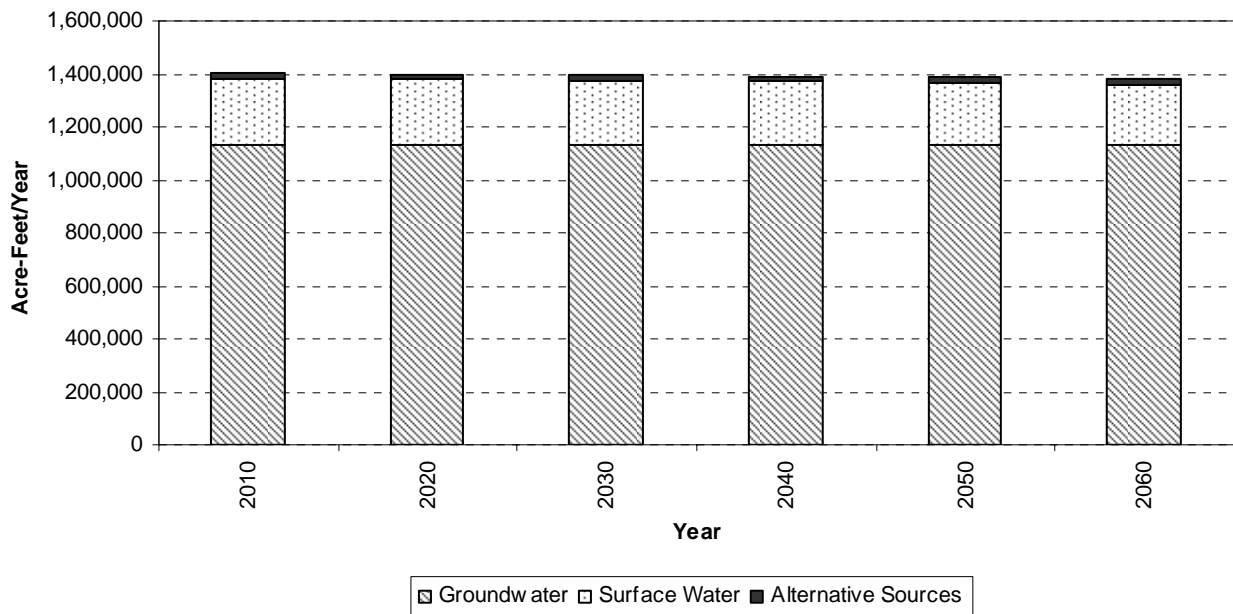


3 WATER SUPPLY ANALYSIS

In Region F, water comes from surface water sources such as run-of-the-river supplies and reservoirs, groundwater from individual wells or well fields, and from alternative sources such as reuse or desalination. Figure 3.1-1 shows the baseline water availability for Water User Groups (WUGs) in Region F. Groundwater is the largest source of water supply available in Region F. Surface water supplies in Figure 3.1-1 are significantly reduced because of the assumptions used in the Colorado River Basin Water Availability Model (WAM) (see Section 3.2)

Figure 3.1-1
Water Availability by Source Type



3.1 Existing Groundwater Supplies

In 2000, groundwater sources supplied 414,000 acre feet of water, accounting for 69 percent of all water used in the region. Groundwater provides most of the irrigation water used in the

region, as well as a significant portion of the water used for municipal and other purposes. Groundwater is primarily found in four major and seven minor aquifers that vary in quantity and quality (Figures 1.2-1 and 1.2-2). The following discussion describes each of these aquifers, including their current use and potential availability. Section 3.1.12 discusses the supply of brackish groundwater potentially available for desalination treatment.

From a planning perspective, groundwater availability should be defined based on locally accepted water use and management policy considerations. These management policy decisions are expressed in the rules and management plans of the various groundwater conservation districts in the region. Some districts consider recharge only, while other districts may consider recharge and an acceptable level of aquifer depletion over time. In some cases, groundwater availability may be limited by the economics of water treatment. For those counties in the region that are not governed by a groundwater conservation district, aquifer availability is based on historical use trends. Figure 1.3-4 shows the counties currently governed by groundwater conservation districts.

Groundwater availability by aquifer and river basin within each county is listed in Table 3.1-1. As discussed above, the availability volumes listed in this table represent an acceptable level of aquifer withdrawal in each county based on policy decisions that attempt to maintain water levels in the aquifers at desired levels (Figure 3.1-2). Also of consideration in much of the region is the desire to maintain aquifers such that springflow and associated base flow to rivers and streams are protected. It is, however, recognized that in times of severe drought, reduction in springflow and surface water flow will likely occur regardless of management policies.

The quantification of groundwater availability considers both aquifer recharge and water held in storage in the aquifer matrix. Groundwater availability is defined by the following formula:

$$\text{Availability} = \text{Drought Year Recharge} + \text{Annual Supply from Storage}$$

The amount of water available from storage may be either 0 (no water from storage, limiting supply to recharge only), 75 percent of the recoverable volume in storage divided by 50 years, or 75 percent of the recoverable volume in storage divided by 100 years (see Figure 3.1-2).

Table 3.1-1
Groundwater Availability in Region F
(Values in Acre-Feet per Year)

County	Aquifer	Basin	Annual Recharge During Drought ^a	Annual Supply from Storage	Annual Availability
Andrews	Cenozoic Pecos Alluvium	Rio Grande	685	504	1,189
	Dockum	Colorado	0	905	905
		Rio Grande	0	5,792	5,792
	Ogallala	Colorado	22,427	8,852	31,279
		Rio Grande	3,293	1,040	4,333
	Edwards-Trinity	Colorado	4,205	435	4,640
Borden	Dockum	Colorado	0	117	117
	Ogallala	Brazos	0	108	108
		Colorado	300	482	782
Brown	Ellenburger-San Saba	Colorado	0	0	0
	Hickory	Colorado	0	0	0
	Trinity	Colorado	2,026	0	2,026
Coke	Dockum	Colorado	12	0	12
	Edwards-Trinity	Colorado	3,242	0	3,242
Coleman	Ellenburger-San Saba	Colorado	0	0	0
	Hickory	Colorado	0	0	0
Concho	Edwards-Trinity	Colorado	11,869	409	12,278
	Hickory	Colorado	0	14,299	14,299
	Lipan	Colorado	5,984	529	6,513
Crane	Cenozoic Pecos Alluvium	Rio Grande	2,537	0	2,537
	Dockum	Rio Grande	0	0	0
	Edwards-Trinity	Rio Grande	115	0	115
Crockett	Dockum	Rio Grande	0	0	0
	Edwards-Trinity	Colorado	636	0	636
		Rio Grande	24,824	0	24,824
Ector	Cenozoic Pecos Alluvium	Rio Grande	1,059	1,845	2,904
	Dockum	Colorado	0	2,498	2,498
		Rio Grande	0	3,479	3,479
	Edwards-Trinity	Colorado	9,027	1,103	10,130
		Rio Grande	1,059	135	1,194
	Ogallala	Colorado	4,850	999	5,849
Glasscock	Dockum	Colorado	0	140	140
	Ogallala	Colorado	940	2,988	3,928
	Edwards-Trinity	Colorado	17,420	3,518	20,938

Table 3.1-1: Groundwater Supplies in Region F (continued)

County	Aquifer	Basin	Annual Recharge During Drought ^a	Annual Supply from Storage	Annual Availability
Howard	Dockum	Colorado	0	900	900
	Edwards-Trinity	Colorado	1,606	94	1,700
	Ogallala	Colorado	2,610	7,799	10,409
Irion	Dockum	Colorado	0	0	0
	Edwards-Trinity	Colorado	9,445	0	9,445
Kimble	Edwards-Trinity	Colorado	23,965	0	23,965
	Ellenburger-San Saba	Colorado	216	0	216
	Hickory	Colorado	0	0	0
Loving	Cenozoic Pecos Alluvium	Rio Grande	457	3,906	4,363
	Dockum	Rio Grande	0	860	860
Martin	Ogallala	Colorado	7,760	11,642	19,402
	Edwards-Trinity	Colorado	2,895	503	3,398
Mason	Edwards-Trinity	Colorado	3,205	623	3,828
	Ellenburger-San Saba	Colorado	3,537	1,113	4,650
	Hickory	Colorado	21,521	54,971	76,492
McCulloch	Edwards-Trinity	Colorado	7,735	514	8,249
	Ellenburger-San Saba	Colorado	3,596	12,926	16,522
	Hickory	Colorado	3,419	122,726	126,145
Menard ^b	Edwards-Trinity	Colorado	15,357	0	19,000
	Ellenburger-San Saba	Colorado	159	0	159
	Hickory	Colorado	0	0	34,000
Midland	Dockum	Colorado	0	45	45
	Ogallala	Colorado	3,270	1,397	4,667
	Edwards-Trinity	Colorado	18,082	1,313	19,395
Mitchell	Dockum	Colorado	8,744	5,274	14,018
Pecos	Dockum	Rio Grande	0	1,089	1,089
	Cenozoic Pecos Alluvium	Rio Grande	50,050	8,528	58,578
	Edwards-Trinity	Rio Grande	91,014	23,835	114,849
	Capitan Reef	Rio Grande	0	34,000	34,000
Reagan	Dockum	Rio Grande	0	54	54
	Edwards-Trinity	Colorado	19,522	9,364	28,886
		Rio Grande	1,629	720	2,349
Reeves	Dockum	Rio Grande	0	3,065	3,065
	Cenozoic Pecos Alluvium	Rio Grande	40,099	20,421	60,520
	Edwards-Trinity	Rio Grande	11,909	41,936	53,845
Runnels	Lipan	Colorado	4,536	0	4,536
Schleicher	Edwards-Trinity	Colorado	12,204	0	12,204
		Rio Grande	3,960	0	3,960

Table 3.1-1: Groundwater Supplies in Region F (continued)

County	Aquifer	Basin	Annual Recharge During Drought ^a	Annual Supply from Storage	Annual Availability
Scurry	Dockum	Brazos	7,898	1,940	9,838
		Colorado	3,226	3,159	6,385
Sterling	Dockum	Colorado	0	0	0
	Edwards-Trinity	Colorado	5,168	0	5,168
Sutton	Edwards-Trinity	Colorado	9,349	0	9,349
		Rio Grande	11,426	0	11,426
Tom Green	Dockum	Colorado	0	54	54
	Edwards-Trinity	Colorado	14,373	664	15,037
	Lipan	Colorado	24,916	12,570	37,486
Upton	Cenozoic Pecos Alluvium	Rio Grande	803	275	1,078
	Dockum	Rio Grande	0	797	797
	Edwards-Trinity	Colorado	6,745	1,303	8,048
		Rio Grande	8,511	1,292	9,803
Ward	Cenozoic Pecos Alluvium	Rio Grande	5,984	11,304	17,288
	Dockum	Rio Grande	0	2,340	2,340
	Capitan Reef	Rio Grande	0	12,000	12,000
Winkler	Cenozoic Pecos Alluvium	Rio Grande	3,727	48,267	51,994
	Dockum	Rio Grande	0	10,746	10,746
	Edwards-Trinity	Colorado	423	94	517
	Capitan Reef	Rio Grande	0	15,000	15,000
Total			591,561	541,600	1,170,804

a Drought recharge equals one half of average annual recharge.

b Supplies for Menard County are from the Menard County Underground Water District management plan.

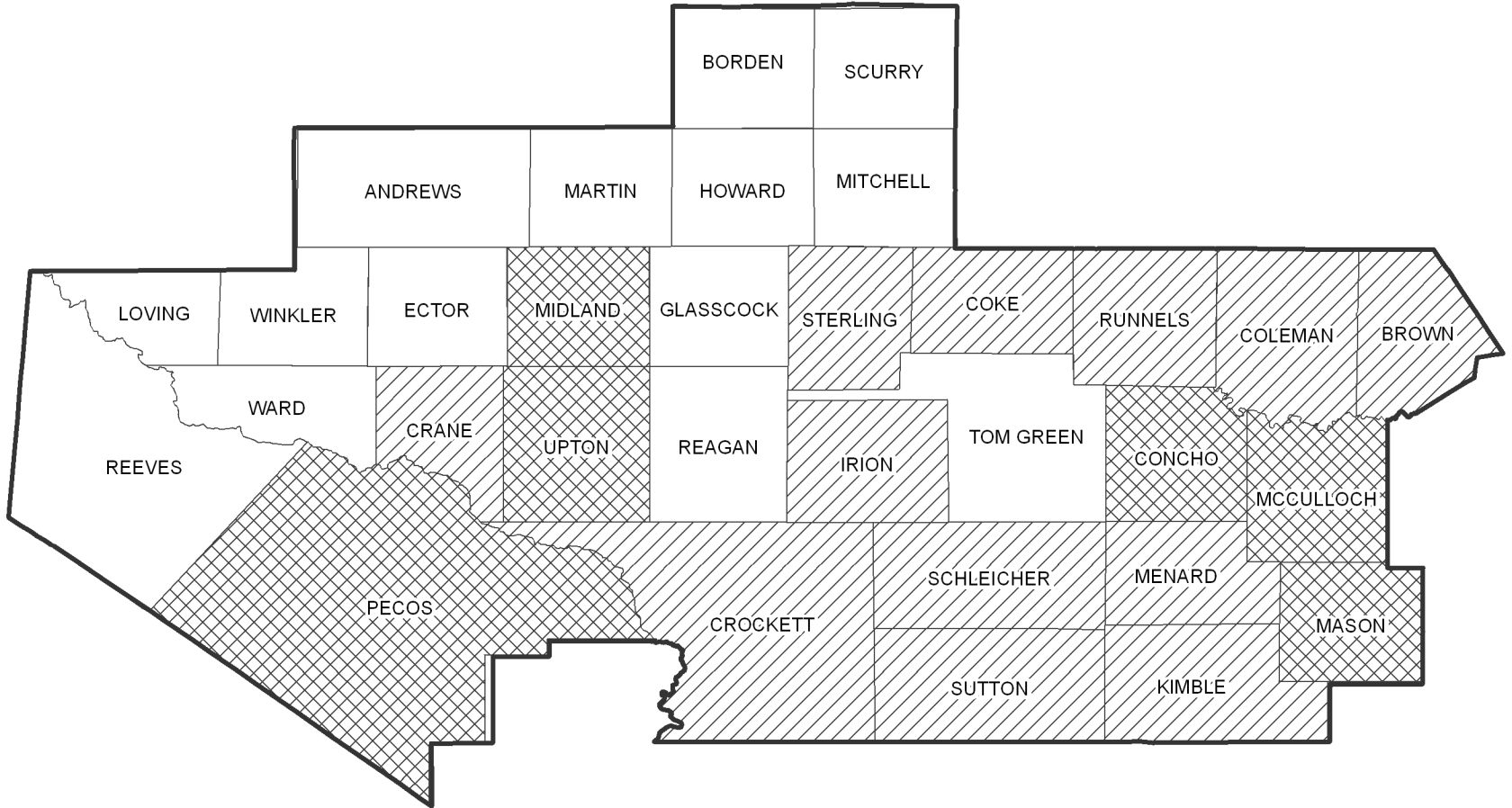
The Edwards-Trinity (Plateau) Groundwater Availability Model (GAM) was not completed in time for its full use during this planning period. Therefore, only key input factors (recharge) from draft versions of the GAM were used. Recharge estimates for the Edwards-Trinity aquifer are one half of average annual recharge as provided in the Edwards-Trinity (Plateau) GAM. No data were available from other GAMs. Recharge for other aquifers in the region, along with water in storage estimates, were retained from the 2001 *Region F Water Plan*. These recharge estimates were from previous studies by TWDB.



Region F Water Plan
Groundwater Availability Determination

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 SCALE: 1:2,750,000
 DESIGNED: G.G.J.
 DRAFTED: G.G.J.

FIGURE 3.1-2



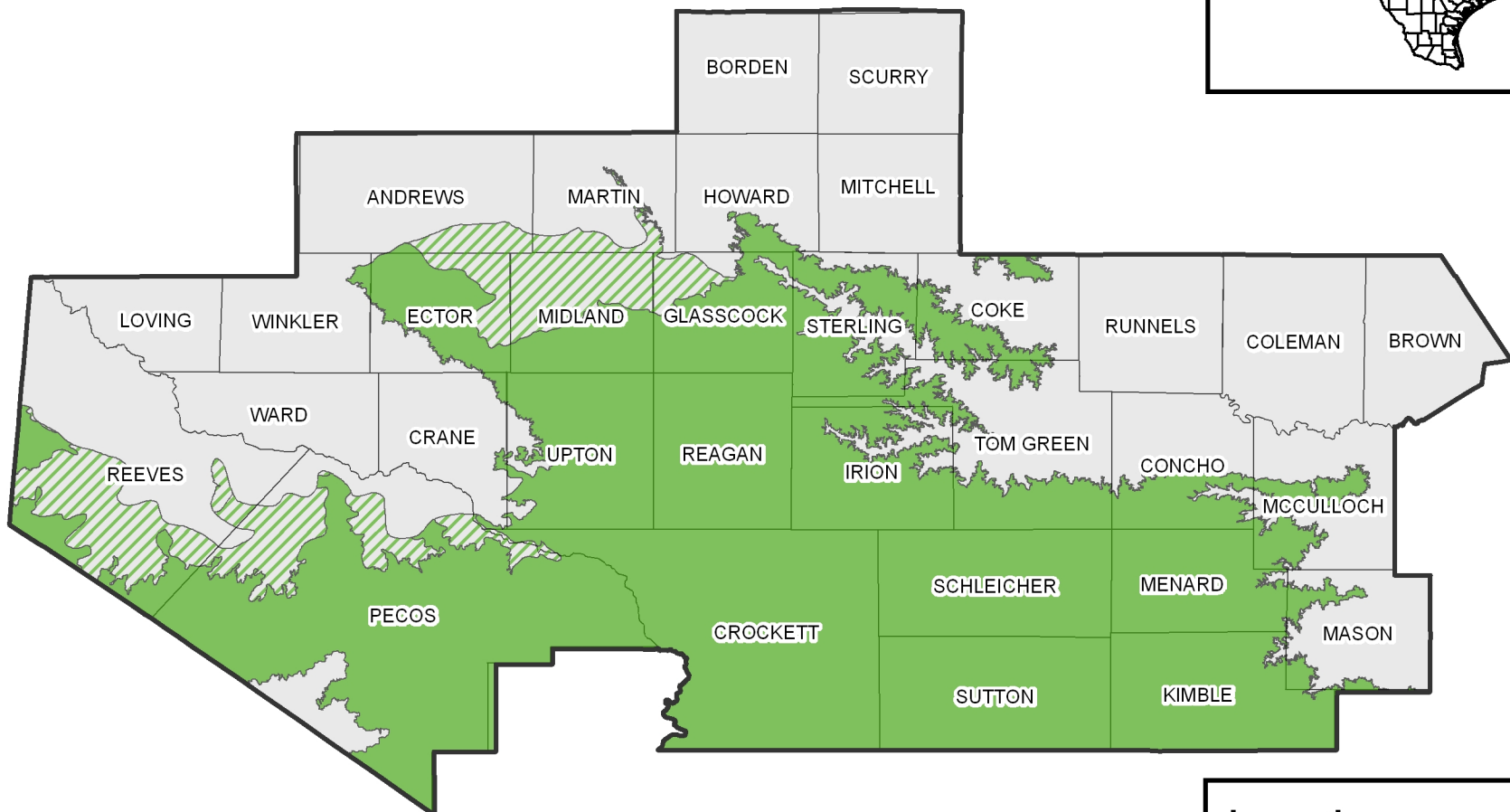
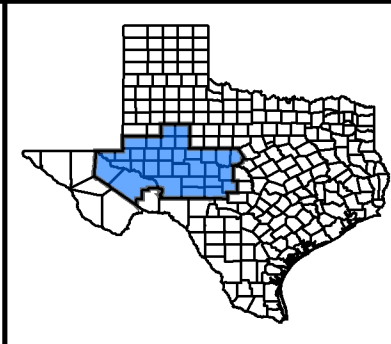
- Recharge and 75% of Recoverable Storage over 50 yrs
- Recharge and 75% of Recoverable Storage over 100 yrs
- Recharge Only

3.1.1 Edwards-Trinity (Plateau) Aquifer

Extending from the Hill Country of Central Texas to the Trans-Pecos region of West Texas, the Edwards-Trinity (Plateau) aquifer is the largest aquifer in areal extent in Region F, occurring in 21 of the 32 Region F counties (Figure 3.1-3). This aquifer is comprised of water-bearing portions of the Edwards Formation and underlying formations of the Trinity Group, and is one of the largest contiguous karst regions in the United States. Regionally, this aquifer is categorized by the TWDB as one aquifer. However, in other parts of the state the Edwards and Trinity components are not hydrologically connected and are considered separate aquifers. The Trinity aquifer is also present as an individual aquifer in Eastern Brown County within Region F. More groundwater is produced from the Edwards-Trinity (Plateau) aquifer (approximately 34 percent) than any other aquifer in the region, three-fourths of which is used for irrigation and livestock watering. Many communities in the region use the aquifer for their public drinking-water supply as well.

