4.4 Manufacturing Needs

Table 4.4-1 summarizes the manufacturing needs for Region F. There are six counties showing manufacturing needs over the planning period: Coleman, Ector, Howard, Kimble, Runnels and Tom Green Counties. Manufacturing needs in Coleman, Ector, Howard, Runnels and Tom Green Counties are associated with needs for the cities of Coleman, Odessa, Big Spring, Ballinger and San Angelo, respectively, and will be met by strategies developed for these cities. Needs for the City of Coleman are met exclusively with the subordination strategy described in Sections 4.2.3 and 4.2.4. Needs for Odessa and Big Spring are met by strategies discussed with Colorado River Municipal Water District strategies in Section 4.8.1. Strategies for San Angelo are found in Section 4.8.3. Only manufacturing needs in Kimble County cannot be met with a municipal strategy and require a stand-alone analysis.

4.4.1 Kimble County

Kimble County has three of the largest cedar processing operations in the world.[32] These operations account for most of the manufacturing water in Kimble County. According to data from the Texas Water Development Board, manufacturing water use in Kimble County has declined significantly from a high of 2,100 acre-feet per year in 1993 to 14 acre-feet per year in 2007. An average of 20 acre-feet of surface water and 1 acre-feet of groundwater were used for manufacturing purposes in Kimble County between 2001 and 2007, excluding 2005. (Historical groundwater and surface water use are not available from TWDB for the year 2005.) The current water use is significantly less than the projections for Kimble County, which range from 702 acre-feet per year in 2010 to 1,002 acre-feet per year in 2060.

The City of Junction is the major user of surface water in Kimble County. However, TWDB records show no industrial sales by the city. There are only two water rights in Kimble County authorized for manufacturing use, with a total authorized diversion of 2,466 acre-feet per year. However, only 51 acre-feet per year are authorized for consumption by these water rights, which is about two percent of the total diversion. The remainder must be returned to the stream. It also appears that a significant part of the historical reported surface water use includes water that is not consumed. Recently the reported water use has changed from total diverted water to consumed water.[33]

Table 4.4-1
Manufacturing Needs in Region F
(Values in Acre-Feet per Year)

Source	2010	2020	2030	2040	2050	2060	Comments
Coleman County							
Lake Coleman	*0*	*0*	*0*	*0*	*0*	*0*	Coleman sales, no supply in WAM
Demand	*6*	*6*	*6*	*6*	*6*	*6*	
Surplus (Need)	*(6)*	*(6)*	*(6)*	*(6)*	*(6)*	*(6)*	
Ector County							
CRMWD system	877	797	1199	902	871	813	Odessa sales
Reuse	1500	1650	1800	1950	2100	2250	Odessa reuse
Edwards-Trinity Plateau	16	17	18	19	19	20	
Total Supply	*2393*	*2464*	*3017*	*2871*	*2990*	*3083*	
Demand	*2759*	*2963*	*3125*	*3267*	*3376*	*3491*	
Surplus (Need)	*(366)*	*(499)*	*(108)*	*(396)*	*(386)*	*(408)*	
Howard County							
CRMWD system	722	703	1,094	1,090	1,103	1,130	Big Spring sales
Edwards-Trinity Plateau	288	288	288	288	288	288	
Ogallala	461	461	461	461	461	461	
Total Supply	1,471	1,452	1,843	1,839	1,852	1,879	
Demand	1,648	1,753	1,832	1,910	1,976	2,099	
Surplus (Need)	(177)	(301)	11	(71)	(124)	(220)	
Kimble County							
Edwards-Trinity Plateau	3	3	3	3	3	3	
Johnson Fork	0	0	0	0	0	0	Self-supplied, no supply in WAM
Total Supply	3	3	3	3	3	3	
Demand	702	767	823	880	932	1,002	
Surplus (Need)	(699)	(764)	(820)	(877)	(929)	(999)	
Runnels County							
Lake Ballinger	0	0	0	0	0	0	Ballinger sales, no supply in WAM
Lake Winters	0	0	0	0	0	0	Winters sales, no supply in WAM
Total Supply	0	0	0	0	0	0	
Demand	63	70	76	82	87	94	
Surplus (Need)	(63)	(70)	(76)	(82)	(87)	(94)	
Tom Green County							
San Angelo System	0	0	0	0	0	0	San Angelo sales, no supply in WAM
Demand	2,226	2,498	2,737	2,971	3,175	3,425	
Surplus (Need)	(2,226)	(2,498)	(2,737)	(2,971)	(3,175)	(3,425)	
Total For Counties with Needs							
Total Need	(3,537)	(4,138)	(3,736)	(4,403)	(4,707)	(5,152)	

Three potential water management strategies have been identified for Kimble County Manufacturing:

- Subordination of downstream senior water rights
- Voluntary redistribution through purchase or lease of existing surface water rights
- New groundwater development from the Edwards-Trinity Plateau aquifer

Region F does not evaluate water conservation for manufacturing because of the relatively small amount of water used and a lack of specific data on manufacturing processes.

Subordination of Senior Water Rights

The two Kimble County manufacturing water rights were not included in the larger subordination analysis associated with the major water rights in the Colorado Basin. As a result the WAM shows that they do not have a reliable supply. As a surrogate for a more thorough analysis, the availability for these water rights was determined running the Colorado WAM in natural order. Natural order ignores the priority of water rights and meets demands from upstream to downstream. In natural order, the combined reliable supply from these two rights is 20 acre-feet per year.

Quantity, Reliability and Cost

Assuming that this diversion represents the two percent of water that is actually consumed, the total recirculated use for these rights would be 1,000 acre-feet per year, which is sufficient to meet demands. However, this supply may not be entirely reliable because diversions may not be available when needed during drought. The cost of this strategy depends on negotiations between the water rights holders. No costs have been developed for the subordination strategy (see Section 4.2.3).

