	7512	6846	5937	5020	4069
Hockley	-3636	401	7	71	191	239
Hood	62147	58481	56687	55766	54999	54242
Hopkins	16289	16123	14623	14107	13061	15575
Houston	898	20	-689	-1497	-2257	-3044
Howard	1871	---	1787	---	---	1504

--- = Not analyzed



**Table B-8. Projected Water Demands in Acre-Feet**  
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County	2000	2010	2020	2030	2040	2050
Hudspeth	25226	27801	30333	32815	35249	37627
Hunt	26102	-107	-5748	-11353	-13262	-14475
Hutchinson	2071	---	8100	---	---	2938
Irion	164	---	318	---	---	542
Jack	2102	2357	2372	2355	2331	2238
Jackson	-20689	-21413	-21425	-21688	-21951	-22287
Jasper	9384	11260	11086	12527	10245	7748
Jeff Davis	529	588	653	722	793	857
Jefferson	2757	-440154	-451487	-461617	-481401	-501720
Jim Hogg	9636	9568	9490	9415	9370	9311
Jim Wells	570	714	841	967	1133	1284
Jones	9602	8471	1779	1773	1722	1631
Karnes	359	696	809	815	811	808
Kaufman	2620	-1024	-3566	-7921	-10145	-17119
Kendall	166	-1059	-2515	-4586	-6836	-9220
Kenedy	11924	11926	11931	11940	11946	11951
Kent	3998	4413	4629	4757	4847	4910
Kerr	28730	27758	26852	25695	24553	23176
Kimble	113	---	22	---	---	-218
King	740	742	748	761	773	783
Kinney	2855	3203	3560	3854	4077	4285
Kleberg	2040	1866	1862	2032	2176	2802
Knox	-4345	-3560	-3401	-2677	-1949	-1260
Lamar	26114	24804	24159	22860	21243	19253
Lamb	0	0	-918	-1371	-1368	-1381
Lampasas	10868	10544	10137	9701	9172	8479
Lasalle	387	368	367	337	300	273
Lavaca	-1358	-1358	-1357	-1357	-1358	-1357
Lee	46361	26219	21095	20943	20762	20496
Leon	827	700	574	401	226	18
Liberty	328	95	1	-5160	-7362	-11177
Limestone	35961	33074	32087	31010	29878	28637
Lipscomb	701	---	1376	---	---	148
Live Oak	451	272	4282	3847	3065	3030
Llano	38306	38349	36652	35152	35009	34756
Loving	-258	---	-250	---	---	-240
Lubbock	14919	14178	9430	8256	37458	36288
Lynn	124	115	118	85	119	136
Madison	0	0	0	0	0	0

--- = Not analyzed





**Table B-8. Projected Water Demands in Acre-Feet**  
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County	2000	2010	2020	2030	2040	2050
Marion	14885	14844	14807	14768	14527	14685
Martin	-1200	---	-479	---	---	294
Mason	1049	---	1609	---	---	2382
Matagorda	105103	85769	85483	84932	78675	77846
Maverick	-42662	-43168	-41632	-41667	-48707	-57582
Mcculloch	972	---	1086	---	---	1070
Mclennan	72063	67954	64133	59205	54878	51332
Mcmullen	10164	10275	10328	10365	10397	10419
Medina	-79157	-73528	-67925	-67128	-62095	-57372
Menard	-30	---	40	---	---	124
Midland	-29072	---	-32826	---	---	-43490
Milam	19601	29531	19273	19178	19099	13929
Mills	6149	6184	6207	6030	6049	5810
Mitchell	2085	---	1161	---	---	-2358
Montague	2237	2551	2648	2714	2740	2753
Montgomery	904	-8675	-20705	-39317	-58209	-79451
Moore	851	---	-218773	---	---	-224415
Morris	29439	29416	29497	29552	29625	29676
Motley	0	0	0	0	0	0
Nacogdoches	13391	10899	8128	-3249	-7471	-12315
Navarro	13881	13283	12929	12300	11858	11438
Newton	912	734	641	582	522	404
Nolan	1053	1015	1199	1698	2501	2438
Nueces	48832	38359	22299	1530	-14905	-28662
Ochiltree	11303	---	10394	---	---	6979
Oldham	456	---	-28291	---	---	-28783
Orange	38991	28730	20098	11225	-723	-13179
Palo Pinto	100454	95585	90961	85857	75318	64659
Panola	13677	14277	8312	185	-105	117
Parker	-1613	-11469	-15008	-24715	-30336	-33874
Parmer	-34176	-42245	-49404	-56597	-62026	-66840
Pecos	2860	---	5181	---	---	8967
Polk	502	383	240	40	-107	-268
Potter	1907	---	-35776	---	---	-45929
Presidio	9668	9865	10020	10086	10516	10921
Rains	1520	1381	217	-1038	-1191	-1362
Randall	1	---	-60150	---	---	-72661
Reagan	-20155	---	-18587	---	---	-16478
Real	971	1027	1070	1091	1110	1127