The Edwards-Trinity (Plateau) aquifer is comprised of lower Cretaceous formations of the Trinity Group and limestone and dolomite formations of the overlying Edwards, Comanche Peak, and Georgetown. These strata are relatively flat lying, and located atop relatively impermeable pre-Cretaceous rocks. The saturated thickness of the entire aquifer is generally less than 400 feet, although the maximum thickness can exceed 1,500 feet. Recharge is primarily through the infiltration of precipitation on the outcrop, in particular where the limestone formations outcrop. Discharge is to wells and to rivers in the region. Groundwater flow in the aquifer generally flows in a south-southeasterly direction, but may vary locally. The hydraulic gradient averages about 10 feet/mile.

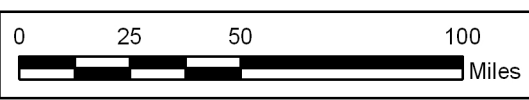
Long-term water-level declines have been observed in areas of heavy pumping, most notably in the Saint Lawrence irrigation district in Glasscock, Reagan, Upton, and Midland Counties, in the Midland-Odessa area in Ector County, and in the Belding Farm area in Pecos County. Figures 3.1-4, 3.1-5 and 3.1-6 show selected hydrographs for the Edwards-Trinity (Plateau) aquifer in Region F. As noted above, some areas have shown consistent water-level declines, as shown in Figure 3.1-4. In some cases, these declines have stopped due to cessation in pumpage, and are currently recovering. Figure 3.1-5 shows selected wells showing increases in water



Legend

Edwards-Trinity Aquifer

- Outcrop
- Downdip
- Counties



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 4055 International Plaza, Suite 200
 Fort Worth, TX 76109-4895
 Phone - (817) 735-7300

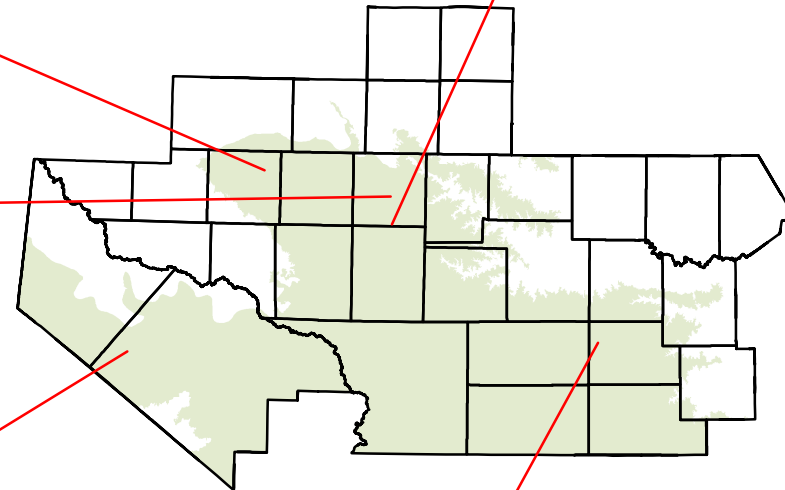
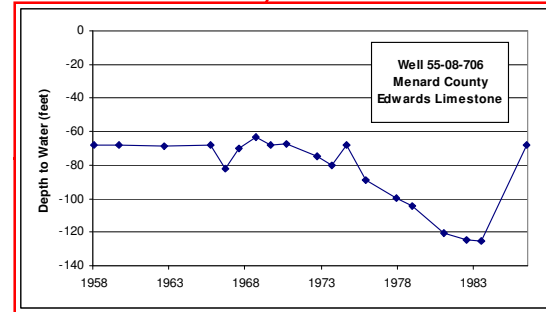
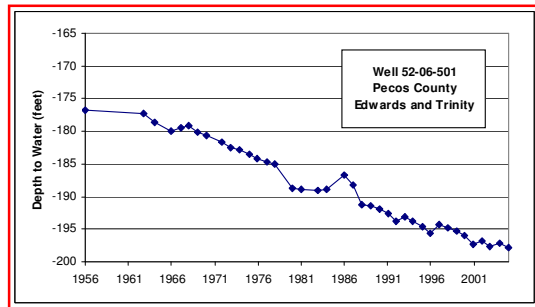
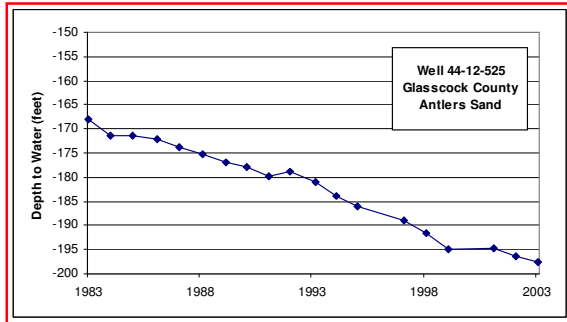
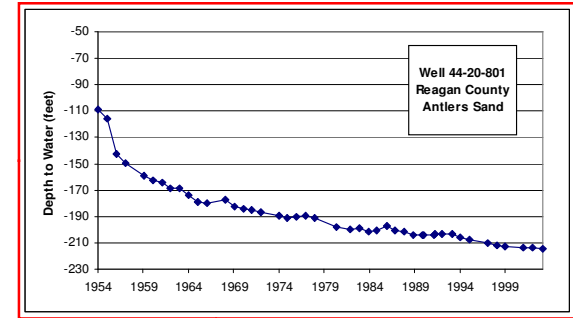
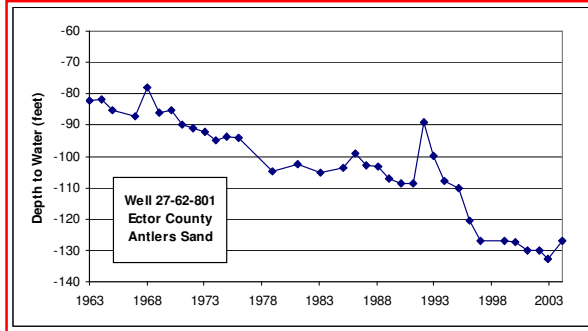


Region F Water Plan

Edwards-Trinity Aquifer

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DRAFTED	G.G.J.

FIGURE 3.1-3



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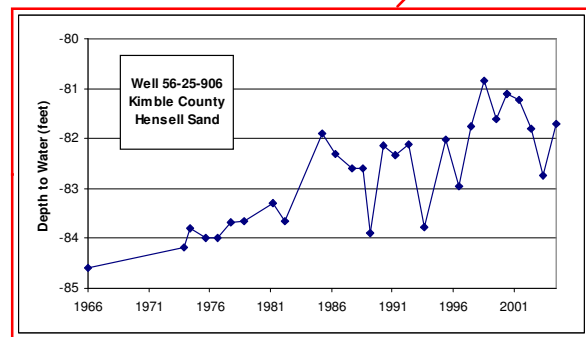
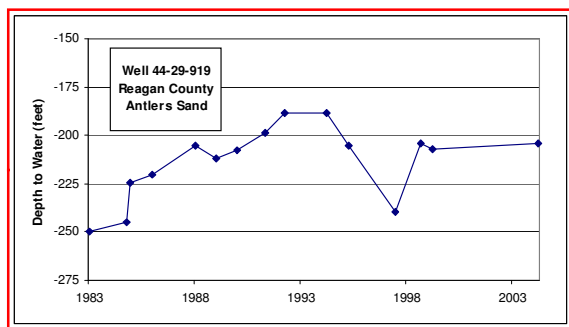
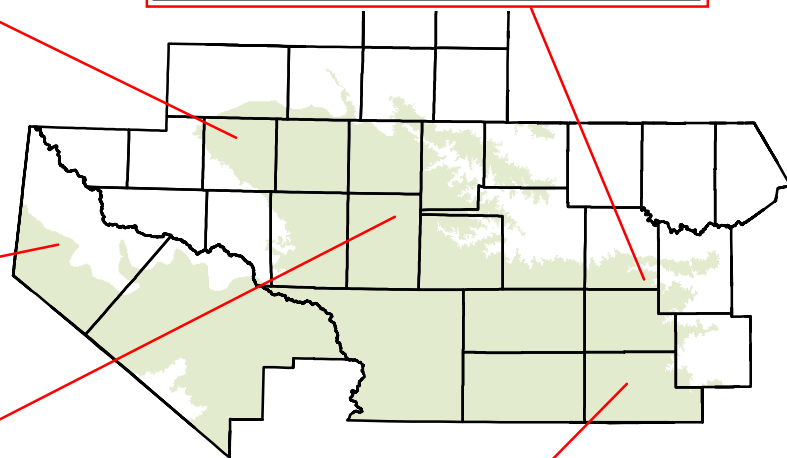
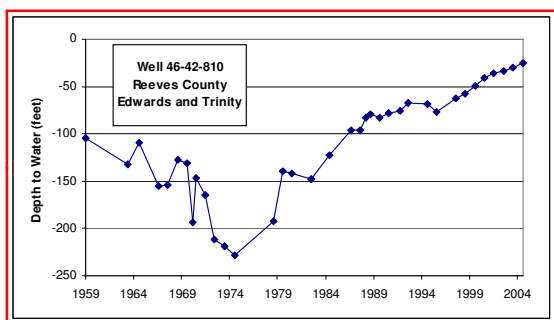
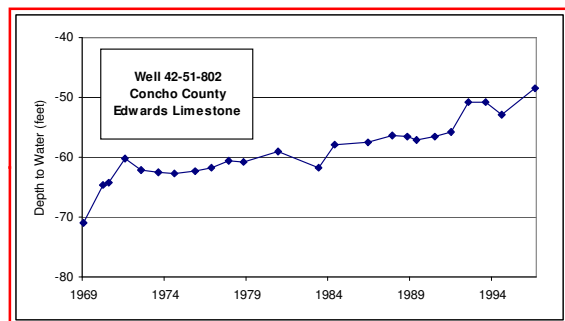
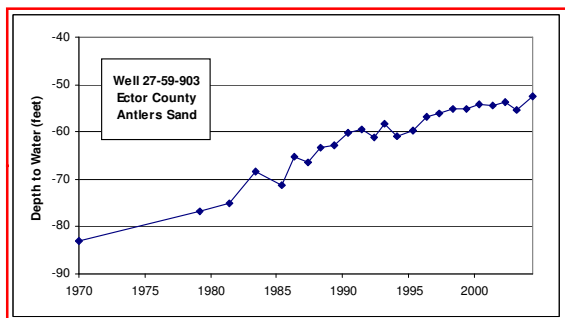


Region F Water Plan

Selected Hydrographs from the Edwards-Trinity (Plateau) Aquifer Showing Declining Water Levels

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DATE	August 5, 2005
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3.1-4
FIGURE



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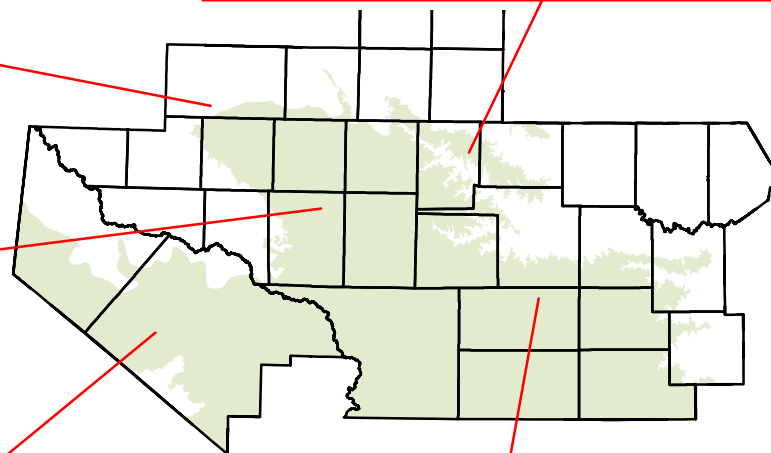
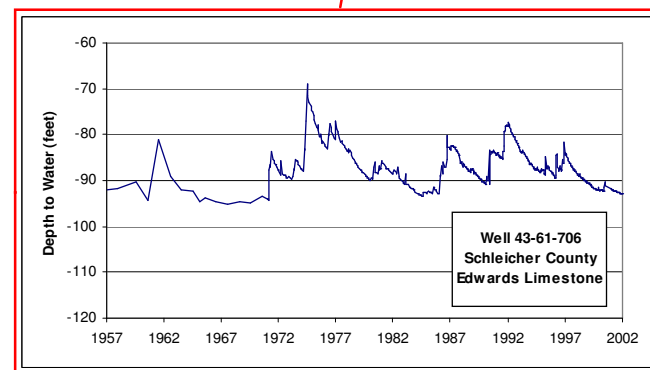
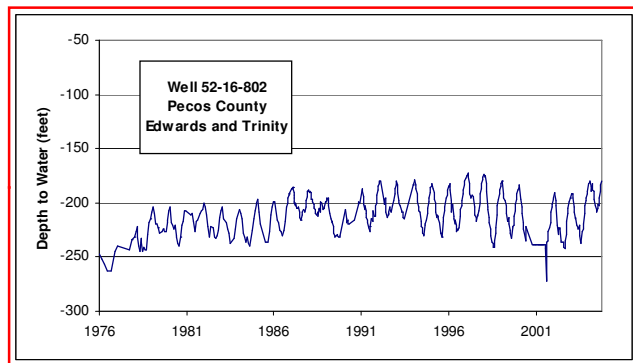
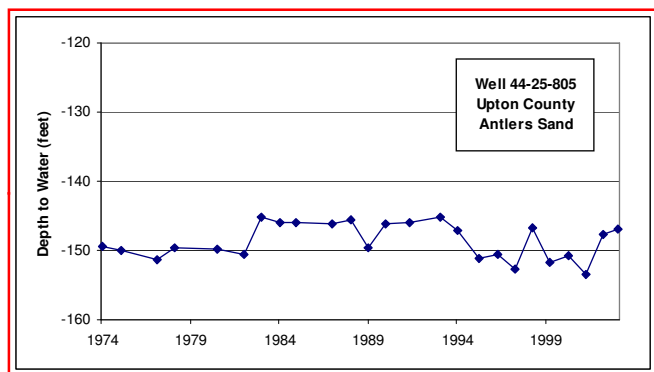
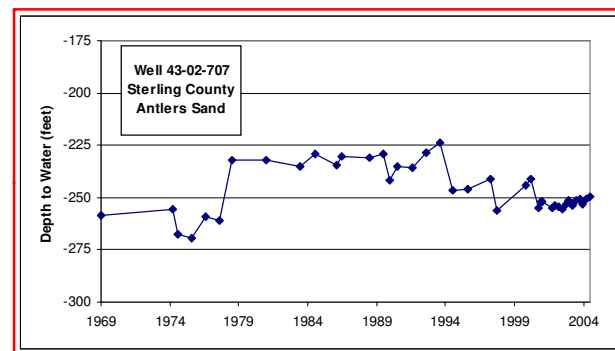
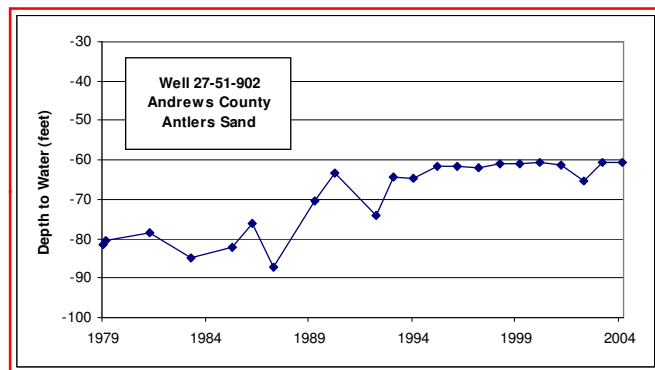


Region F Water Plan

Selected Hydrographs from the Edwards-Trinity (Plateau) Aquifer Showing Rising Water Levels

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FILE	
DATE	August 5, 2005
SCALE	
DESIGNED	ACAD
DRAFTED	BJS

3.1-5
FIGURE



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Region F Water Plan

Selected Hydrographs from the Edwards-Trinity (Plateau) Aquifer Showing Stable Water Levels

FN JOB NO.	
FILE	
DATE	August 5, 2005
SCALE	
DESIGNED	ACAD
DRAFTED	BJS

3.1-6
FIGURE

levels over time. However, most Edwards-Trinity (Plateau) wells in the region show fairly stable water levels, or are slightly declining, as shown by the hydrographs in Figure 3.1-6. Well 52-16-802 in Pecos County (Figure 3.1-6) shows the water level variations throughout the year as pumpage increases in the summer and stops in the winter.

Edwards Formation

Groundwater is produced from the Edwards Formations portion of the Edwards-Trinity (Plateau) aquifer in a majority of the region. Groundwater in the Edwards and associated limestones occurs primarily in solution cavities that have developed along faults, fractures, and joints in the limestone. These formations are the main water-producing units in about two-thirds of the aquifer extent. The largest single area of pumpage from the Edwards portion of the aquifer in Region F is in the Belding Farms area of Pecos County.

Due to the nature of groundwater flow in the Edwards, it is very difficult to estimate aquifer properties for this portion of the Edwards-Trinity (Plateau) aquifer. However, based on aquifer characteristics of the Edwards elsewhere, wells producing from the Edwards portion of the Edwards-Trinity (Plateau) aquifer are expected to be much more productive than from the Trinity portion of the aquifer.

The chemical quality of the Edwards and associated limestones is generally better than that in the underlying Trinity aquifer. Groundwater from the Edwards and associated limestones is fairly uniform in quality, with water being a very hard, calcium bicarbonate type, usually containing less than 500 mg/l total dissolved solids (TDS), although in some areas the TDS can exceed 1,000 mg/l.

Trinity Group

Water-bearing units of the Trinity Group are used primarily in the northern third and on the southeastern edge of the aquifer. In most of the region, the Trinity is seldom used due to the presence of the Edwards above it, which produces better quality water at generally higher rates. In the southeast portion, the Trinity consists of, in ascending order, the Hosston, Sligo, Cow Creek, Hensell and Glen Rose Formations. In the north where the Glen Rose pinches out, all of the Trinity Group is referred to collectively as the Antlers Sand. The greatest withdrawal from the Trinity (Antlers) portion of the aquifer is in the Saint Lawrence irrigation area in Glasscock, Reagan, Upton and Midland Counties.

Reported well yields from the Trinity portion of the Edwards-Trinity (Plateau) aquifer commonly range from less than 50 gallons per minute (gpm) from the thinnest saturated section to rarely as much as 1,000 gpm, although higher yields occur in locations where wells are completed in jointed or cavernous limestone. Specific capacities of wells range from less than 1 to greater than 20 gpm/ft.

The water quality in the Trinity tends to be poorer than in the Edwards. Water from the Antlers is of the calcium bicarbonate/sulfate type and very hard, with salinity increasing towards the west. Salinities in the Antlers typically range from 500 to 1,000 mg/l TDS, although groundwater with greater than 1,000 mg/l TDS is common.

Edwards-Trinity (Plateau) Aquifer Recharge

Accurate recharge estimates are a key factor in estimating long-term groundwater availability in an aquifer system. The Edwards-Trinity (Plateau) aquifer covers all or parts of 21 of the 32 counties in Region F and provides water for many WUGs in the region. Therefore, in support of the aquifer availability analysis, a three-year study of the groundwater recharge in the Edwards portion of the aquifer was conducted. The goal of the study was to better understand the nature and timing of recharge events and to consider alternative methods of estimating recharge. This study entailed:

1. Design of monitoring well and rain gage networks in the study area,
2. Collection and evaluation of new and historical data to help estimate recharge characteristics,
3. Development of a rainfall-runoff model for the South Concho watershed in Tom Green and Schleicher Counties,
4. Documentation and discussion of data collection, recharge evaluation, statistical analyses, model development and results, and conclusions.

Monthly and (in some cases) daily water level and precipitation data were collected during 2003 and 2004, and in a few areas into 2005. Fifteen wells were monitored daily with transducers and about 100 wells were measured manually on a monthly basis. Precipitation data were assimilated from nine National Weather Service gages and over 60 volunteer-monitored gages. The project was performed within the boundaries of and with the assistance of groundwater conservation districts. Seven districts assisted in establishing the monitor well and rain gage networks, and collected and recorded the data used in the study:

- Glasscock Groundwater Conservation District
- Sterling County Underground Water Conservation District
- Irion County Water Conservation District
- Lipan-Kickapoo Water Conservation District (Tom Green, Concho, and Runnels Counties)
- Emerald Underground Water Conservation District (Crockett County)
- Plateau Underground Water Control and Supply District (Schleicher County)
- Sutton County Underground Water Conservation District

A full discussion of the study and the results are contained in a separately bound document titled *Evaluation of Edwards-Trinity (Plateau) Aquifer Recharge in a Portion of the Region F Planning Area*. Summary conclusions from the study include:

- Based on measured precipitation and groundwater levels, recharge of the Edwards-Trinity (Plateau) is highly variable both geographically and in time.
- Statistical evaluation of observed rainfall and water level data indicate that, because of the numerous factors that affect groundwater recharge, including temporal changes in precipitation, evapotranspiration, and geographic variations in hydrogeology and soils, a unique regional linear correlation between rainfall and recharge does not exist.
- Long periods of wet conditions in winter months tend to result in more recharge than similar periods in the summer due to the increased evapotranspiration and drier soil conditions in the summer.
- A South Concho watershed rainfall-runoff model developed for this study reproduced measured streamflow conditions relatively well and was helpful in identifying conditions that were conducive to increased groundwater recharge.
- Because the rainfall-runoff model accounts for temporal changes in precipitation, evapotranspiration and to some degree, geographic variations in hydrogeology and soils, model results were used to develop a relationship between annual precipitation and recharge for the South Concho watershed. The relationship can be used to estimate a “threshold” annual precipitation that results in groundwater recharge for the South Concho watershed. Due to the variability of factors impacting recharge potential, it is recommended that similar models be developed for individual watersheds.

3.1.2 Ogallala Aquifer

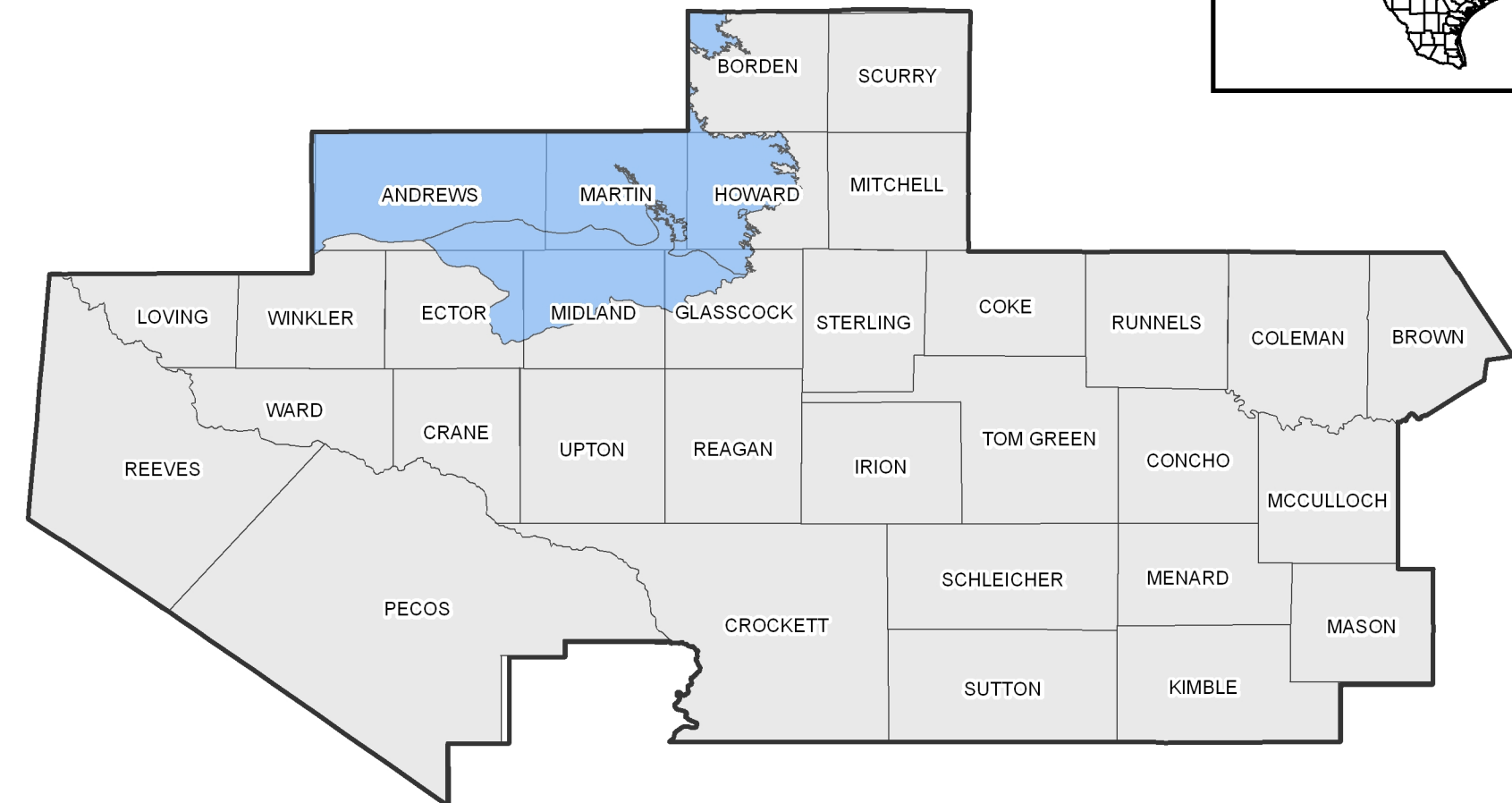
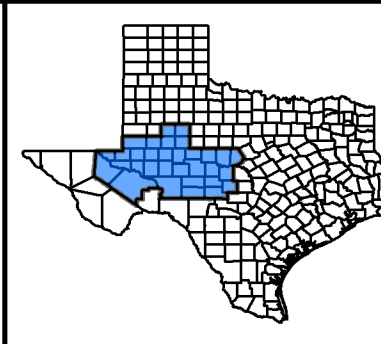
The Ogallala is one of the largest sources of groundwater in the United States, extending from South Dakota to the Southern High Plains of the Texas Panhandle. In Region F, the aquifer occurs in seven counties in the northwestern part of the region including Andrews, Borden, Ector, Howard, Glasscock, Martin and Midland Counties (Figure 3.1-7). The aquifer provides approximately 20 percent of all groundwater used in the region. The formation is hydrologically connected to the underlying Edwards-Trinity (Plateau) aquifer in southern Andrews and Martin Counties, and northern Ector, Midland and Glasscock Counties.

In Region F, agricultural irrigation and livestock consumption account for approximately two-thirds of the total use of Ogallala groundwater. Municipal use accounts for approximately 20 percent. Most of the withdrawals from the aquifer occur in Midland, Martin, and Andrews Counties.

The Ogallala is composed of coarse to medium grained sand and gravel in the lower strata grading upward into fine clay, silt and sand. Recharge occurs principally by infiltration of precipitation on the surface and to a lesser extent by upward leakage from underlying formations. Highest recharge infiltration rates occur in areas overlain by sandy soils and in some playa lake basins. Groundwater in the aquifer generally moves slowly in a southeastwardly direction. Water quality of the Ogallala in the Southern High Plains ranges from fresh to moderately saline, with dissolved solids averaging approximately 1,500 mg/l.

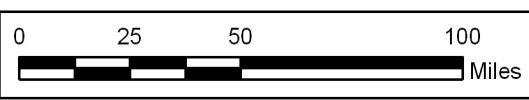
3.1.3 Cenozoic Pecos Alluvium Aquifer

The Cenozoic Pecos Alluvium aquifer is located in the upper part of the Pecos River Valley of West Texas in Andrews, Crane, Crockett, Ector, Loving, Pecos, Reeves, Upton, Ward and Winkler Counties (Figure 3.1-8). Consisting of up to 1,500 feet of alluvial fill, the Cenozoic Pecos Alluvium occupies two hydrologically separate basins: the Pecos Trough in the west and the Monument Draw Trough in the east. The aquifer is hydrologically connected to underlying water-bearing strata, including the Edwards-Trinity in Pecos and Reeves Counties, the Triassic Dockum in Ward and Winkler Counties, and the Rustler in Reeves County.



Legend

- Ogallala Aquifer
- Counties



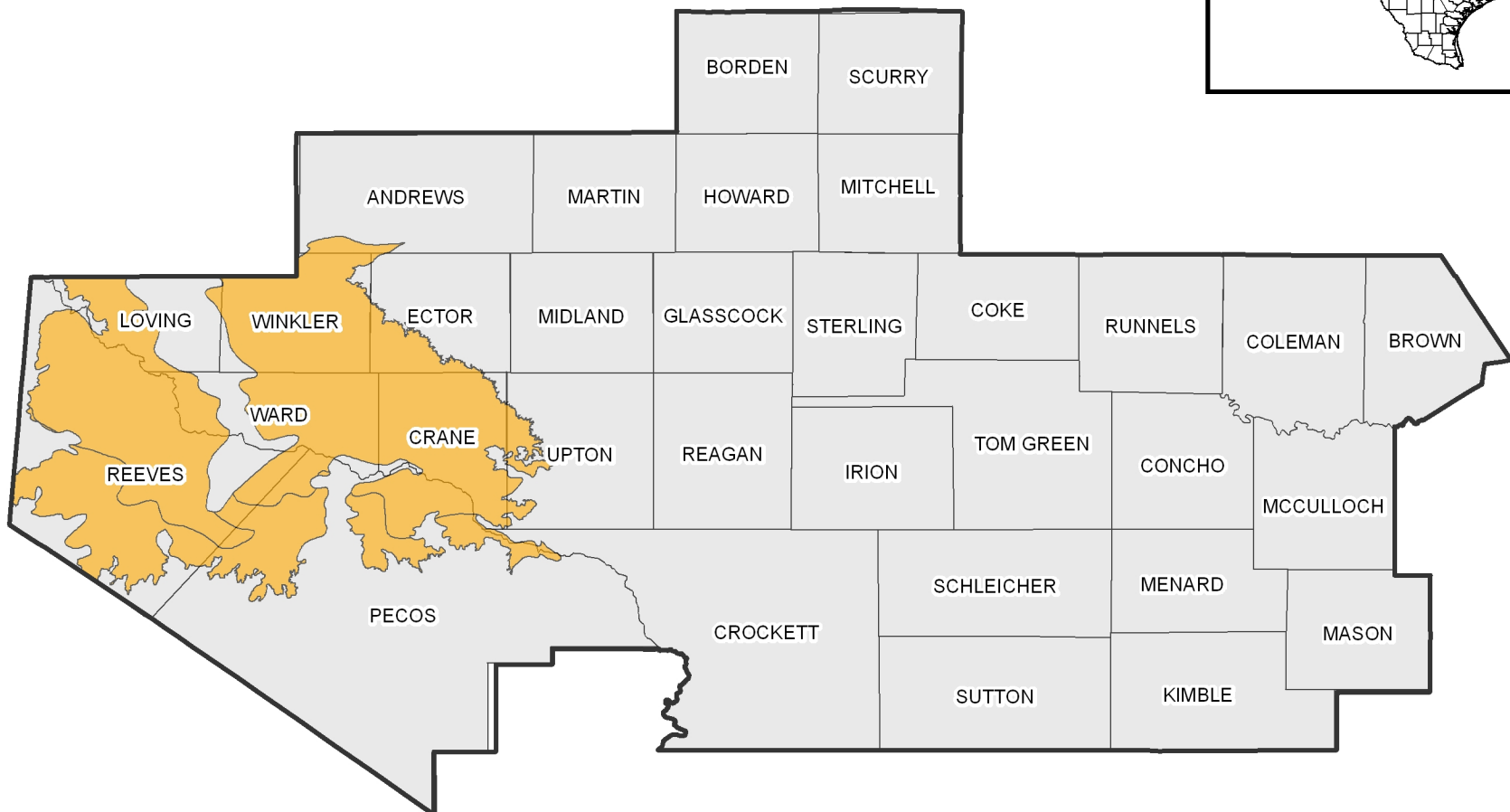
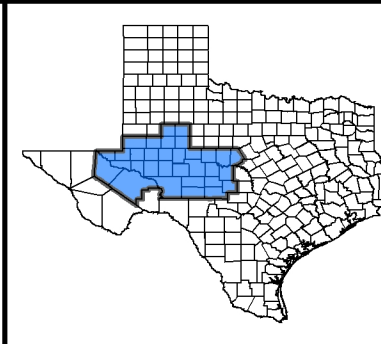
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Ogallala Aquifer

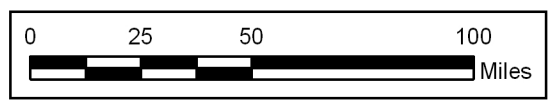
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FIGURE 3.1-7



Legend

- Cenozoic Pecos Alluvium Aquifer
- Counties



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Cenozoic Pecos Alluvium Aquifer

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FIGURE 3.1-8

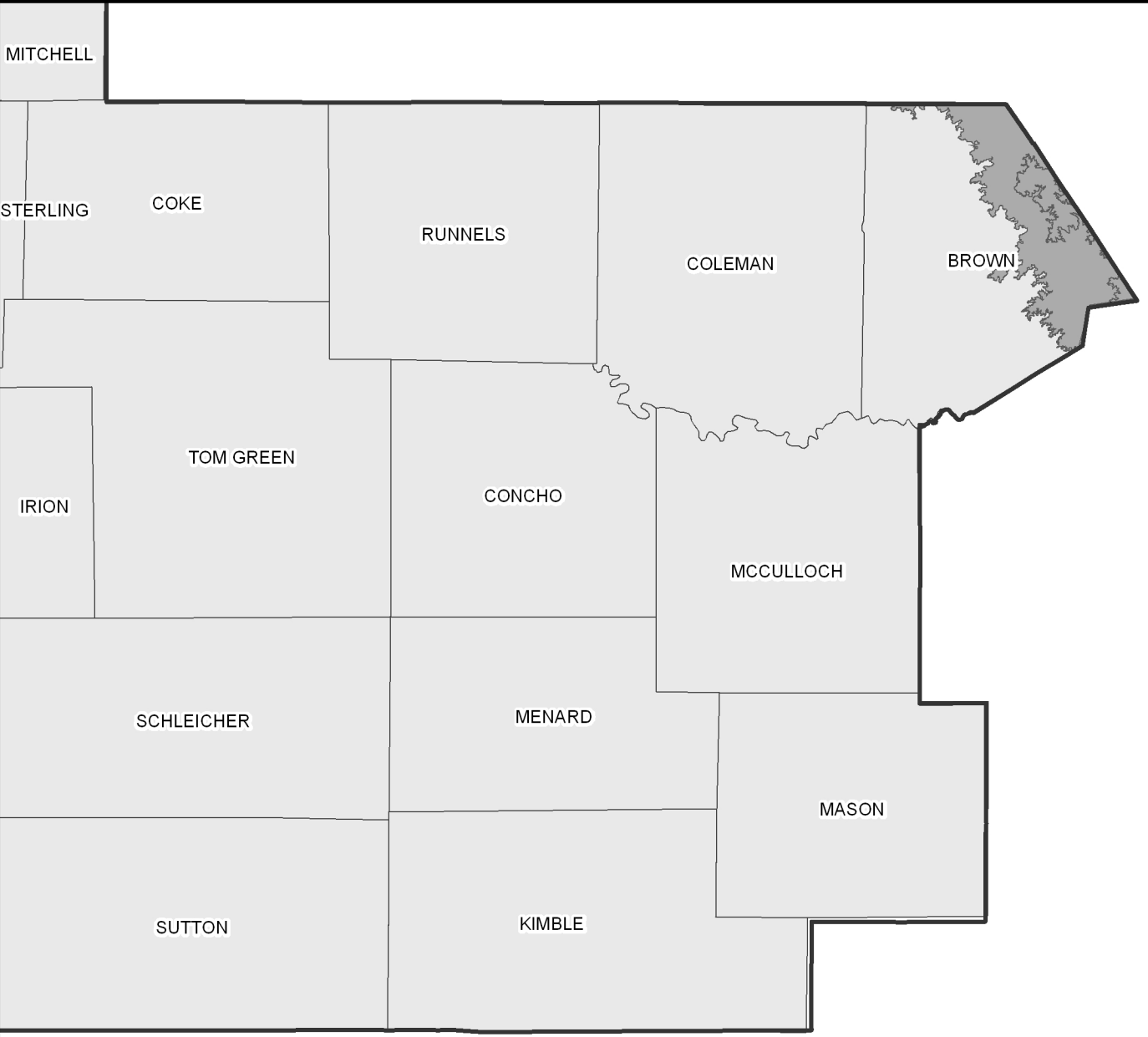
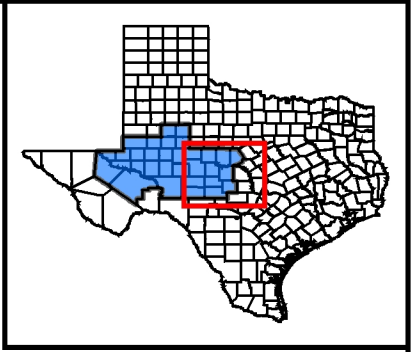
The western basin (Pecos Trough) contains poorer quality water and is used most extensively for irrigation of salt-tolerant crops. The eastern basin (Monument Draw Trough) contains relatively good quality water that is used for a variety of purposes, including industrial use, power generation, and public water supply.

The Cenozoic Pecos Alluvium is the second most used aquifer in the region, representing approximately 31 percent of total groundwater use. Agricultural related consumption (irrigation and livestock) accounts for approximately 80 percent of the total, while municipal consumption and power generation account for about 15 percent of aquifer use. Lateral subsurface flow from the Rustler aquifer into the Cenozoic Pecos Alluvium has significantly affected the chemical quality of groundwater in the overlying western Pecos Trough aquifer. Most of this basin contains water with greater than 1,000 mg/l TDS, and a significant portion is above 3,000 mg/l TDS. The eastern Monument Draw Trough is underlain by the Dockum aquifer but is not as significantly affected by its quality difference. Water levels in the past fifty years have generally been stable. However, in Reeves and Pecos Counties water levels have dropped an average of 80 feet.

3.1.4 Trinity Aquifer

The Trinity aquifer is a primary groundwater source for eastern Brown County (Figure 3.1-9). Small isolated outcrops of Trinity Age rocks also occur in south central Brown County and northwest Coleman County. However, these two areas are not classified as the contiguous Trinity aquifer by the TWDB. Agricultural related consumption (irrigation and livestock) accounts for approximately 80 percent of the total withdrawal from the aquifer.


The Trinity was deposited during the Cretaceous Period and is comprised of (from bottom to top) the Twin Mountains, Glen Rose and Paluxy Formations. In western Brown and Coleman Counties, the Glen Rose is thin or missing and the Paluxy and Twin Mountains coalesce to form the Antlers Sand. The Paluxy consists of sand and shale and is capable of producing small quantities of fresh to slightly saline water. The Twin Mountains formation is composed of sand, gravel, shale, clay and occasional conglomerate, sandstone and limestone beds. It is the principal aquifer and yields moderate to large quantities of fresh to slightly saline water. Maximum thickness of the Trinity aquifer is approximately 200 feet in this area.



Legend

- Trinity Aquifer
- Counties





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Trinity Aquifer

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FIGURE 3.1-9

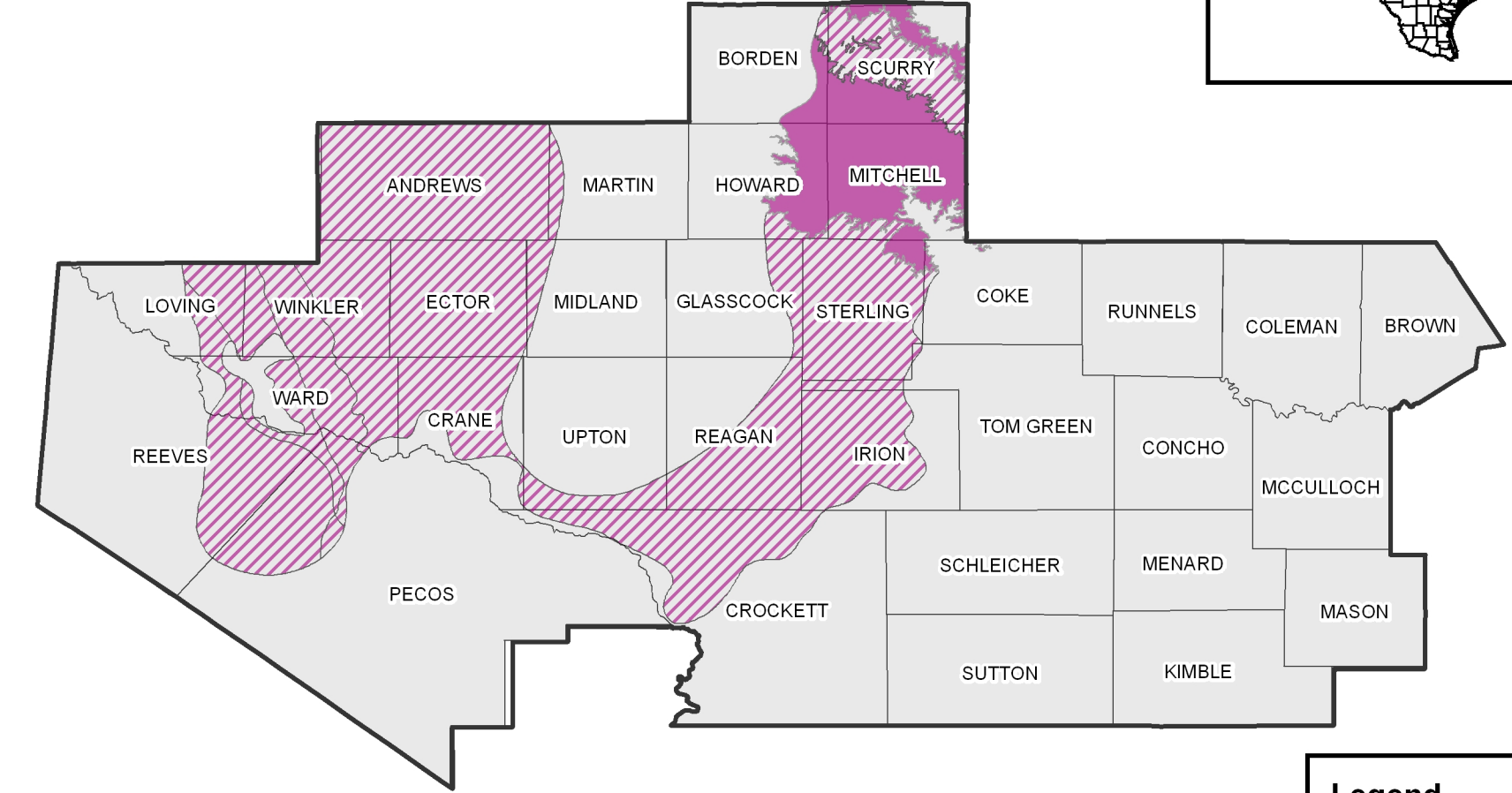
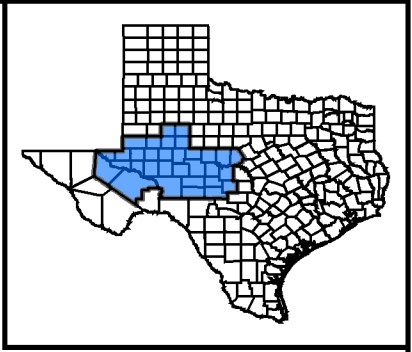
Trinity aquifer water quality is acceptable for most municipal, industrial, and irrigation purposes. Dissolved solids range from approximately 150 to over 7,000 mg/l in Brown County; however, most wells have dissolved solids concentrations of less than 1,000 mg/l. The potential for updip movement of poor quality water exists where large and ongoing water level declines have reversed the natural water level gradient and have allowed water of elevated salinity to migrate back updip toward pumpage centers.