--- = Not analyzed



**Table B-8. Projected Water Demands in Acre-Feet**  
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County	2000	2010	2020	2030	2040	2050
Red River	12606	9043	6672	3380	3439	3498
Reeves	-39210	---	-37634	---	---	-35134
Refugio	1397	1450	1505	1527	1548	1575
Roberts	6257	---	6385	---	---	6273
Robertson	53718	44030	44143	44564	44954	45286
Rockwall	2941	-6362	-10849	-15603	-21694	-28106
Runnels	2231	---	2280	---	---	2136
Rusk	-2673	-7115	-11746	-16857	-16932	-17098
Sabine	1707	1474	1236	-911	-1198	-1534
San Augustine	-48	-130	-197	-334	-424	-551
San Jacinto	3026	2686	2098	-231	-539	-928
San Patricio	22071	15930	11033	8790	-493	-11789
San Saba	38033	38093	38148	38176	38206	38206
Schleicher	324	---	423	---	---	548
Scurry	2514	---	3135	---	---	3340
Shackelford	660	744	818	905	971	1018
Shelby	4004	2951	1792	337	-1300	-3295
Sherman	0	---	2154	---	---	0
Smith	1241	1073	915	693	456	155
Somervell	211	-21	-243	-509	-824	-1195
Starr	-9137	-12311	-14811	-19271	-24360	-29623
Stephens	22901	19637	18271	17327	16361	15346
Sterling	112	---	328	---	---	443
Stonewall	1053	1125	1160	1234	1302	1335
Sutton	313	---	311	---	---	467
Swisher	-45349	-45145	-42545	-44533	-44228	-43921
Tarrant	30270	-25625	-79466	-109210	-147498	-174233
Taylor	22606	19662	16387	13554	10660	8601
Terrell	784	795	812	830	849	860
Terry	-961	-935	-891	-871	-846	-792
Throckmorton	-189	-168	-144	-122	-105	-98
Titus	67604	64452	64813	51657	50978	50258
Tom Green	-32219	---	-38154	---	---	-44394
Travis	237628	211121	159179	84723	61545	34825
Trinity	1735	1739	1754	1747	1736	1679
Tyler	1815	-3353	-8492	-13668	-18723	-23787
Upshur	11321	5699	5720	5501	5248	5103
Upton	-6822	---	-5708	---	---	-4871
Uvalde	-50723	-45829	-41096	-39854	-35912	-32332

--- = Not analyzed



**Table B-8. Projected Water Demands in Acre-Feet**  
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County	2000	2010	2020	2030	2040	2050
Val Verde	8216	7587	7199	6819	5861	4757
Van Zandt	4699	4036	-2276	-3950	-4442	-5092
Victoria	20752	15585	13730	11316	6208	916
Walker	7457	6633	6159	-6101	-6759	-7050
Waller	237	135	-2385	-6499	-8455	-11051
Ward	-4643	---	-5781	---	---	-10068
Washington	14683	14524	14431	14398	14577	14829
Webb	32903	19606	4988	-30591	-35745	-44111
Wharton	-21840	-22341	-22900	-23552	-24292	-25139
Wheeler	1372	---	610	---	---	420
Wichita	23269	-6323	-3064	28	2986	2617
Wilbarger	16728	13370	9894	6352	-13199	-12814
Willacy	-22276	-23094	-23587	-24481	-28051	-32544
Williamson	54537	37231	21694	6685	-5999	-18441
Wilson	8933	7679	7089	5510	3907	2305
Winkler	0	---	309	---	---	528
Wise	11531	-1722	-3429	-6126	-7981	-9418
Wood	6827	6512	6235	5806	869	-7250
Yoakum	0	0	-457	-1935	-2030	-2158
Young	1301	1304	1324	1338	1351	1359
Zapata	800	-133	-1387	-3082	-5655	-9355
Zavala	-77016	-72903	-68924	-84700	-81319	-78147