3.1.5 Dockum Aquifer

The Dockum aquifer is used for water supply in 12 counties in Region F, including Andrews, Crane, Ector, Howard, Loving, Mitchell, Reagan, Reeves, Scurry, Upton, Ward and Winkler Counties (Figure 3.1-10). The Dockum outcrops in Scurry and Mitchell Counties, and elsewhere underlies rock formations comprising the Ogallala, Edwards-Trinity, and Cenozoic Pecos Alluvium. Although the Dockum aquifer underlies much of the region, its low water-yielding potential and generally poor quality results in its classification as a minor aquifer.

Most Dockum water used for irrigation is withdrawn in Mitchell and Scurry Counties, while public supply use of Dockum water occurs mostly in Reeves and Winkler Counties. Elsewhere, the aquifer is used extensively for oil field water flooding operations.

The primary water-bearing zone in the Dockum Group, commonly called the “Santa Rosa”, consists of up to 700 feet of sand and conglomerate interbedded with layers of silt and shale. The Santa Rosa abuts the overlying Trinity aquifer along a defined corridor that traverses Sterling, Irion, Reagan and Crockett Counties. Within this corridor, the Trinity and Dockum are hydrologically connected, thus forming a thicker aquifer section. A similar hydrologic relationship occurs in Ward and Winkler Counties, where the Santa Rosa unit of the Dockum is in direct contact with the overlying Cenozoic Pecos Alluvium aquifer. Local groundwater reports use the term “Allurosa” aquifer in reference to this combined section of water-bearing sands.



Legend

Dockum Aquifer

- Outcrop
- Downdip
- Counties



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Dockum Aquifer

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FIGURE 3.1-10

Recharge to the Dockum primarily occurs in Scurry and Mitchell Counties where the formation outcrops at the land surface. As discussed in the previous paragraph, recharge potential also occurs where water-bearing units of the Trinity and Cenozoic Pecos Alluvium directly overlie the Santa Rosa portion of the Dockum. Elsewhere, the Dockum is buried deep below the land surface, is finer grained, and receives very limited lateral recharge. Groundwater pumped from the aquifer in these areas will come directly from storage and will result in water level declines.

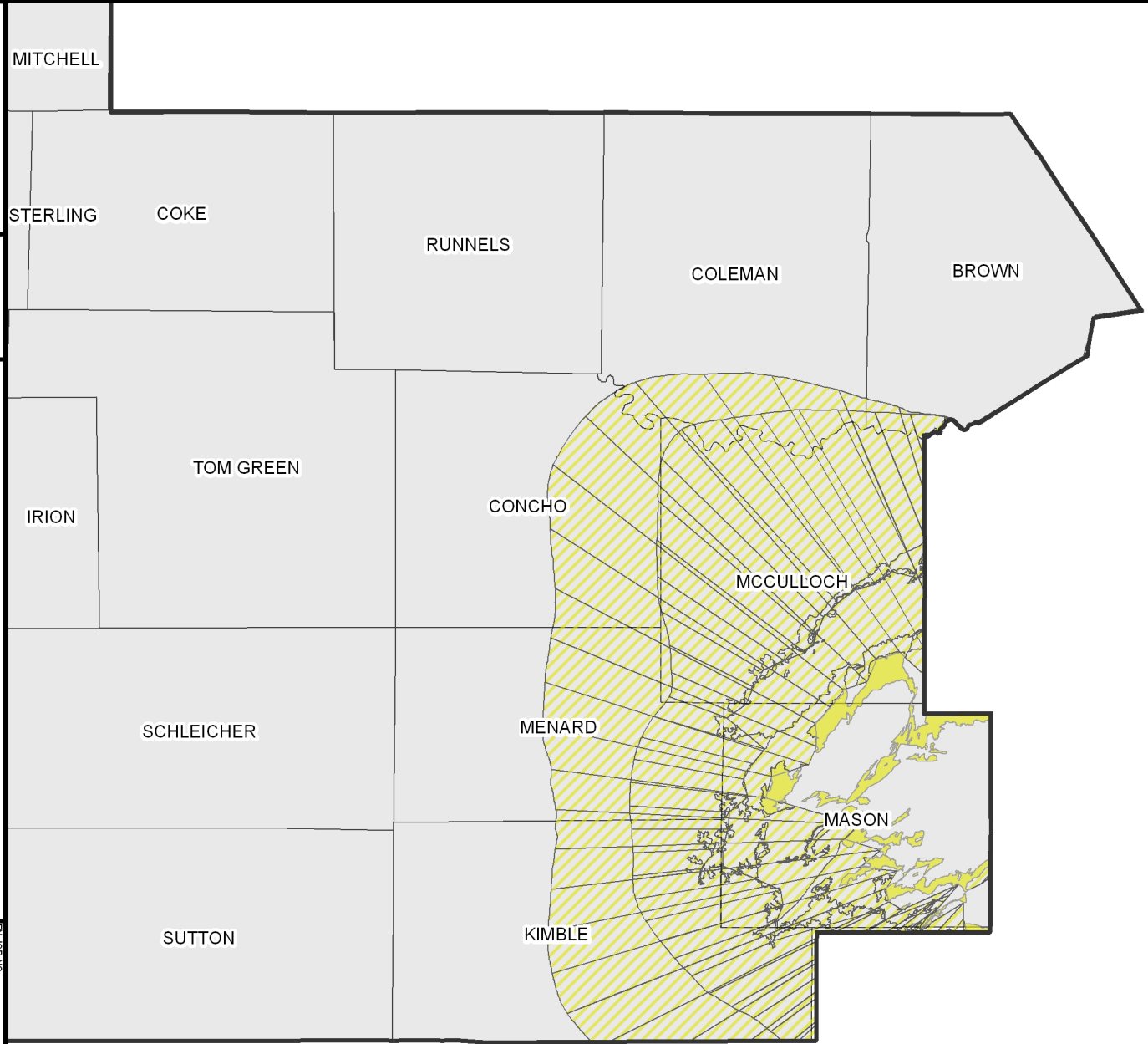
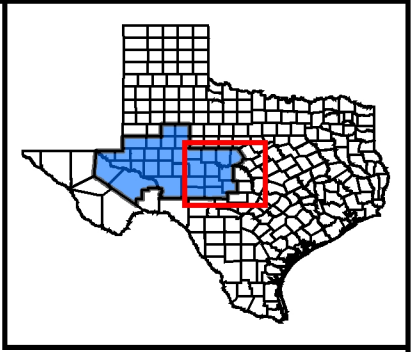
The chemical quality of water from the Dockum aquifer ranges from fresh in outcrop areas to very saline in the deeper central basin area. Groundwater pumped from the aquifer in Region F has average dissolved solids ranging from 558 mg/l in Winkler County to over 2,500 mg/l in Andrews, Crane, Ector, Howard, Reagan and Upton Counties.

3.1.6 Hickory Aquifer

The Hickory aquifer is located in the eastern portion of Region F and outcrops in Mason and McCulloch Counties (Figure 3.1-11). Besides these two counties, this aquifer also supplies groundwater to Concho and Menard Counties. The Hickory Sandstone Member of the Cambrian Riley Formation is composed of some of the oldest sedimentary rocks in Texas. Irrigation and livestock account for approximately 80 percent of the total pumpage, while municipal water use accounts for approximately 18 percent. Mason County uses the greatest amount of water from the Hickory aquifer, most of which is used for irrigation.

In most northern and western portions of the aquifer, the Hickory Sandstone Member can be differentiated into lower, middle and upper units, which reach a maximum thickness of 480 feet in southwestern McCulloch County. Block faulting has compartmentalized the Hickory aquifer, which locally limits the occurrence, movement, productivity, and quality of groundwater within the aquifer.


Hickory aquifer water is generally fresh, with dissolved solids concentrations ranging from 300 to 500 mg/l. Much of the water from the Hickory aquifer exceeds drinking water standards for alpha particles, beta particles and radium particles in the downdip portion of the aquifer. The middle Hickory unit is believed to be the source of alpha, beta and radium concentrations in excess of drinking water standards. The water can also contain radon gas. The upper unit of the



Legend

Hickory Aquifer

- Outcrop
- Downdip
- Counties



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Hickory Aquifer

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FIGURE 3.1-11

Hickory aquifer produces groundwater containing concentrations of iron in excess of drinking water standards. Wells in the shallow Hickory and the outcrop areas have local concentrations of nitrate in excess of drinking water standards.

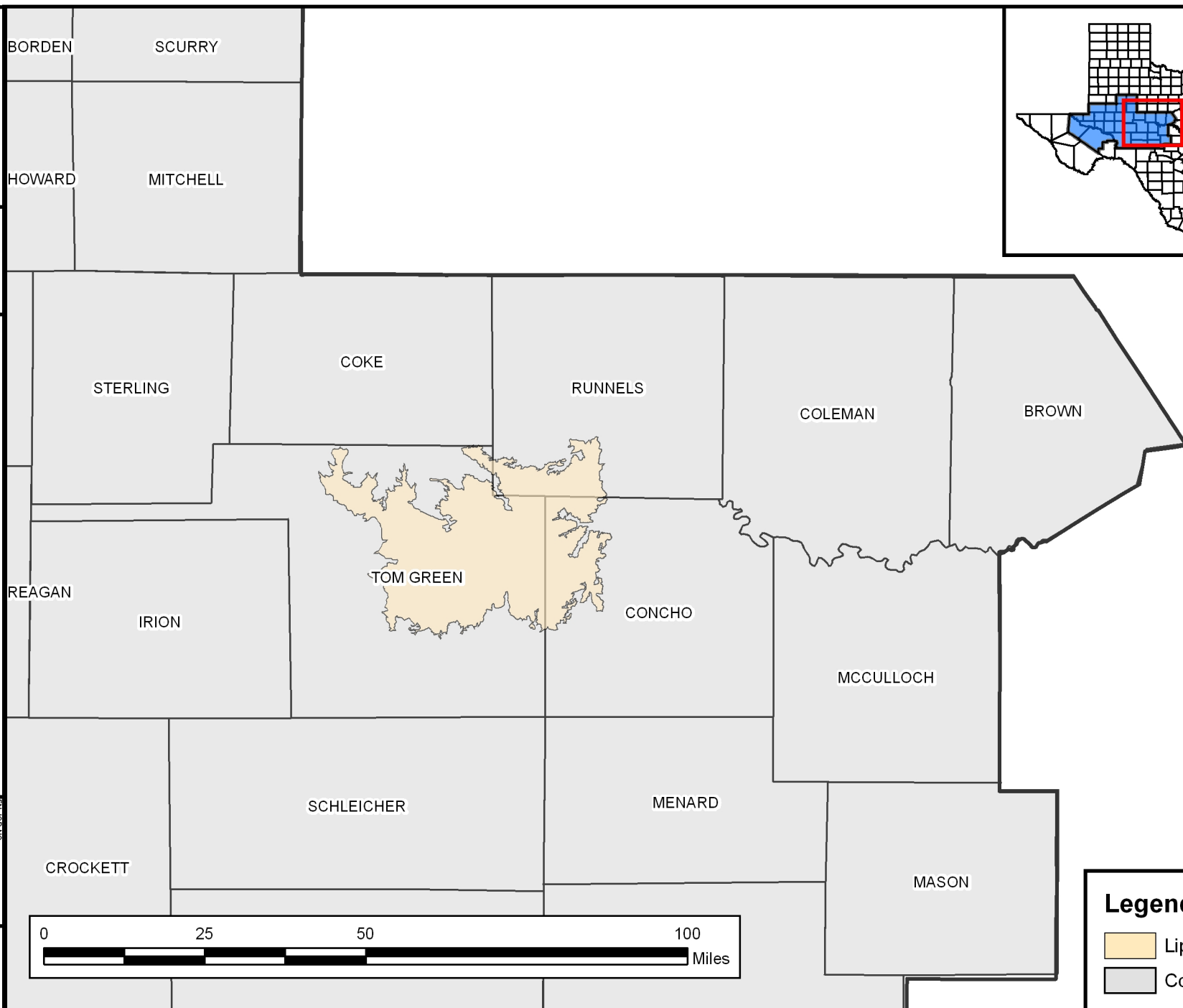
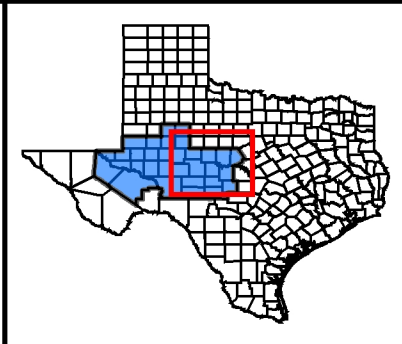
Yields of large-capacity wells usually range between 200 and 500 gpm. Some wells have yields in excess of 1,000 gpm. Highest well yields are typically found northwest of the Llano Uplift, where the aquifer has the greatest saturated thickness.

3.1.7 Lipan Aquifer



The Lipan aquifer occurs in Concho, Runnels and Tom Green Counties (Figure 3.1-12). The aquifer is principally used for irrigation, with limited rural domestic and livestock use. The Lipan aquifer is comprised of saturated alluvial deposits of the Leona Formation and the updip portions of the underlying Choza Formation, Bullwagon Dolomite, and Standpipe Limestone of Permian-age that are hydrologically connected to the Leona. Total thickness of the Leona alluvium ranges from a few feet to about 125 feet. However, most of the groundwater is contained within the underlying Permian units.

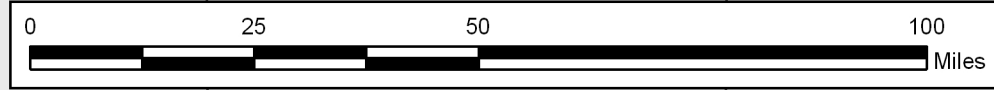
Typical irrigation practice in the area is to withdraw water held in storage in the aquifer during the growing season with expectation of recharge recovery during the winter months. The Lipan-Kickapoo Water Conservation District controls overuse by limiting well density.


Groundwater in the Leona Formation ranges from fresh to slightly saline and is very hard, while water in the underlying updip portions of the Choza, Bullwagon and Standpipe tends to be slightly saline. The chemical quality of groundwater in the Lipan aquifer generally does not meet drinking water standards but is suitable for irrigation. In some cases Lipan water has TDS concentrations in excess of drinking water standards due to influx of water from lower formations. In other cases the Lipan has excessive nitrates because of agricultural activities in the area. Well yields generally range from 20 to 500 gpm with the average well yielding approximately 200 gpm.



Legend

-  Lipan Aquifer
-  Counties





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Lipan Aquifer

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FIGURE 3.1-12

FIGURE

Oil field activities and irrigation practices have affected the quality of the groundwater in the Lipan aquifer. Leaking, abandoned oil wells have allowed brine to infiltrate into fresh-water zones in local areas. Seasonal heavy irrigation pumpage has encouraged the upward migration of poorer quality water from deeper zones. Additionally, irrigation return flow has concentrated minerals in the water through evaporation and the leaching of natural salts from the unsaturated zone.

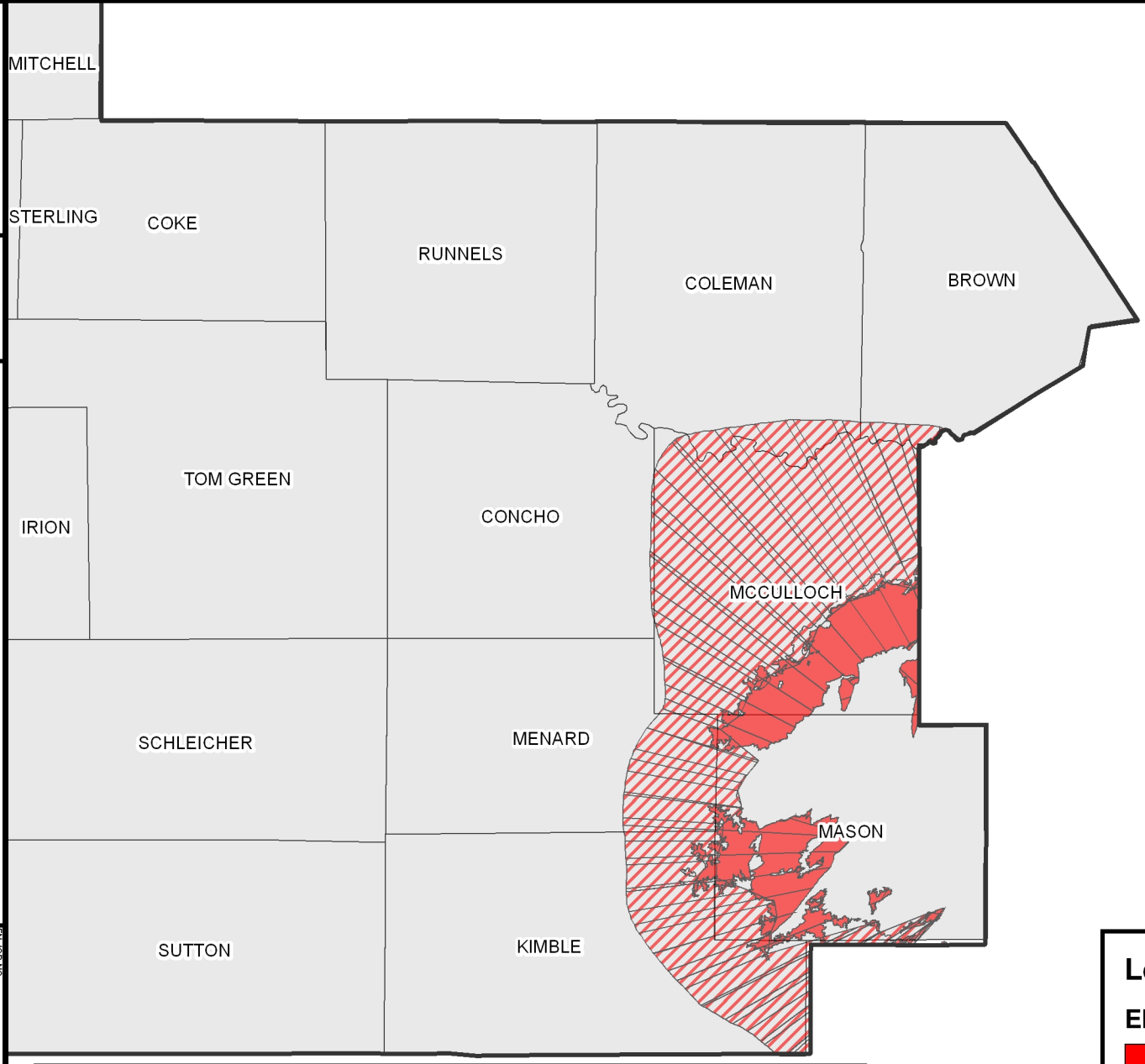
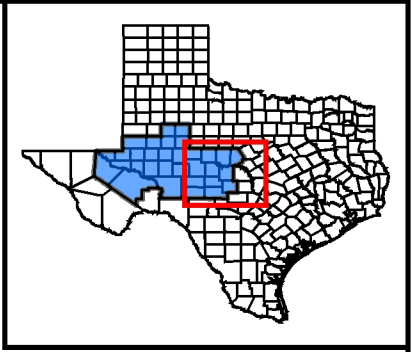
3.1.8 Ellenburger-San Saba Aquifer

Including the downdip boundary as designated by the TWDB, the Ellenburger-San Saba aquifer occurs in Brown, Coleman, Kimble, Mason, McCulloch and Menard Counties within Region F (Figure 3.1-13). Currently, most pumpage from the aquifer occurs in McCulloch County. In Brown and Coleman Counties, the aquifer is present in only the extreme southern part, and most of the aquifer in this area contains water in excess of 1,000 mg/l TDS. The downdip boundary of the aquifer, which represents the extent of water with less than 3,000 mg/l TDS, is roughly estimated due to lack of data.

The Ellenburger-San Saba aquifer is comprised of the Cambrian-age San Saba member of the Wilberns Formation and the Ordovician-age Ellenburger Group, which includes the Tanyard, Gorman and Honeycut Formations. Discontinuous outcrops of the aquifer generally encircle older rocks in the core of the Llano Uplift. The maximum thickness of the aquifer is about 1,100 feet. In some areas, where the overlying beds are thin or absent, the Ellenburger-San Saba aquifer may be hydrologically connected to the Marble Falls aquifer. Local and regional block faulting has significantly compartmentalized the Ellenburger-San Saba, which locally limits the occurrence, movement, productivity, and quality of groundwater within the aquifer.




Water produced from the aquifer has a range in dissolved solids between 200 and 3,000 mg/l, but is usually less than 1,000 mg/l. The quality of water deteriorates rapidly away from outcrop areas. Approximately 20 miles or more downdip from the outcrop, water is typically unsuitable for most uses. All the groundwater produced from the aquifer is inherently hard.

Principal use from the aquifer is for livestock supply in Mason and McCulloch Counties, and a minor amount in Menard County. Maximum yields of large-capacity wells generally range between 200 and 600 gpm, most other wells typically yield less than 100 gpm.




Legend

Ellenburger-San Saba Aquifer

-  Outcrop
-  Downdip
-  Counties





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Ellenburger-San Saba Aquifer

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FIGURE 3.1-13

3.1.9 Marble Falls Aquifer

The Marble Falls is the smallest aquifer in the region, occurring in very limited outcrop areas in Kimble, Mason and McCulloch Counties (Figure 3.1-14). Groundwater in the aquifer occurs in fractures, solution cavities, and channels in the limestones of the Marble Falls Formation of the Pennsylvanian-age Bend Group. Where underlying beds are thin or absent, the Marble Falls and Ellenburger-San Saba aquifers may be hydrologically connected.

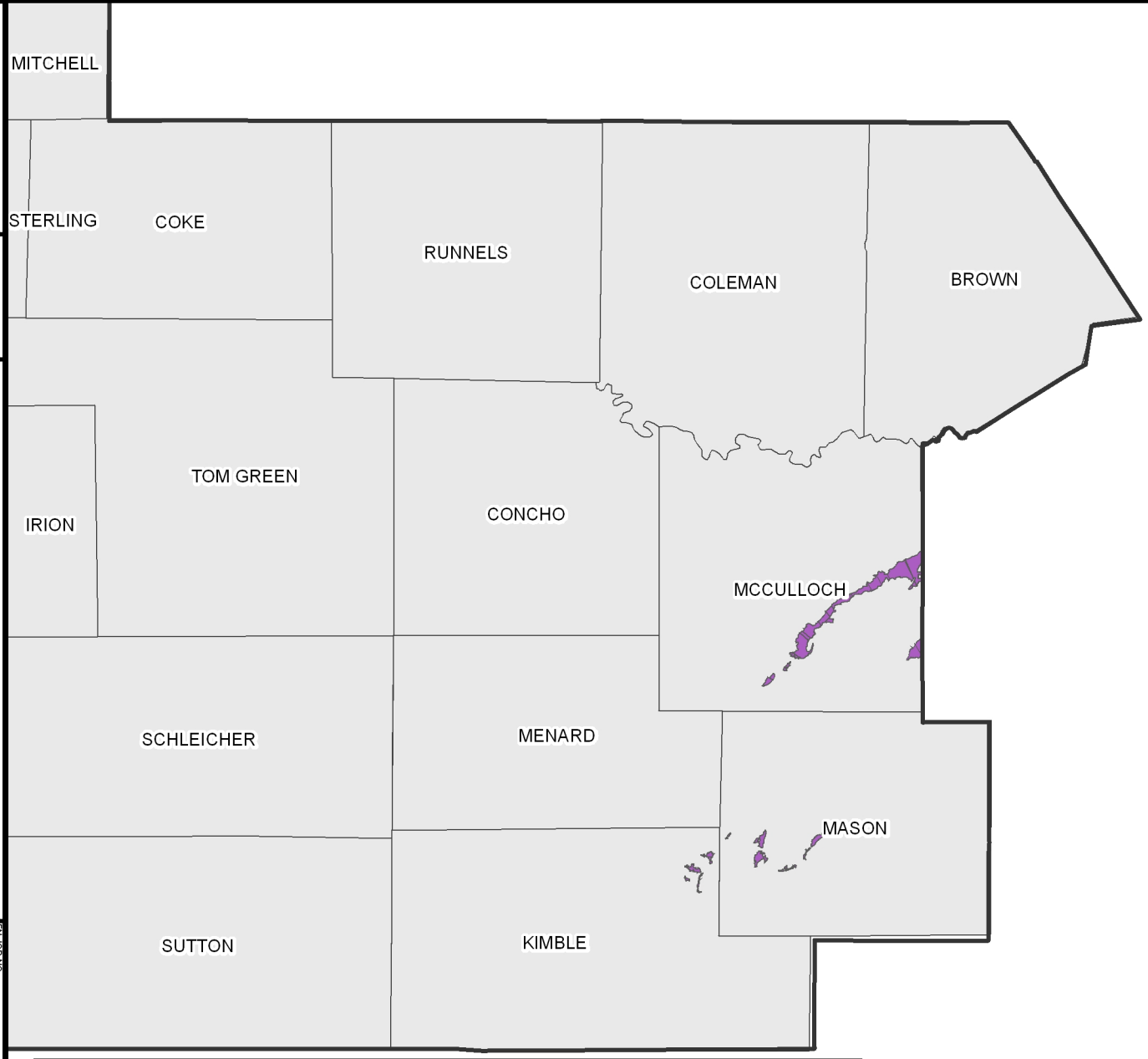
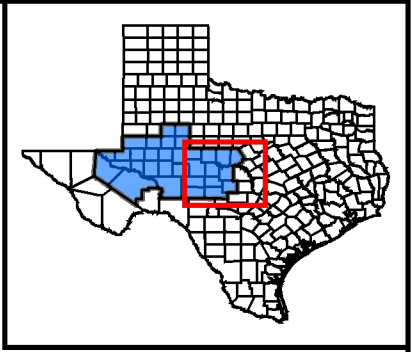
A limited amount of well data suggests that water quality is acceptable for most uses only in wells located on the outcrop and in wells that are less than 300-feet deep in the downdip portion of the aquifer. The downdip artesian portion of the aquifer is not extensive, and water becomes significantly mineralized within a relatively short distance downdip from the outcrop area. Most water produced from the aquifer occurs in Mason County, with lesser amounts in McCulloch County.

3.1.10 Rustler Aquifer



The Rustler Formation outcrops outside of Region F in Culberson County, but the majority of its downdip extent occurs in Loving, Pecos, Reeves and Ward Counties (Figure 3.1-15). The Rustler Formation consists of 200 to 500 feet of anhydrite and dolomite with a basal zone of sandstone and shale deposited in the ancestral Permian-age Delaware Basin. Water is produced primarily from highly permeable solution channels, caverns and collapsed breccia zones.


Groundwater from the Rustler Formation may locally migrate upward, impacting water quality in the overlying Edwards-Trinity and Cenozoic Pecos Alluvium aquifers. The Rustler is primarily used for livestock watering and a minor amount of irrigation, mostly in Pecos County.

Throughout most of its extent, the Rustler is relatively deep below the land surface, and generally contains water with dissolved constituents (TDS) well in excess of 3,000 mg/l. Only in western Pecos, eastern Loving and southeastern Reeves Counties has water been identified that contains less than 3,000 mg/l TDS. The dissolved-solids concentrations increase down gradient, eastward into the basin, with a shift from sulfate to chloride as the predominant anion. No groundwater from the Rustler aquifer has been located that meets drinking water standards.



Legend

-  Marble Falls Aquifer
-  Counties



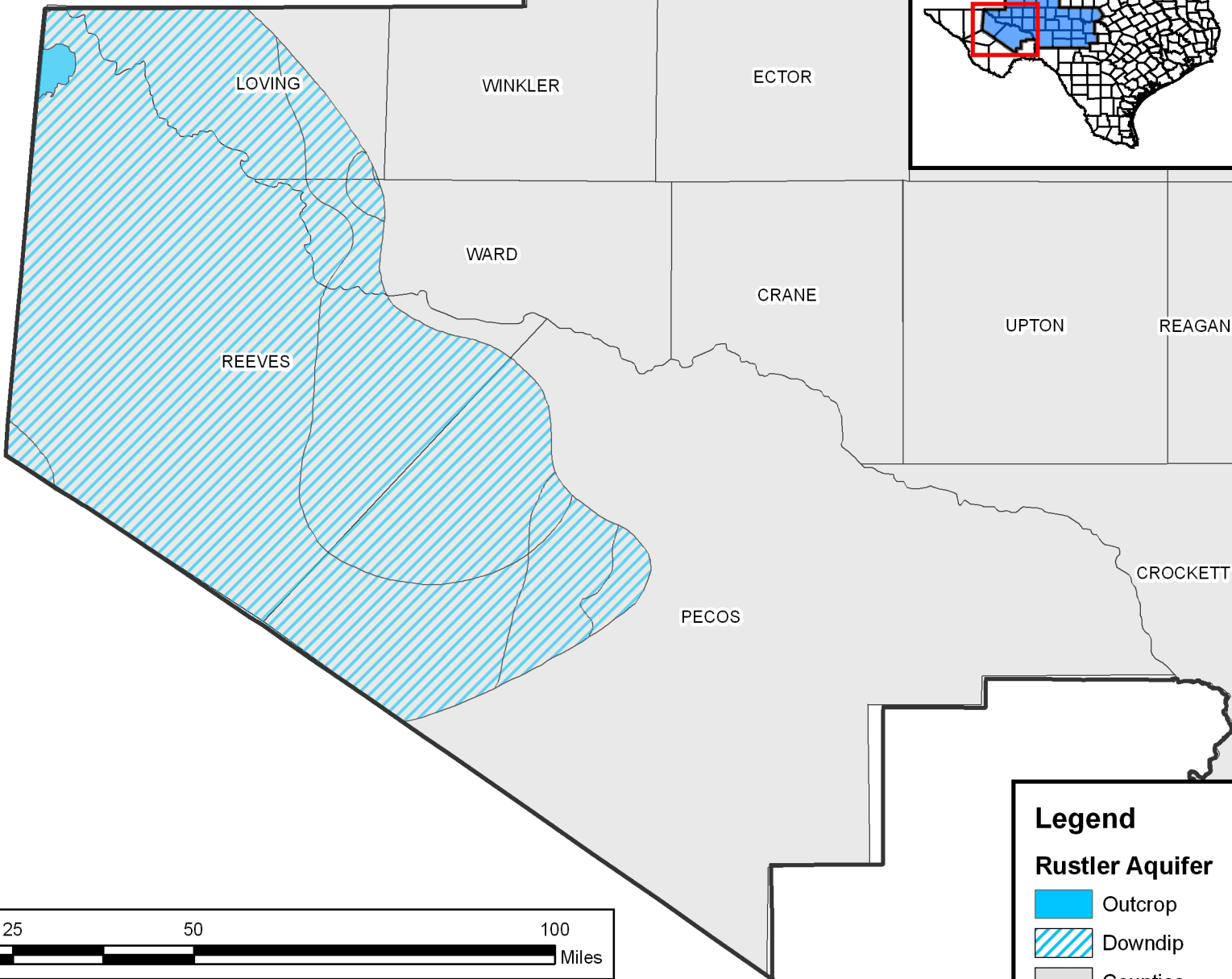
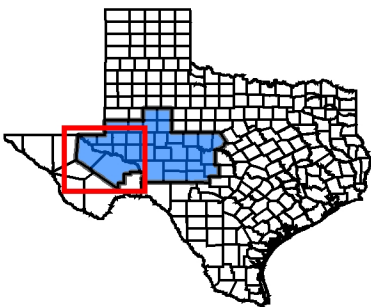
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Marble Falls Aquifer

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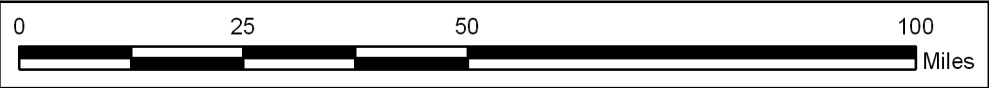
FIGURE 3.1-14



Legend

Rustler Aquifer

- Outcrop
- Downdip
- Counties



Region F Water Plan

Rustler Aquifer

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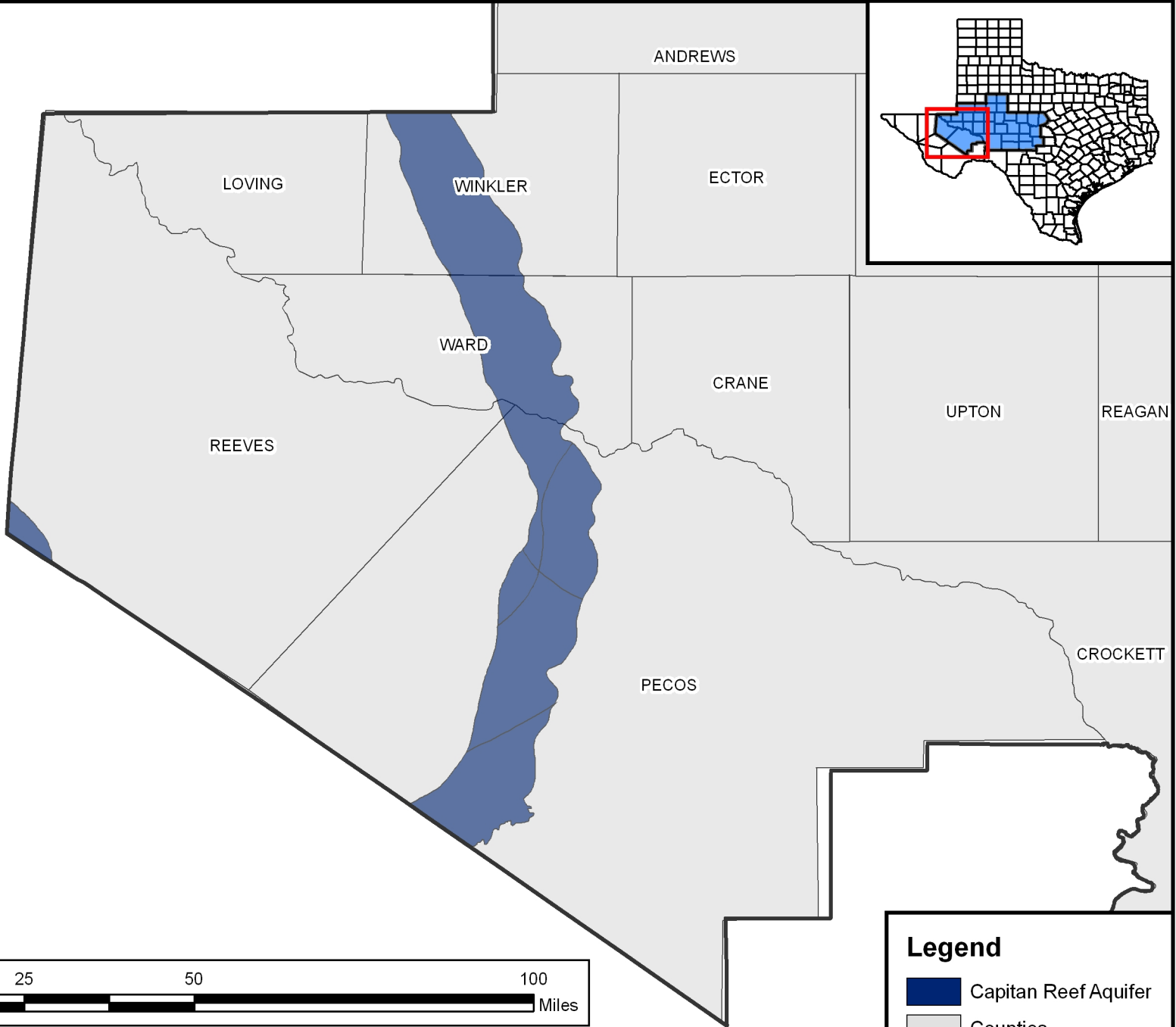
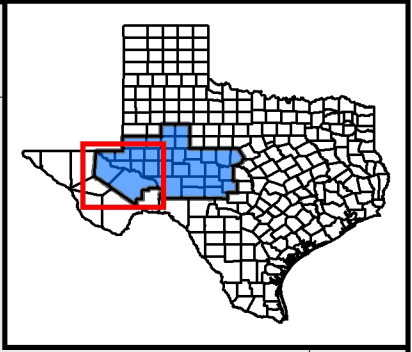
3.1.11 Capitan Reef Aquifer

The Capitan Reef formed along the margins of the ancestral Delaware Basin, an embayment covered by a shallow sea in Permian time. In Texas, the reef parallels the western and eastern edges of the basin in two arcuate strips 10 to 14 miles wide and is exposed in the Guadalupe, Apache and Glass Mountains. From its exposure in the Glass Mountains in Brewster and southern Pecos Counties, the reef plunges underground to a maximum depth of 4,000 feet in northern Pecos County. The reef trends northward into New Mexico where it is a major source of water in the Carlsbad area.

The aquifer is composed of up to 2,000 feet of massive, vuggy to cavernous dolomite, limestone and reef talus. Water-bearing formations associated with the aquifer system include the Capitan Limestone, Goat Sheep Limestone, and most of the Carlsbad facies of the Artesia Group, which includes the Grayburg, Queen, Seven Rivers, Yates and Tansill Formations. The Capitan Reef aquifer underlies the Cenozoic Pecos Alluvium, Edwards-Trinity (Plateau), Dockum and Rustler aquifers in Pecos, Ward and Winkler Counties (Figure 3.1-16).

The aquifer generally contains water of marginal quality, with TDS concentrations ranging between 3,000 and 22,000 mg/l. High salt concentrations in some areas are probably caused by migration of brine waters injected for secondary oil recovery. The freshest water is located near areas of recharge where the reef is exposed at the surface. Yields of wells commonly range from 400 to 1,000 gpm.



Most of the groundwater pumped from the aquifer has historically been used for oil reservoir water-flooding operations in Ward and Winkler Counties. A few irrigation wells have also tapped the aquifer in Pecos County. Otherwise, very little reliance has been placed on this aquifer due to its depth, limited extent, and marginal quality. The Capitan Reef aquifer may be a potential of brackish water supply for desalination treatment.



Legend

- Capitan Reef Aquifer
- Counties



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	<p>Capitan Reef Aquifer</p>		<p>FILE H/Capitan Reef.mxd</p>	
		<p>SCALE 1:1,358,000</p>	<p>3.1-16</p>	
		<p>DATE March 11, 2005</p>	<p>FIGURE</p>	
		<p>DESIGNED G.G.J.</p>		
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3.1.12 Brackish Groundwater Availability

Additional supplies of water in Region F may be obtained from the desalination of existing brackish or saline water sources. Desalination technology is improving, and costs are continuing to decrease, meaning more brackish groundwater supplies may become economically feasible to use as a water supply to meet regional water demands.

Many of the major and minor aquifers in Region F contain significant quantities of groundwater with TDS concentrations ranging between 1,000 and 5,000 mg/l. While some of this water is currently being used for agricultural and industrial purposes, much of it remains unused.

It is unlikely that desalination will be sufficiently economical to be a significant supply for end uses such as irrigated agriculture.

Although extensive brackish and saline water occurs in the deep, typically hydrocarbon-producing formations throughout Region F, for the most part these are not effective water supplies for meeting regional water demands. Many of these formations typically produce groundwater with very high salinities and are found at depths too great to be economically feasible as a water supply. It should be noted that most of the deeper, hydrocarbon-producing formations do have some potential to produce brackish groundwater at reasonable rates from shallower depths in and near where they outcrop, which for many of these units is in the eastern third of the region. If areas in or near the outcrop area of any of these deeper units are to be targeted, additional data and study on a site-specific basis will be required.

Additional information on brackish water supplies may be found in Appendix 3A.