--- = Not analyzed



#### **B.2.4 Surface Water Availability**

Most surface water in Texas has been appropriated, especially in the west where groundwater banking is most needed. However, the results of the Water Availability Modeling (WAM), sponsored by the Texas Commission on Environmental Quality (TCEQ), indicate that streamflow exceeded appropriated amounts at many locations during the historical analysis period. Local precipitation and streamflow response patterns may exhibit flashy behavior and result in short-term streamflow in excess of diversion system withdrawal capacity or reservoir storage capacity. Also, flashy streamflow may exceed limitations on permitted monthly diversion amounts. In the case of agricultural irrigation, excess water may be available during periods outside the local growing season when no diversions occur. All of these situations result in streamflow that is possibly available for groundwater banking, even though a given basin may be termed fully appropriated.

Surface water availability for selected Texas river basins was quantified using data from the WAM project. The WAM models were designed to provide information on surface water availability for evaluating existing and new appropriation permits and for developing or reviewing overall surface water management plans. An overview of the WAM modeling and data for some Texas river basins are available at the Texas Natural Resource Conservation Commission (TNRCC) website (<http://www.tnrcc.state.tx.us/permitting/waterperm/wrpa/wam.html>). At present, WAM models have been developed for 22 of the 23 Texas river basins, with the Rio Grande basin to be completed by December 31, 2003. The WAM manual is also available through the TNRCC website, and is a good resource for specific information on modeling requirements and procedures. The following is a brief description of the WAM modeling process.

The WAM models contain several components, including GIS spatial data files and tools, a database of permitted water rights and historical water use, naturalized streamflows, and Water Rights Analysis Package (WRAP) software. The GIS components were provided by the Center for Research in Water Resources (CRWR) at the University of



Texas at Austin. The remaining components were provided by the TCEQ Water Rights Permitting and Availability division.

Naturalized streamflows, defined as the flows that would have occurred in the absence of human activity, were generated from historical stream gauge data and remove the effects of reservoir development and water use. Naturalized streamflows were developed for specific locations, termed control points, for each month of the historical period of record, which spanned from 51 to 63 years for the basins analyzed for this report. Control points represent reservoir, diversion, and return flow locations associated with specific water rights and additionally key stream network features including stream gauge, confluence, and basin outflow locations. The control points, water rights, and naturalized flows are used as inputs to the WRAP model. The WRAP model, developed at Texas A & M University, utilizes historical hydrologic river basin characteristics and specific water rights information (based on seniority) to determine water availability at specific control points. The WRAP model results for each control point are cross-referenced and linked to a corresponding set of GIS spatial data files for the basin(s) being modeled. At present, comprehensive cross-reference linkages between the WRAP control points and the GIS files have not been completed. The files provided with this report represent the best currently available information as provided by the TCEQ.

The WRAP model provides many statistical analyses at various levels of detail. For this report, unappropriated streamflow associated with specific control points was used. Unappropriated streamflow is defined as the portion of the naturalized streamflow still remaining after all depletions are made and return flows are returned for all the water rights included in the simulation. Streamflow depletions are the amounts appropriated to meet water rights diversions and account for reservoir net evaporation-precipitation, and/or refill reservoir storage. Each depletion value is also associated with a particular water right.

The WRAP model unappropriated streamflows, expressed as the average number of acre-feet per year during the period of analysis, are provided with this report as attribute



data in GIS data files. The eight river basins that intersect the counties identified as candidates for groundwater banking are included (Table B-9). WAM model results for two scenarios are included, termed RUN3 and RUN8 by the TCEQ. The RUN3 scenario is used by the TCEQ to review new perpetual water right application requests and requests for amendment of existing perpetual water rights. RUN3 represents the most conservative approach and assumes that all existing water rights are fully exercised and that there is no return flow. The RUN8 scenario is used to review new term permit water right application requests and requests for amendment of existing term permit water rights. RUN8 is based on current conditions and uses the maximum actual diversion amounts for each existing water right over the last 10 year period of the analysis, combined with full estimated return flows and year 2000 reservoir conditions.