3.2 Existing Surface Water Supplies

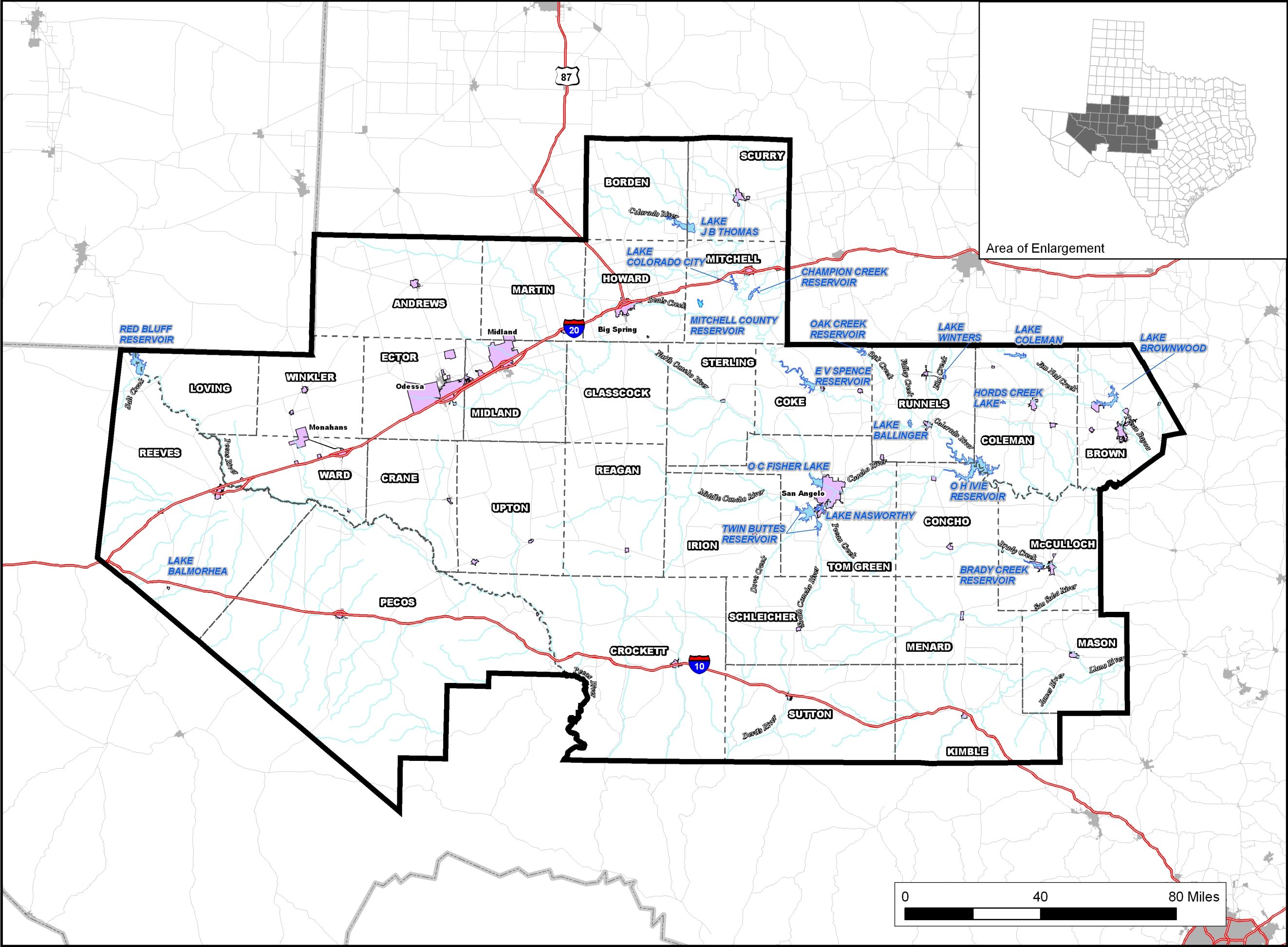
In the year 2000, approximately 187,000 acre-feet of surface water was used in Region F, supplying 31 percent of the water supply in the region. Surface water from reservoirs provides most of the municipal water supply in Region F. Run-of-the-river water rights are used primarily for irrigation. Table 3.2-1 shows information regarding the 18 major reservoirs in Region F. Figure 3.2-1 shows the location of these reservoirs. Additional information regarding water rights and historical water use may be found in Chapter 1. A comprehensive list of Region F water rights may be found in Appendix 3B.

**Table 3.2-1
Major Reservoirs in Region F**

Reservoir Name	Basin	Stream	County(ies)	Water Right Number(s)	Priority Date	Permitted Conservation Storage (Acre-Feet)	Permitted Diversion (Acre-Feet per Year)	Owner	Water Rights Holder(s)
Lake J. B. Thomas	Colorado	Colorado River	Borden and Scurry	CA-1002	08/05/1946	204,000	30,000 *	CRMWD	CRMWD
Lake Colorado City	Colorado	Morgan Creek	Mitchell	CA-1009	11/22/1948	29,934	5,500	TXU	TXU
Champion Creek Reservoir	Colorado	Champion Creek	Mitchell	CA-1009	04/08/1957	40,170	6,750	TXU	TXU
Oak Creek Reservoir	Colorado	Oak Creek	Coke	CA-1031	04/27/1949	30,000	10,000	City of Sweetwater	City of Sweetwater
Lake Coleman	Colorado	Jim Ned Creek	Coleman	CA-1702	08/25/1958	40,000	9,000	City of Coleman	City of Coleman
E. V. Spence Reservoir	Colorado	Colorado River	Coke	CA-1008	08/17/1964	488,760	43,000 *	CRMWD	CRMWD
Mitchell County Reservoir	Colorado	Off-channel	Mitchell		2/14/1990	27,266			
Lake Winters/ New Lake Winters	Colorado	Elm Creek	Runnels	CA-1095	12/18/1944	8,347	1,755	City of Winters	City of Winters
Lake Brownwood	Colorado	Pecan Bayou	Brown	CA-2454	09/29/1925	114,000	29,712	Brown Co. WID	Brown Co. WID
Hords Creek Lake	Colorado	Hords Creek	Coleman	CA-1705	03/23/1946	7,959	2,260	COE	City of Coleman
Lake Ballinger / Lake Moonen	Colorado	Valley Creek	Runnels	CA-1072	10/04/1946	6,850	1,000	City of Ballinger	City of Ballinger
O. H. Ivie Reservoir	Colorado	Colorado River	Coleman, Concho and Runnels	A-3866 P-3676	02/21/1978	554,340	113,000	CRMWD	CRMWD
O. C. Fisher Lake	Colorado	North Concho River	Tom Green	CA-1190	05/27/1949	119,000	80,400	COE	Upper Colorado River Authority
Twin Buttes Reservoir	Colorado	South Concho River	Tom Green	CA-1318	05/06/1959	186,000	29,000	U.S. Bureau of Reclamation	City of San Angelo
Lake Nasworthy	Colorado	South Concho River	Tom Green	CA-1319	03/11/1929	12,500	25,000	City of San Angelo	City of San Angelo
Brady Creek Reservoir	Colorado	Brady Creek	McCulloch	CA-1849	09/02/1959	30,000	3,500	City of Brady	City of Brady
Red Bluff Reservoir	Rio Grande	Pecos River	Loving and Reeves	CA-5438	01/01/1980	300,000	292,500	Red Bluff Water Power Control District	Red Bluff Water Power Control District
Lake Balmorhea	Rio Grande	Toyah Creek	Reeves	A-0060 P-0057	10/05/1914	13,583	41,400	Reeves Co WID #1	Reeves Co WID #1
<i>Total</i>						<i>2,212,709</i>	<i>723,777</i>		

Note: A major reservoir has more than 5,000 acre-feet of storage.

* Total diversions under CA 1002 and CA 1008 limited to 73,000 acre-feet per year. 7,000 ac-ft per year can be diverted at either Thomas or Spence.



3.2-1

Figure

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Region F

Major Reservoirs

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Freese and Nichols

4055 International Plaza Suite 200

Fort Worth, Texas 76109-4895

817-735-7300

All surface water supplies in this chapter are derived from Water Availability Models (WAMs) developed by the Texas Commission on Environmental Quality (TCEQ). The TWDB requires the use of the Full Authorization Run (Run 3) of the approved TCEQ WAM for each basin as the basis for water availability in regional water planning¹. Three WAM models are available in Region F: (a) the Colorado WAM, which covers most of the central and eastern portions of the region, (b) the Rio Grande WAM, which covers the Pecos Basin, and (c) the Brazos WAM. There are approximately 492,000 acre-feet of permitted diversions in the Colorado Basin in Region F, slightly more than half of the permitted diversions in the region. There are 481,144 acre-feet of permitted diversions in the Rio Grande Basin. There is one water right in the Brazos Basin in Region F with a permitted diversion of 63 acre-feet per year.

Table 3.2-2 compares the firm yield of the 17 major reservoirs in Region F used in the 1997 State Water Plan², the 2001 Region F Plan³, and from the TCEQ WAM⁴ (Mitchell County Reservoir was not included in the 1997 or 2001 water plans). Table 3.2-3 compares run-of-the-river supplies from the 2001 Region F Plan to the supplies from the TCEQ WAM. (In most cases, the run-of-the-river supplies from the 2001 Region F Plan are identical to those used in the 1997 State Water Plan.) The supplies derived using the WAM are very different from those assumed in previous plans. Total supplies from reservoirs are about 75 percent of that assumed in the 2001 Region F Plan. Total run-of-the-river supplies are about one third of the supplies in the previous plan. Nearly all of the supply reductions are associated with sources in the Colorado Basin.

The reason for this change is that previous studies made significantly different assumptions about the availability of water supplies in the Colorado Basin. The WAMs assume that priority of diversion and storage determines water availability regardless of geographic location, the type of right, or purpose of use. Previous water plans assumed that municipal reservoir supplies in the Colorado Basin were not subject to priority calls by senior water rights. The methodology used to develop run-of-the-river supplies in the previous state water plans is not well documented. (Run-of-the-river supplies from the 1997 plan were adopted for the 2001 Region F Plan.) It is unclear why the WAM shows less run-of-the-river supplies in the Colorado Basin.

TWDB requires the use of the TCEQ WAM for regional water planning even though the Colorado WAM uses many assumptions that are very different than the way that the basin has

Table 3.2-2
Comparison of Firm Yields of Region F Reservoirs from the 1997 State Water Plan, the
2001 Region F Plan, and the TCEQ Water Availability Model
(Values in Acre-Feet per Year)

Reservoir Name	Basin	Yield from 1997 State Water Plan^a	Yield from 2001 Region F Plan^a	WAM Firm Yield^b
Lake J. B. Thomas	Colorado	151,800 ^c	9,900	100 ^d
E. V. Spence Reservoir	Colorado		38,776	
O. H. Ivie Reservoir	Colorado		96,169	
Lake Colorado City	Colorado	5,500	4,550	0
Champion Creek Reservoir	Colorado	5,000	4,081	10
Oak Creek Reservoir	Colorado	4,800	5,684	5
Lake Coleman	Colorado	7,090	8,822	5
Lake Winters/ New Lake Winters	Colorado	1,160	1,407	0
Lake Brownwood	Colorado	31,400	41,800	47,200 ^e
Hords Creek Lake	Colorado	1,200	1,425	0
Lake Ballinger / Lake Moonen	Colorado	1,600	3,566	30
O. C. Fisher Lake	Colorado	13,200	2,973	0
Twin Buttes Reservoir	Colorado	31,400	8,900	10 ^d
Lake Nasworthy	Colorado	500	7,900	
Brady Creek Reservoir	Colorado	3,100	2,252	
Red Bluff Reservoir	Rio Grande	32,000	31,000	41,725 ^e
Lake Balmorhea	Rio Grande	1,000	182	0
<i>Total</i>		<i>290,750</i>	<i>269,387</i>	<i>202,085</i>

a 1997 and 2001 Water Plan yields are for year 2000 sediment conditions

b WAM yields are for original sediment conditions except where noted

c Individual yields not reported for Thomas, Spence or Ivie in the 1997 State Water Plan

d Individual yields not computed in the Colorado WAM report

e WAM yield using year 2000 sediment conditions at reservoir

historically been operated. More detailed information about these assumptions may be found in Appendix 3C. It is the opinion of the Region F Water Planning Group that the Colorado WAM does not give a realistic assessment of water supplies for planning purposes because it ignores the historical operation of the basin and previous agreements among water right holders. Requiring use of the Colorado WAM for regional planning is a significant policy shift by the State of Texas that overturns years of water planning in the Colorado Basin, including the 1997

Table 3.2-3
Comparison of Run-of-the-River Supplies from Previous State Water Plans to Supplies
from the Water Availability Models^a
(Values in Acre-Feet per Year)

County	1997 and 2001 Plan Supplies	WAM Supplies	Increase (Decrease) in Yield
Andrews	125	0	(125)
Borden	145	0	(145)
Brown	3,256	778	(2,478)
Coke	275	48	(227)
Coleman	2,326	31	(2,295)
Concho	727	263	(464)
Crane	1,434	0	(1,434)
Crockett	361	0	(361)
Ector	1,800	23	(1,777)
Howard	24	0	(24)
Irion	1,980	580	(1,400)
Kimble	3,502	1,488	(2,014)
Loving	0	0	0
Martin	550	0	(550)
Mason	0	0	0
McCulloch	550	128	(422)
Menard	3,792	3,238	(554)
Midland	1,400	0	(1,400)
Mitchell	235	15	(220)
Pecos	0	4,444	4,444
Reagan	0	0	0
Reeves	182	0	(182)
Runnels	5,500	771	(4,729)
Schleicher	0	0	0
Scurry	1,170	69	(1,101)
Sterling	0	48	48
Sutton	475	8	(467)
Tom Green	15,839	3,454	(12,385)
Upton	0	0	0
Ward	0	0	0
Winkler	0	0	0
<i>Total</i>	<i>45,648</i>	<i>15,386</i>	<i>(30,262)</i>

a Does not include unpermitted supplies for livestock or diverted water from CRMWD chloride projects

and 2001 State Water Plans, and ignores many existing agreements among water rights holders in the basin. Using the WAM for water supply planning tends to overestimate available supplies in the lower Colorado River Basin, while underestimating available supplies in the upper basin.

In order to address these water supply issues, a joint modeling effort was conducted with the Lower Colorado Regional Water Planning Group (Region K). This modeling effort analyzed the impact of subordination of major senior water rights in the lower Colorado Basin to major water rights in Region F, as well as subordination of major Region F water rights to each other. The subordination strategy and the results of the subordination modeling are described in Chapter 4.

3.3 Alternative Water Supplies

This section highlights sources of water that have not traditionally been used for water supply, but which could potentially be a significant resource for consideration in future water planning. In Region F, these sources include desalination of brackish water (groundwater and surface water) and reclaimed water.

This section provides information about the current status of alternative water supplies in Region F. Information on brackish groundwater sources may be found in Section 3.1.12. Potential strategies using brackish water or reuse may be found in Chapter 4.

3.3.1 Desalination

Desalination processes are used to treat water for use as a public water supply, or for non-potable uses sensitive to the salt content of the water. Desalination can be defined as any process that removes salts from water.⁵ The Texas secondary drinking water standard for chloride is 300 mg/l. Consumers can generally detect a salty taste in water that has chloride concentration above about 250 mg/l. However, because chloride is only one component of the dissolved solids typically present in water, the specific taste threshold for TDS is difficult to pinpoint.⁶ The Texas secondary drinking water standard for TDS is 1,000 mg/l. Although secondary standards are recommended limits and not required limits, TWDB will not fund a municipal project that uses a water source with TDS greater than 1,000 mg/l unless desalination is part of the planned treatment process, greatly increasing the cost of new water supplies. Region F believes that this policy should be revised allowing for local conditions such as the economy, availability of water,

community concerns for the aesthetic of water, and technologies such as point-of use on a voluntary basis.

Water is considered brackish if the total dissolved solids (TDS) range from 1,000 mg/l to 10,000 mg/l. Brackish waters have historically not been considered a water supply source except in limited applications. Until recently desalination of brackish waters was too expensive to be a feasible option for most public water suppliers. However, the costs associated with desalination technology have declined significantly in recent years, making it more affordable for communities to implement. If an available source of brackish water is nearby, desalination can be as cost-effective as transporting better quality water a large distance. There is also little competition for water from brackish sources because very little brackish water is currently used for other purposes, making it easier to develop brackish sources.

Two factors significantly impact the cost-effectiveness of desalination: water quality and disposal options. Treatment costs are directly correlated to the quality of the source water. Use of brackish waters with higher ranges of TDS may not be cost-effective. The presence of other constituents, such as calcium sulfate, may also impact the cost-effectiveness of desalination. The disposal of brine waste from the desalination process can be a significant portion of the costs of a project. The least expensive option is discharge to a receiving body of water or land application. However, a suitable receiving body with acceptable impacts to the environment may not be available. Disposal by deep well injection is the most likely practical and cost-effective method of disposal for large-scale desalination projects in Region F. However, current permitting policy for deep-well injection treats the brine waste from desalination the same as a hazardous chemical waste, requiring a Class I or V permit depending on the native water quality of the injection zone and the quality of the injected brine. If the native water quality in the injection zone is 10,000 mg/l or less, then the underground reservoir is classified as an Underground Source of Drinking Water (USDW) and will likely require a Class V Authorization supplemented with portions of a Class I application. Therefore the time and cost for permitting can be substantial. However, the disposal of water from oil field operations, which is similar or worse in quality to the reject from desalination, requires a Class II permit from the Railroad Commission of Texas, which has a less intensive permitting process. A streamlined permitting process would greatly increase the economic feasibility of large-scale desalination projects in West Texas.

TWDB is currently developing a database of the desalination facilities operating in Texas. The starting point for development of the database is a list from the Texas Commission on Environmental Quality (TCEQ) of all Texas facilities utilizing treatment processes for removal of salts, irrespective of the TDS concentrations in the source waters. Thus, any reverse osmosis (RO) treatment facility providing a public water supply is included in the database, including production of polished water for various industrial processes that would be negatively affected by using tap water. These facilities are being surveyed to obtain information about the source water quality, the treatment processes, and the production volumes. According to the unconfirmed data, a total of about 8.4 million gallons of water per day (MGD) is desalinated on a regular basis in Region F by municipal, commercial and industrial facilities.⁷ However, the consultant preparing the database has indicated that many of the production estimates in the TCEQ list appear to be overstated.⁸ Also, much of the source water for the desalination activities would not be considered brackish water. The current TWDB list of desalination facilities does not distinguish between brackish source waters and source waters classified as fresh water.

A major treatment facility for brackish water currently operating in Region F is at Fort Stockton. Fort Stockton draws water from the Edwards-Trinity Aquifer that must be treated to reduce TDS to acceptable levels. The Fort Stockton plant consists of microfiltration (MF) and ultraviolet (UV) disinfection pretreatment, followed by RO and chlorination. Feed water with a TDS concentration of approximately 1,400 mg/l is blended with RO permeate at a ratio of 60:40. The maximum capacity of the RO permeate stream is approximately 3.8 MGD. Currently, the Fort Stockton facility produces an average of approximately 6.0 MGD blended water, at 800 mg/l TDS. Concentrate streams are disposed of using evaporation ponds. Future plans for the Fort Stockton facility include the possible installation of a dedicated treatment train for the city's industrial customers.^{9,10}

Two water suppliers in the region will soon begin treating high-TDS surface waters to replace or supplement their use of groundwater. The City of Brady and the Millersview-Doole Water Supply Corporation (MDWSC) are both planning to build RO desalination plants, each with an initial capacity of approximately 1.5 MGD. The City of Brady will be using water from the Brady Creek Reservoir and the MDWSC will use Lake Ivie as a water source. Lake Ivie TDS levels range from 1,100 to 1,500 mg/l and the levels at the Brady Creek Reservoir are

similar. These facilities will produce finished water with a TDS level under 1,000 mg/l. Ultimately, both plants plan to expand to 3.0 MGD each.^{11,12}

Industrial and commercial users in the region also desalinate water for various uses. Several energy companies, as well as the Midland Country Club, convenience stores, commercial water suppliers, and other smaller businesses utilize RO processes to desalinate groundwater or to tailor the quality of another source water to their use. Until the TWDB database is complete, it is not feasible to estimate how much of the industrial and commercial desalination utilizes a brackish water source.

3.3.2 Use of Reclaimed Water

Reclaimed water can be defined as any water that has already been used for some purpose, and is used again for another purpose instead of being discharged or otherwise disposed. Although water initially used for agricultural and industrial purposes can be reclaimed, this discussion will focus on reuse of treated municipal wastewater effluent. Reclaimed water has been used for agricultural irrigation and some industrial purposes for many years. Additionally its use has recently gained a level of public acceptance that allows water managers to readily implement other reuse strategies. Although there is still public resistance to the notion of the reuse of wastewater effluent for potable water supply, there is increasingly widespread use of reclaimed water for agricultural and industrial purposes and for irrigation of parks and landscaping. The use of reclaimed water requires development of the infrastructure necessary to transport the treated effluent to secondary users. For some uses, the wastewater may be difficult to treat to the required standard.

The TWDB notes three important advantages of the use of reclaimed water:

- Effluent from municipal wastewater plants is a drought-proof supply.
- Treated effluent is the *only* source of water that automatically increases as economic and population growth occurs in the community.
- The source of treated effluent is usually located near the intended use, not at some yet-to-be developed, distant reservoir or well field.¹³

The use of reclaimed water can occur directly or indirectly. Direct use is typically defined as use of the effluent before it is discharged, under arrangements set up by the generator of the wastewater. Indirect reuse occurs when the effluent is discharged to a stream and later diverted

from the stream for some purpose, such as municipal, agricultural or industrial supply. Indirect reuse is sometimes difficult to quantify because the effluent becomes mixed with the waters of the receiving body. A water rights permit may be needed to enable the diversion of the effluent from the stream.

A number of communities in Region F have direct wastewater reuse programs in place, utilizing municipal wastewater effluent for landscape irrigation or for industrial or agricultural purposes. The major municipal reuse programs in Region F are listed in Table 3.3-1. Smaller programs (less than 0.1 MGD) are also reported in Howard, Irion, Martin, and Reagan counties. The City of Midland's reuse program ranks Midland County among the top five counties in Texas for municipal reuse. San Angelo is considering options for expanding its use of reclaimed water. Industrial reuse is described by TWDB as being under-reported, but Ector County is listed as having 2.09 MGD of industrial reuse, ranking the county among the top five in Texas for that category.

Table 3.3-1
Recent Reuse Quantities in Region F

City	County	Use	Year 2000		Year 2001		Year 2002	
			(MGD)	(Ac-Ft/Yr)	(MGD)	(Ac-Ft/Yr)	(MGD)	(Ac-Ft/Yr)
Midland	Midland	Irrigation	10.7	12,000	11.3	12,700	11.3	12,700
San Angelo	Tom Green	Irrigation	7.6	8,500	8.2	9,200	7.6	8,500
Odessa	Ector	Industrial, Irrigation	3.2	3,600	3.4	2,800	3.3	3,700
Monahans	Ward	Irrigation	no data	no data	0.6	670	0.6	670
Andrews	Andrews	Irrigation	0.5	560	no data	no data	no data	no data
Winters	Runnels	Irrigation	0.2	220	0.2	220	0.2	220
Snyder	Scurry	Irrigation	no data	no data	0.1	110	0.1	110
TOTAL			22.2	24,880	23.8	26,700	23.1	25,900

Source of Data: TWDB reuse database¹⁴

For planning purposes only the reuse for Midland, San Angelo and Odessa will be considered as a current supply. It is uncertain whether the TWDB considered the other reuse projects as a source when developing demands for the cities of Monahans, Andrews, Winters and Snyder. To be conservative, it will be assumed that the demand for these cities does not include the demands for reuse supplies. The supplies are small and should not have a significant impact on the development of the plan.

3.4 Currently Available Supplies for Water User Groups

Summary tables in Appendix 3D present the currently available water available for each water user group (WUG), arranged by county. (Water user groups are cities with populations greater than 500, water suppliers who serve an average of at least 0.25 million gallons per day (MGD) annually, “county other” municipal uses, and countywide manufacturing, irrigation, mining, livestock, and steam electric uses.) Unlike the overall water availability figures in Sections 3.1 and 3.2, currently available supplies are limited by the ability to deliver and/or use water. These limitations may include firm yield of reservoirs, well field capacity, aquifer characteristics, water quality, water rights, permits, contracts, regulatory restrictions, raw water delivery infrastructure and water treatment capacities where appropriate. Currently available supplies in each county are shown in Table 3.5-1. The total of the currently available supply by use type is shown in Figure 3.5-1.

Historical water use from TWDB provides the basis for livestock water availability. Surface water supplies for livestock in Region F come primarily from private stock ponds, most of which are exempt under §11.142 of the Texas Water Code and do not require a water right. In addition, a significant portion of the mining demand in Brown and Crane Counties appears to be based on recirculated surface water from exempt sources. Therefore, a supply to meet the demand is assumed to come from exempt sources to prevent an unwarranted shortage.

3.5 Currently Available Supplies for Wholesale Water Providers

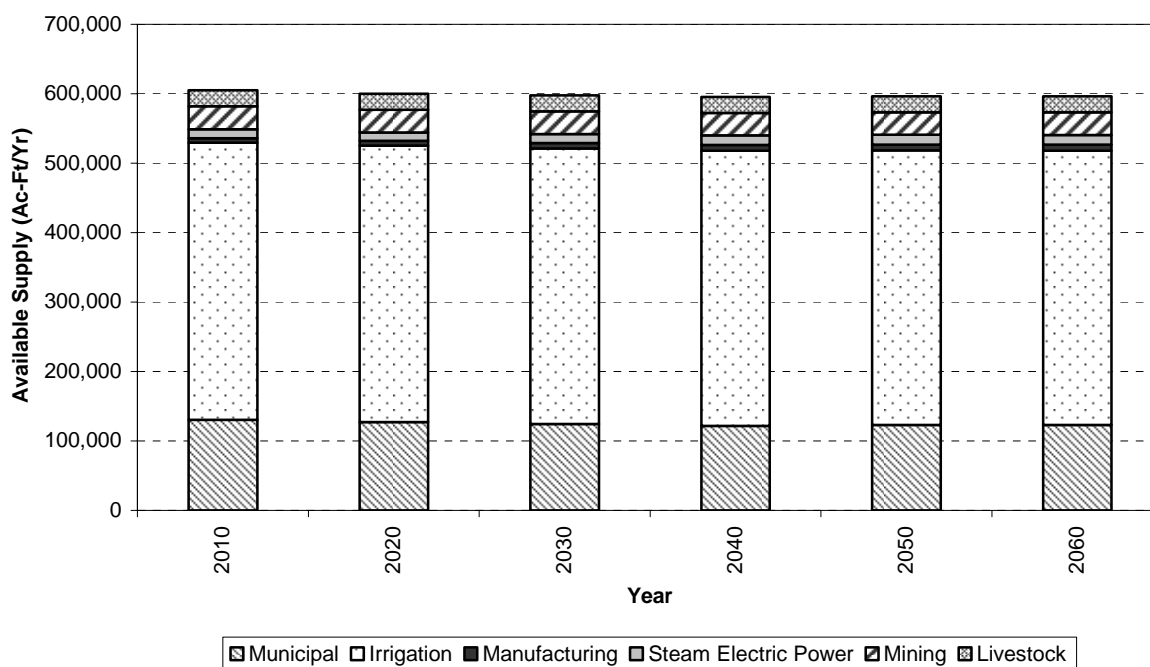
There are seven designated wholesale water providers in Region F. A wholesale water provider has wholesale water contracts for 1,000 acre-feet per year or is expected to contract for 1,000 acre-feet per year or more over the planning period. Similar to the currently available supply for water user groups, the currently available supply for each wholesale water provider is limited by the ability to deliver water to end-users. These limitations include firm yield of reservoirs, well field capacity, aquifer characteristics, water quality, water rights, permits, contracts, regulatory restrictions and infrastructure. A summary of currently available supplies for each wholesale water provider is included in Table 3.5-2. Brief descriptions of the supply sources are presented below.

Table 3.5-1
Summary of Currently Available Supply to Water Users by County
(Values in Acre-Feet per Year)

County	Year 2010	Year 2020	Year 2030	Year 2040	Year 2050	Year 2060
Andrews	24,542	24,542	24,542	25,780	25,780	25,780
Borden	2,316	2,317	2,316	2,316	2,316	2,316
Brown	21,694	21,784	21,787	21,752	21,764	21,821
Coke	2,115	2,105	2,349	2,358	2,366	2,345
Coleman	1,823	1,826	1,821	1,818	1,817	1,819
Concho	7,005	6,999	7,033	7,028	7,026	7,020
Crane	2,872	2,899	2,911	2,920	2,931	2,945
Crockett	5,980	5,997	6,006	6,014	6,022	6,030
Ector	44,137	39,262	45,886	47,042	48,181	48,569
Glasscock	24,906	24,906	24,906	24,906	24,906	24,906
Howard	14,258	14,038	16,371	16,379	16,368	16,156
Irion	2,331	2,331	2,325	2,316	2,309	2,305
Kimble	2,749	2,746	2,746	2,746	2,746	2,746
Loving	667	667	666	666	666	666
Martin	14,949	14,949	14,949	15,022	14,760	14,496
Mason	12,356	12,355	12,356	12,356	12,356	12,356
McCulloch	6,486	6,562	6,705	6,770	6,831	6,919
Menard	4,650	4,647	4,646	4,646	4,646	4,646
Midland	59,310	59,746	47,107	42,471	42,519	42,533
Mitchell	7,882	7,872	7,858	7,838	7,821	7,793
Pecos	91,772	91,792	91,801	91,800	91,796	91,782
Reagan	28,950	28,950	28,950	28,950	28,950	28,950
Reeves	74,003	74,248	74,438	74,583	74,736	74,674
Runnels	4,838	4,833	4,860	4,857	4,860	4,878
Schleicher	4,921	4,910	4,903	4,898	4,894	4,897
Scurry	11,199	11,104	11,707	11,667	11,643	11,550
Sterling	2,187	2,225	2,240	2,244	2,236	2,247
Sutton	4,884	4,879	4,879	4,874	4,873	4,872
Tom Green	75,044	75,049	75,154	75,182	75,218	75,248
Upton	10,543	10,547	10,549	10,551	10,552	10,554
Ward	16,950	16,283	16,081	15,924	15,759	15,609
Winkler	16,768	16,768	16,768	16,768	16,768	16,768
<i>Total</i>	<i>605,087</i>	<i>600,138</i>	<i>597,616</i>	<i>595,442</i>	<i>596,416</i>	<i>596,196</i>

Currently available supply reflects the most limiting factor affecting water availability to users in the region. These limitations include firm yield of reservoirs, well field capacity, aquifer characteristics, water quality, water rights, permits, contracts, regulatory restrictions, raw water delivery infrastructure and water treatment capacities

Figure 3.5-1
Supplies Currently Available to Water User Groups by Type of Use



Colorado River Municipal Water District (CRMWD). CRMWD supplies raw water from Lake J.B. Thomas, E.V. Spence Reservoir, and O.H. Ivie Reservoir, and well fields in Ward, Martin, Scurry and Ector Counties. Water for oil and gas production, which is classified as a mining use, is supplied from several chloride control projects. CRMWD owns and operates more than 600 miles of 18-inch to 60-inch water transmission lines to provide water to its member cities and customers¹⁵.

Brown County Water Improvement District Number One (BCWID). BCWID owns and operates Lake Brownwood, as well as raw water transmission lines that supply the District's water treatment facilities, irrigation customers and the City of Early. BCWID operates two water treatment facilities in the City of Brownwood which together have a combined capacity of 16 mgd¹⁶. Other customers divert water directly from the lake.

Table 3.5-2
Currently Available Supplies for Wholesale Water Providers
(Values in Acre-Feet per Year)

Major Water Provider	Source	Basin	2010	2020	2030	2040	2050	2060
BCWID	Lake Brownwood ^a	Colorado	29,712	29,712	29,712	29,712	29,712	29,712
CRMWD	Lake Ivie ^b	Colorado	66,350	65,000	63,650	62,300	60,950	59,600
	Spence Reservoir ^b	Colorado	560	560	560	560	560	560
	Thomas Reservoir ^b	Colorado	0	0	0	0	0	0
	Ward County Well Field ^c	Rio Grande	5,200	0	0	0	0	0
	Martin County Well Field	Colorado	1,035	1,035	1,035	1,035	1,035	1,035
	Ector County Well Field	Colorado	440	440	440	440	440	440
	Scurry County Well Field	Colorado	900	900	900	900	900	900
Great Plains Water System	Andrews County Well Field ^d	Colorado	6,456	6,456	6,456	6,456	6,456	6,456
City of Odessa	CRMWD System ^b	Colorado & Rio Grande	4,063	4,434	5,990	6,285	6,485	6,541
UCRA	O.C. Fisher Reservoir ^b	Colorado	0	0	0	0	0	0
	Mountain Creek Reservoir ^b	Colorado	0	0	0	0	0	0
City of San Angelo	Twin Buttes/Nasworthy ^b	Colorado	0	0	0	0	0	0
	O.C. Fisher Reservoir ^b	Colorado	0	0	0	0	0	0
	Spence Reservoir ^e	Colorado	0	0	0	0	0	0
	Lake Ivie ^f	Colorado	10,974	10,751	10,528	10,304	10,081	9,858
University Lands	CRMWD Ward Co Well Field ^c	Rio Grande	5,200	0	0	0	0	0
	Midland Paul Davis Well Field ^g	Colorado	0	0	0	0	0	0
	City of Andrews Well Field ^h	Colorado	0	0	0	0	0	0
	<i>Total</i>		<i>119,916</i>	<i>108,537</i>	<i>108,743</i>	<i>107,688</i>	<i>106,538</i>	<i>115,102</i>

- a Yield of Lake Brownwood limited by water right.
b Yield from the Colorado WAM. See subordination strategy for actual supply used in planning.
c Contract between CRMWD and University Lands expires in 2019.
d Region F supplies only.
e Supplies from Spence Reservoir currently not available to the City of San Angelo pending rehabilitation of Spence pipeline.
f For planning purposes supplies limited to 16.54 percent of the safe yield of Ivie Reservoir.
g Contract between University Lands and the City of Midland expires in 2008. Current supplies estimated at 4,722 acre-feet per year.
h Contract between University Lands and the City of Andrews expires in 2010. Current supplies estimated at 3,353 acre-feet per year.

Upper Colorado River Authority (UCRA). The UCRA owns water rights in O.C. Fisher Reservoir in Tom Green County and Mountain Creek Lake in Coke County. O.C. Fisher supplies are contracted to the Cities of San Angelo and Miles, and Mountain Creek Lake supplies are contracted to the City of Robert Lee.

Great Plains Water System, Inc. The Great Plains Water System provides water from the Ogallala Aquifer in Andrews County in Region F and Gaines County in Region O. The System owns an extensive pipeline system that has historically provided water primarily for oil and gas operations, although a small amount of municipal water has been supplied to rural Ector County as well. The System's largest customer is the recently established steam electric operation in Ector County.

City of Odessa. The City of Odessa is a CRMWD member city. As a member city, all of Odessa's future needs will be provided from CRMWD sources. The City of Odessa sells treated water to the Ector County Utility District and the Odessa Country Club, and treated effluent to industrial users.

City of San Angelo. The City of San Angelo's sources of supply are Lake O.C. Fisher (purchased from Upper Colorado River Authority), Twin Buttes Reservoir, Lake Nasworthy, local surface water rights, O.H. Ivie Reservoir (purchased from CRMWD), and E.V. Spence Reservoir (purchased from CRMWD). The city owns several run-of-the river water rights on the Concho River which enable the city to make use of uncontrolled supplies from the Concho River. San Angelo owns and operates a raw water transmission line from Spence Reservoir and a 5-mile water transmission line from a pump station on the CRMWD Ivie pipeline just north of the city. The city also owns an undeveloped well field in McCulloch County. San Angelo supplies raw water to the power plant located on Lake Nasworthy. The city provides treated water to the City of Miles and to rural customers in Tom Green County. Treated wastewater from the city is currently used for irrigation.

University Lands. University Lands manages properties belonging to the University of Texas System in West Texas. University Lands does not directly supply water; CRMWD, the City of Midland and the City of Andrews have developed water well fields on property managed by University Lands. The well fields produce water from the Cenozoic Pecos Alluvium aquifer in Ward County and the Ogallala aquifer in Martin and Andrews Counties.

3.6 Impact of Drought on Region F

During the past century, recurring drought has been a natural part of Texas' varying climate, especially in the arid and semi-arid regions of the state. An old saying about droughts in west Texas is that "droughts are a continual thing that are interrupted by short periods of rainfall."¹⁷ Droughts, due to their complex nature, are difficult to define and understand, especially in a context that is useful for communities that must plan and prepare for drought. Drought directly impacts the availability of ground and surface water supplies for agricultural, industrial, municipal, recreational, and designated aquatic life uses. The location, duration, and severity of drought determine the extent to which the natural environment, human activities, and economic factors are impacted.

Geography, geology and climate vary significantly from east to west in Region F. Ecoregions within Region F vary from the Edwards Plateau to the east, Central Great and Western High Plains in the central and northern portions of the region, and Chihuahuan Deserts to the west. Annual rainfall in Region F ranges from an average of more than 28 inches in the east to slightly more than 10 inches in the west. Likewise, the annual gross reservoir evaporation rate ranges from 60 inches in the east to approximately 75 inches in the western portion of the region. Extended periods of drought are common in the region, with severe to extreme droughts having occurred in the 1950s and 1990s.

3.6.1 Drought Conditions

Numerous definitions of drought have been developed to describe drought conditions based on various factors and potential consequences. In the simplest of terms, drought can be defined as "a prolonged period of below-normal rainfall." However, the *State Drought Preparedness Plan*¹⁸ provides more specific and detailed definitions:

- *Meteorological Drought.* A period of substantially diminished precipitation duration and/or intensity that persists long enough to produce a significant hydrologic imbalance.
- *Agricultural Drought.* Inadequate precipitation and/or soil moisture to sustain crop or forage production systems. The water deficit results in serious damage and economic loss to plant and animal agriculture. Agricultural drought usually begins after meteorological drought but before hydrological drought and can also affect livestock and other agricultural operations.
- *Hydrological Drought.* Refers to deficiencies in surface and subsurface water supplies. It is measured as streamflow, and as lake, reservoir, and groundwater levels. There is

usually a lack of rain or snow and less measurable water in streams, lakes, and reservoirs, making hydrological measurements not the earliest indicators of drought.

- *Socioeconomic Drought.* Occurs when physical water shortages start to affect the health, well-being, and quality of life of the people, or when the drought starts to affect the supply and demand of an economic product.

These definitions are not mutually exclusive, and provide valuable insight into the complexity of droughts and their impacts. They also help to identify factors to be considered in the development of appropriate and effective drought preparation and contingency measures.

Droughts have often been described as “insidious by nature.” This is mainly due to several factors:

- Droughts cannot be accurately characterized by well-defined beginning or end points.
- Severity of drought-related impacts is dependent on antecedent conditions, as well as ambient conditions such as temperature, wind, and cloud cover.
- Droughts, depending on their severity, may have significant impacts on human activities; and human activities during periods of drought may exacerbate the drought conditions through increased water usage and demand.

Furthermore, the impact of a drought may extend well past the time when normal or above-normal precipitation returns.

Various indices have been developed in an attempt to quantify drought severity for assessment and comparative purposes. One numerical measure of drought severity that is frequently used by many federal and state government agencies is the Palmer Drought Severity Index (PDSI). It is an estimate of soil moisture that is calculated based on precipitation and temperature. The PDSI ranges from +6.0 for the wettest conditions to –6.0 for the driest conditions. A PDSI of –3.99 to –3.0 is termed “severe drought” and a PDSI of –6.0 to –4.0 is described as “extreme drought”. The Texas Water Development Board (TWDB) uses the PDSI to monitor wet/dry conditions in Texas. In 2000, all counties of Region F experienced at least some periods of severe or extreme drought. However, the PDSI is an indicator of an agricultural drought only. It has little relationship with a hydrological drought.

3.6.2 Drought of Record and Recent Droughts in Region F

In general, the drought of record is defined as the worst drought to occur in a region during the entire period of meteorological record keeping. For most of Texas, the drought of record

occurred from 1950 to 1957. During the 1950s drought, many wells, springs, streams, and rivers went dry and some cities had to rely on water trucked in from other areas to meet drinking water demands. By the end of 1956, 244 of the 254 Texas counties were classified as disaster areas due to the drought, including all of the counties in Region F.

During the past decade, most regions of Texas have experienced droughts resulting in diminished water supplies for agricultural and municipal use, decreased flows in streams and reservoirs, and significant economic loss. Droughts of moderate to extreme conditions occurred in 1996, 1998, and 2000 in various regions of the state, including Region F. The worst year during the recent drought was 2000, when most Region F counties experienced extreme drought for the entire growing season.

Meteorological Drought in Region F

Meteorological drought is characterized by below-normal precipitation for an extended period of time. Figures 3.6-1 and 3.6-3 show the historical annual precipitation totals for Midland and San Angelo for the period from 1951 to 2003. As is typical in Texas, the average annual precipitation in Region F increases from west to east. Midland is further west, and averages about 14 inches a year over the period shown. San Angelo averages about 19 inches of precipitation per year. The patterns of wet and dry years have some general correlation, but can vary significantly. Figures 3.6-2 and 3.6-4 show the rainfall variation from the annual average for the two locations. For both the 1950's drought and the recent drought, annual rainfall is significantly below average for an extended number of years. The current drought appears more severe than the 1950's drought. Nine of the ten years during the current drought show rainfall less than the historic average. This occurred at no other time in the period of record.

Hydrological Drought in Region F

Available water supplies for municipal and agricultural use have been a major concern in the region since the end of the 19th century. During the past 80 years, eighteen major reservoirs have been constructed for water storage, recreation and flood control throughout Region F. Table 3.2-1 summarizes pertinent data for these reservoirs, including conservation storage capacities. The locations of these reservoirs are shown on Figure 3.2-1.