**Table B-9. WRAP Model Statistics for the RUN3 Scenarios for the Seven Analyzed Basins<sup>a</sup>**

River Basin	Analysis Date	Historical Period	Years Spanned	Control Points	Water Rights	Reservoirs
Brazos	11/15/02	1940-97	58	3811	1732	650
Canadian	12/06/01	1948-98	51	85	56	47
Colorado	11/21/02	1940-98	59	2262	1664	504
Guadalupe & San Antonio	09/10/02	1934-89	56	1331	1063	231
Nueces	10/02/02	1934-96	63	544	411	122
Red	12/30/01	1948-98	51	443	558	240
Trinity	11/13/02	1940-96	57	1323	1174	699

<sup>a</sup> RUN8 scenarios were conducted for the same hydrologic periods, though the numbers of control points, water rights, and reservoirs may differ slightly. The Guadalupe and San Antonio basins were modeled together with WRAP but have separate GIS files.

Three GIS files are provided for each river basin listed in Table B-9: *Wam\_riv\_cp*, *Wam\_riv\_bas*, and *Wam\_riv\_str*, where "riv" represents the first three letters of the river basin name. The "cp" files are point coverages representing the control point locations. Not all control points are associated with a water right location; they may represent intermediate points on the stream network required for calculations, such as confluences and streamflow gauges. In some cases, multiple control points may occupy the same location and indicate a single diversion or return flow point associated with multiple water



rights. In still other cases, multiple control points may be associated with a single water right. The “bas” files are polygon coverages representing drainage basin areas for specific control points, though generally not all control points have an associated drainage basin polygon. The “str” files are line coverages representing the WAM model stream networks generated from 30m Digital Elevation Model (DEM) grid files of the land surface for each river basin. The “str” files are provided for reference only and some stream network lines in the file may not represent actual flowing stream locations.

Attribute names, descriptions, and units for each of these files are given in Table B-10. Attribute data for each river basin include the average annual unappropriated streamflow results from the RUN3 and RUN8 scenarios and, for reference, the naturalized streamflow. Due to the incomplete state of the currently available cross-reference files,, varying degrees of success were achieved in linking the WRAP model result with the GIS features.

**Table B-10. Attributes for WAM modeling GIS files <sup>a</sup>**

File	Attribute Name	Description	Units
Control Point (CP) and Basin (BAS)	WAM_ID	Control point identification number	
	Nat	Naturalized streamflow	acre-feet/year
	Una3	Unappropriated streamflow for RUN3 scenario	acre-feet/year
	Una8	Unappropriated streamflow for RUN8 scenario	acre-feet/year
DEM Streams (STR)	Length_ft	Stream segment length	feet
	Name	Stream name	

<sup>a</sup> NAT, UNA3, and UNA8 streamflow values are annual averages for the period of hydrologic analysis (Table B-9). Stream names were not present in all files.

Limitations must be considered in applying the WAM modeling results reported in the GIS files. The streamflow amounts are reported here simply as annual average values and provide only an indication of availability. Streamflows for any particular time interval during an analysis period may be significantly different from the attribute values in the GIS files. In extreme cases, reported streamflows may be dominated by only a few months or years of actual flow averaged with long periods of no flow. The user must



examine more detailed model output to gain insight into the interannual and seasonal streamflow variability at specific locations.

### ***B.2.5 Environmental Hazards***

The Environmental Hazards GIS layer was derived from four GIS layers: Landfills, Permitted Industrial and Hazardous Waste Sites, Superfund Sites, and Radioactive Waste Sites. These GIS layers were downloaded from The Texas Natural Resources Information System (TNRIS) Data Catalog ([http://www.tnris.state.tx.us/DigitalData/data\\_cat.htm](http://www.tnris.state.tx.us/DigitalData/data_cat.htm)). These four files were merged into a single GIS shapefile.

The Landfill layer contains both open and closed municipal solid waste landfill sites in the State of Texas. The Industrial and Hazardous Waste Sites layer contains point locations for operating permitted industrial and hazardous waste locations in Texas. The Superfund layer contains all sites in the State of Texas that have been designated as Superfund cleanup sites; it includes both federal and state sites. The Radioactive Waste Sites layer contains all sites in the State of Texas that have been designated as radioactive waste sites.

The database file containing this information is *environmental\_hazards.shp*.