Figure 3.6-1
Annual Precipitation at Midland, Texas from 1951 to 2003

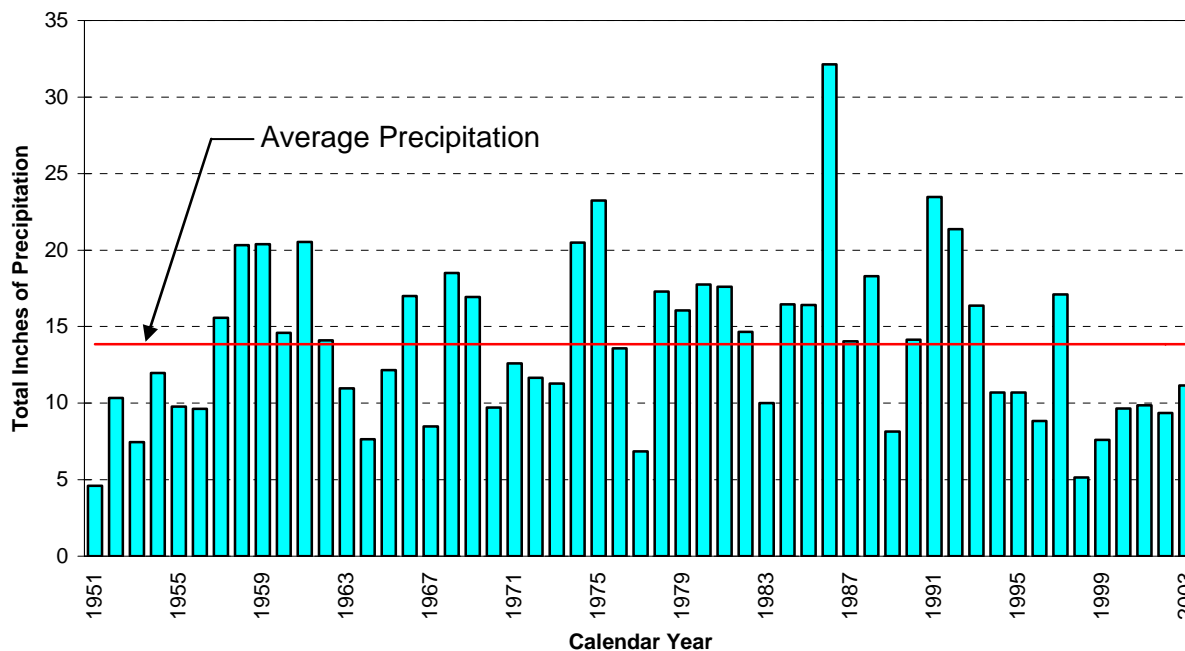
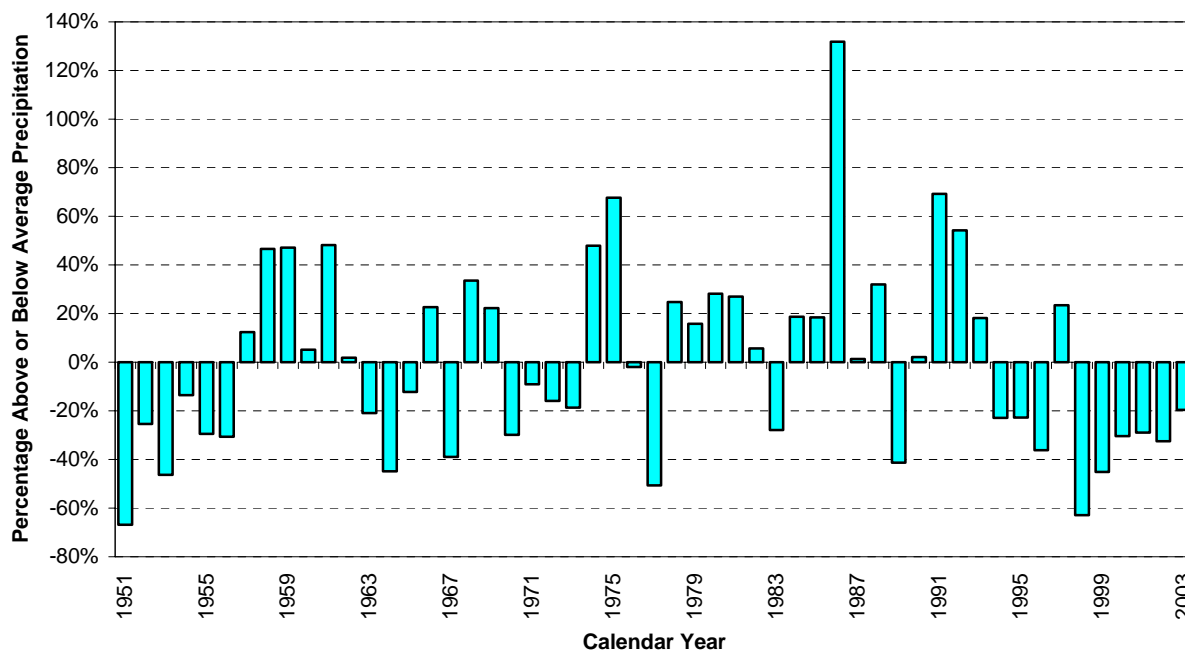


Figure 3.6-2
Precipitation Variation from Average at Midland, Texas from 1951 to 2003



Data for Figures 3.6-1 and 3.6-2 are from the National Climate Data Center, Station ID #5890

Figure 3.6-3
Annual Precipitation at San Angelo, Texas from 1951 to 2003

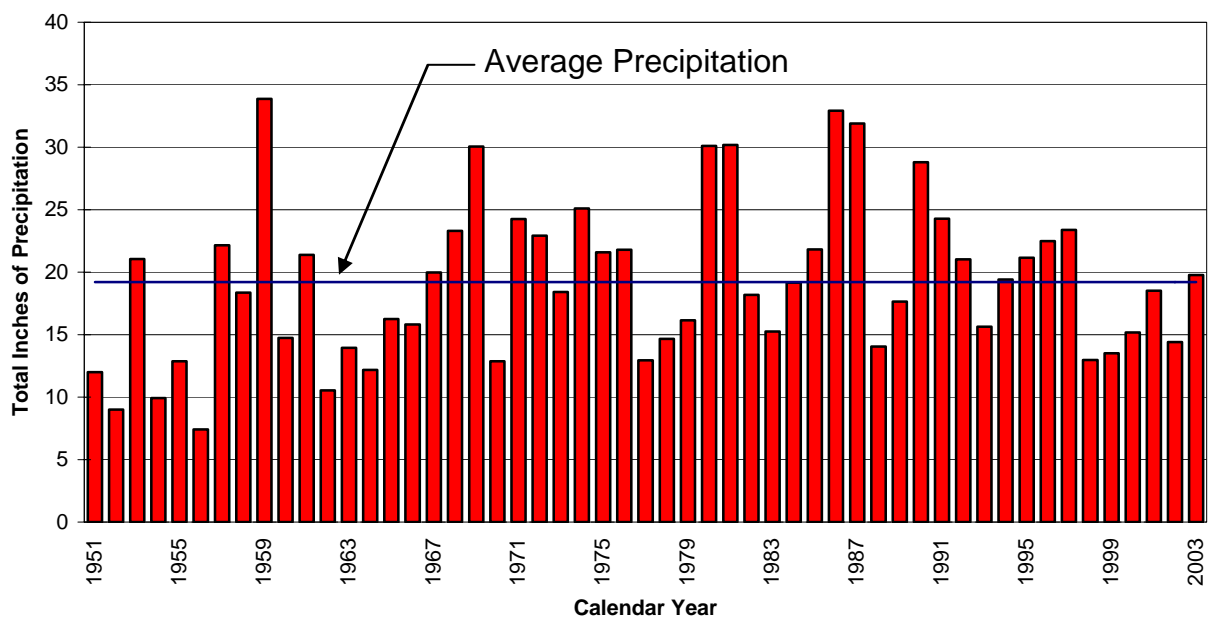
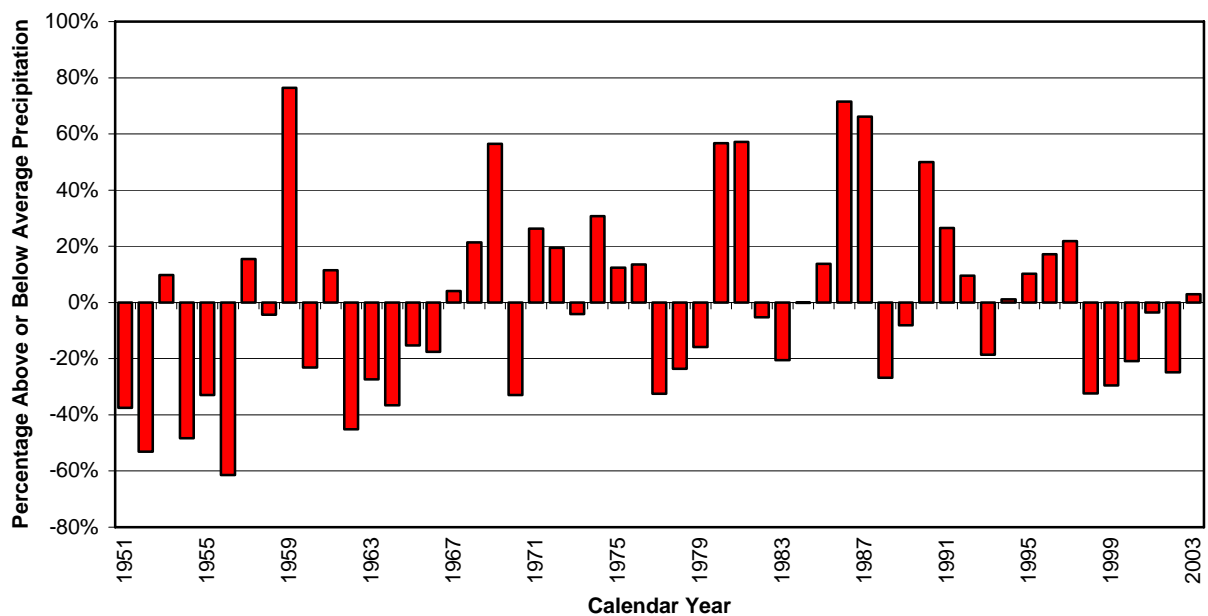


Figure 3.6-4
Precipitation Variation from Average at San Angelo, Texas from 1951 to 2003



Data for Figures 3.6-3 and 3.6-4 are from the National Climate Data Center, Station ID #5890

Frequent and extended hydrological droughts have occurred in almost every decade since 1940. The most severe droughts occurred in the 1950s, 1960s, 1980s and the late 1990s through early 2000. The most recent drought is quite possibly the worst hydrologic drought experienced in that period.

According to TWDB records, reservoir levels in Region F have generally decreased over the past ten to fifteen years, and most have only begun to recover in recent months. A summary of major reservoirs in the region follows:

- O.H. Ivie Reservoir experienced a sharp decrease in storage in 1996, recovered in 1997 and then experienced a steady decline until hitting a low of about 30% capacity in 2004. The reservoir began to recover late in 2004 with additional rainfall in the watershed. The January 2005 levels were about 40% of capacity.
- Levels at E.V. Spence Reservoir began a general decline in 1992 and hit a low of less than 10% capacity in 2002. As of January 2005, reservoir levels had risen to 18% of capacity.
- Levels at O.C. Fisher and Twin Buttes Reservoirs also declined in the past 10 years, both hitting critically low levels. In January 2005, levels at O.C. Fisher and Twin Buttes were only at 6% of storage capacity.
- Lake Brownwood, in the northeastern corner of Region F, suffered two to three years of declining water levels in the late 1990's. It hit a low of about 50% in 2000, but recovered by late 2002 to levels above 90%.
- Red Bluff Reservoir, on the Pecos River at the western edge of Region F, dropped from a high of about 50% capacity in 1992 to a low of about 10% in 2001, but had recovered to a 39% level by January 2005.

These data indicate the degree of drought in Region F during the past 10 to 15 years and the percent recovery in five of the region's major reservoirs. By the end of the 1990's, many Region F reservoirs were at their lowest recorded levels. However, for the same period, the TWDB reported the statewide reservoir storage level at approximately 90 percent of capacity. The reported statewide reservoir storage level in the late 1990's indicates that many reservoirs in other regions of the state were at or near 100 percent of capacity and drought conditions were not occurring in these regions.

Agricultural Drought in Region F

Because a substantial portion of water used in Region F is for agriculture, a drought can result in serious economic losses to farmers and ranchers. During the 1950's drought, many Texas ranchers and farmers incurred increased levels of debt or were forced to abandon their

operations. Some ranchers singed the spines off of prickly pear cactus so their cattle would have something to eat. Ranch debt reached a high of \$3 billion and 143 rural counties statewide experienced a population decline during the drought.¹⁹ In Region F, the population declined in 18 of the region's 32 counties between 1950 and 1960.

Agricultural drought can occur even when calendar-year precipitation totals are not abnormally low, especially if the rainfall is inadequate during the growing season. Researchers at the Texas A&M University Sonora Experiment Station report that the precipitation during the growing season averaged only about 7 inches per year during the 1990's, compared to a long-term average of 15 inches. Researchers also calculated the PDSI for the Sonora station and noted that the period from August 1999 through September 2000 had the lowest continuous PDSI values for any 12-month or greater time period since the 1950's drought.

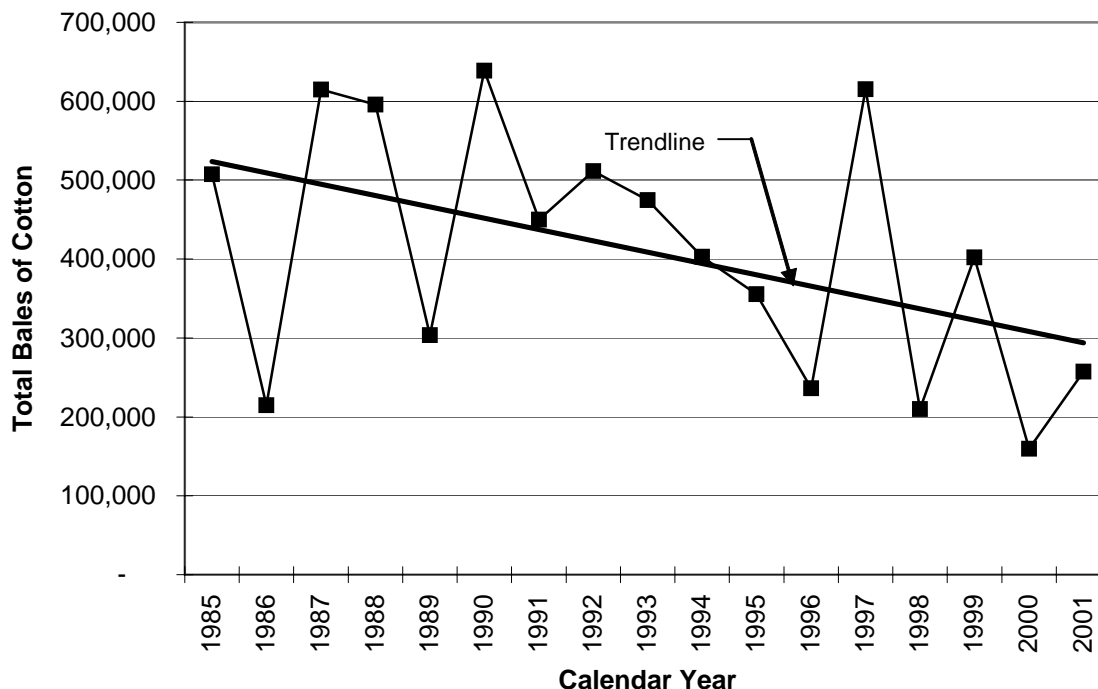
Annual production of agricultural crops can be used as an indicator of impacts due to droughts. Various factors, such as market demand and production costs, can also play a significant role with respect to the number of acres planted and harvested for specific crops. However, a decline in crop production over a prolonged period may indicate an impact of drought.

In general, cotton is a good indicator of agricultural drought impacts in Region F because it is the major agricultural crop in the region and it can be grown with or without irrigation. Between 1951 and 1958, the number of acres planted in cotton statewide declined by 57 percent and the number of acres harvested declined by 55 percent. Agricultural production of cotton in Region F counties also declined significantly due to the prolonged drought. Figure 3.6-5 shows a graph of annual Region F cotton production from 1985 to 2001.

During this period, winter wheat crops in Region F were not as seriously impacted by the drought, because the precipitation deficits were more pronounced during the warmer months. Livestock production was also impacted by the drought. During the hot, dry summer of 2000, large grass die-offs occurred in parts of west Texas. The drought was severe enough to even cause some live oak trees to die.²⁰

In 2001, Brian Chandler, a Midland farmer, testified before the US Senate Agriculture Committee on behalf of the National Farmers Union urging Congress to provide federal assistance for farmers and ranchers who had suffered drought-related production losses in 2001.

Figure 3.6-5
Annual Cotton Production in Region F from 1985 to 2001



He stated that, due to the drought conditions, his dry-land crops were decimated in 2001. The limited crop that was produced was sold at depressed prices. His livestock operation was severely curtailed due to the lack of small-grain crops and an 80 percent loss in his hay production. Ranchers were forced to sell their cattle at less-than-optimal weight because of the limited ability to sustain their herds as a direct result of the drought conditions. The flooded markets resulted in lower prices per pound at auction²¹.

In 1997, a wet year sandwiched between two dry years, agricultural production for Region F totaled over \$621,000,000. In 2002, not having yet recovered from the sustained drought, production was 24 percent less than in 1997. A few counties, however, saw increased production levels for livestock from 1997 to 2002 as ranchers thinned out herds down to levels that could be sustained through the dry conditions. Tom Green County, which accounted for about 20 percent of agricultural production in the region in 2002, reported a 31 percent decline in crop production from 1997, but a 29 percent increase in livestock production. Since May 15, 2003 through the fall of 2005 above average rainfall has resulted in improved conditions for Region F agriculture. However, runoff remains below normal.

Socio-Economic Drought in Region F

As presented previously, drought can have a significant and prolonged impact on the economy and social fabric within a region. Region F is not an exception to this fact. The drought of record in the 1950's produced drastic decreases in the annual production values for agriculture and livestock. At the same time, census data indicate that thousands of rural residents in Region F migrated from rural county areas to the main metropolitan centers in the region. This type of migration can have a significant impact on the demographics, health, and social needs in both rural and municipal settings.

Much of the economic activity in Region F has historically been associated with the oil and gas industry. In the past few years much of that industry has declined, with many oil-related employers closing or moving their operations elsewhere. Cities in Region F have been actively seeking new industries to replace the loss in the oil and gas sector, but the recent drought and uncertainty about water supplies has hindered that process. Rural communities need new business and industries to replace the agricultural sector and population losses. The Governor's Office, Texas Department of Agriculture, and the U.S. Department of Agriculture are trying to promote and assist rural areas. These efforts are being hindered by the availability of water and the cost of securing and producing water that meets water quality standards.

3.6.3 Potential Environmental Impacts of Drought in Region F

Increasing water supply demand for municipal and agricultural uses, the encroachment of invasive brush (e.g., mesquite, Ashe juniper, and salt cedar), and extended drought conditions during the 1990's, have resulted in a net decrease in water supplies available to sustain designated aquatic life uses in areas of the region. Combined with reservoir construction on the Concho and Colorado Rivers, the quantity of water available to maintain instream flows has declined. However, the Texas Parks and Wildlife Department (TPWD) and U.S. Fish and Wildlife Service (USFWS) are collaborating to determine instream flow levels necessary to maintain designated aquatic life uses.

In December 2004, the USFWS issued a revised Biological Opinion²² concerning the status of threatened aquatic species. The Biological Opinion changes the magnitude of required releases from the E.V. Spence and O.H. Ivie Reservoirs under certain conditions. These changes

will result in a decrease in the volume of mandatory releases from the two reservoirs, especially during periods of extended drought and low reservoir levels.

These reduced flows and the elimination of mandatory water releases during periods of no inflow to the reservoirs, will provide relief to the water suppliers and their users, especially during periods of low rainfall or extended drought. In the Biological Opinion, USFWS has determined that these reduced flows are not likely to jeopardize the continued existence of threatened species, nor likely to destroy or adversely impact designated critical habitat for the species.

3.6.4 Impacts of Recent Drought on Water Supply

The Colorado WAM uses naturalized flows from 1940 through 1998. As a result, the WAM does not include most of a major drought in Region F. Indications are that for many reservoirs the recent drought may be more severe than previous droughts, potentially lowering the available supply from the reservoirs.

To assess the potential impact of the recent drought on water supplies in Region F, historical gauge flows at key locations in Region F were developed covering the period from 1999 through 2004. These flows were incorporated into a special simplified version of the Colorado WAM (MiniWAM). The MiniWAM includes only major reservoirs in Region F and the City of Junction's run-of-the-river right. Flows from 1940 through 1998 are based on the modeled flows available to these water rights. Impacts of the new drought on reservoir yields in Region F using WAM Run 3 (no subordination) are negligible due to the low yields of the reservoirs. Impacts are more readily seen with the subordination strategy, which is discussed in Section 4.2.3. With subordination, the analysis showed that most of the Colorado Basin Reservoirs in Region F have experienced new drought-of-record conditions as a result of the current drought. More detailed information on the impact of drought may be found in Appendix 4E.

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