Environmental Issues

Implementation of this strategy is expected to have minimal impacts on environmental flows, over-banking flows, or habitats because of the small consumptive use authorized by these two water rights.

Agricultural and Rural Issues

There are no agricultural or rural issues associated with this project.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

The natural order simulation assumes that no downstream water rights make priority calls on these two water rights. In practice, it would be extremely difficult to enter subordination agreements with all senior downstream rights. Normally only water rights with large diversions enter into subordination agreements. However, these agreements may not prevent smaller rights from making priority calls. Given the relatively small consumptive use associated with these rights, even a priority call by a small water right could impact availability.

Other Water Management Strategies Directly Affected

Voluntary redistribution to meet Kimble County manufacturing needs may be affected.

Voluntary Redistribution through Lease or Purchase of Existing Water Rights

Voluntary redistribution through purchase or lease of existing water rights is a feasible strategy that is complementary to subordination. The leased or purchased water rights must have priority dates senior to the two manufacturing rights for this strategy to be effective. Diversions for these rights could be moved upstream, or the rights could simply not be exercised, eliminating the possibility of a priority call. For example, according to the Colorado WAM there are 1,475 acre-feet per year of reliable irrigation diversions in Kimble County. However, Kimble County irrigation has a surplus of 786 acre-feet per year in 2010, increasing to 964 acre-feet per year by 2060. This implies that at least some irrigation rights may be available for purchase or lease.

Region F has not identified specific rights for purchase, so no quantity, costs or impacts can be developed at this time. These transactions would be made between private corporations and individuals and valuating these transactions is not appropriate for regional water planning.

New Groundwater Development from the Edwards-Trinity Plateau Aquifer

There are undeveloped groundwater supplies in the Edwards-Trinity Plateau aquifer in Kimble County. Water from this source is not widely used because of low well yields in most areas. Some areas have poor water quality as well. However, there appears to be some areas within the county that have sufficient well yields to meet manufacturing water needs. This strategy assumes that 5 new wells with an average transmission distance of 15 miles could be constructed to supply manufacturing water.

Quantity, Reliability and Cost

This strategy could be implemented if the Kimble County manufacturing water needs are for consumptive use and not for recirculated water. This strategy assumes that up to 1,000 acre-feet of water per year could be produced from the Edwards-Trinity (Plateau) aquifer. Reliability would be moderate to high, depending on well capacity. The cost of water would be approximately $1,080 per acre-foot ($3.31/1,000 gallons). Table 4.4-2 summarizes the costs for this strategy.

Table 4.4-2
New Water Wells in the Edwards-Trinity (Plateau) Aquifer
Kimble County Manufacturing

Supply from Strategy	**1,000 acre-feet per year**
Total Capital Costs (2008 Prices)	$ 9,080,000
Annual Costs	$ 1,080,000
Unit costs (during amortization)	$ 1,080 per acre-foot
	$ 3.31 per 1,000 gallons
Unit Costs (after amortization)	$ 288 per acre-foot
	$ 0.88 per 1,000 gallons

Environmental Issues

A specific drilling location for this strategy has not been identified. Many areas of good well production in the Edwards-Trinity Plateau aquifer are associated with surface water discharge from springs. Groundwater development from this source should be evaluated for potential impacts on spring flows and base flows of area rivers. It is unlikely that this strategy would cause subsidence.

Agricultural and Rural Issues

There are no agricultural or rural issues associated with this project.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

The most significant challenge for this strategy is locating areas with sufficient well production and low potential for impacts on spring flows. There is also uncertainty regarding the amount of water actually needed to meet consumptive manufacturing needs in Kimble County. It is quite likely that the actual amount of water needed is overstated in the projections.

Other Water Management Strategies Directly Affected

Other Kimble County manufacturing strategies.

Recommended Strategies for Kimble County Manufacturing

Since it appears that the manufacturing demands for Kimble County include a significant amount of recirculated water, the most likely strategy to meet future manufacturing needs is subordination of downstream water rights. Voluntary redistribution by purchase or lease of other water rights could be effective as well, depending on which water rights are available for purchase. Drilling of water wells by manufacturing interests in Kimble County is recommended as an alternate strategy for manufacturing needs.

Table 4.4-3 summarizes the recommended strategies for Kimble County manufacturing. Costs for this strategy have not been developed because of the uncertainty regarding the implementation of these strategies.

Table 4.4-3
Recommended Strategies for Kimble County Manufacturing
(Values in Acre-Feet per Year)

	2010	2020	2030	2040	2050	2060
Existing Supplies	3	3	3	3	3	3
Subordination, voluntary redistribution & recirculation	1,000	1,000	1,000	1,000	1,000	1,000
Total Supplies	*1,003*	*1,003*	*1,003*	*1,003*	*1,003*	*1,003*
Demand	*702*	*767*	*823*	*880*	*932*	*1,002*
Surplus (Need)	*301*	*236*	*180*	*123*	*71*	*1*

4.5 Steam-Electric Power Needs

By 2060 the region has water needs for Steam-Electric Power Generation of almost 20,600 acre-feet. These shortages are the result of three factors:

- Little or no yield in reservoirs using Colorado WAM Run 3, which is required for use in the regional water plans by the TWDB,
- Limited groundwater supplies in Ward and Andrews Counties, and
- Increased demands that cannot be met with existing supplies, particularly in Ector County.

Table 4.5-1 compares region-wide demands to existing available supplies. In areas where there are insufficient supplies, steam-electric power generation has been limited to the maximum recent historical use.

The projections for growth in steam-electric power water use in Region F are based on state-wide projections for new generation capacity and do not necessarily reflect site-specific water needs.[34] In Region F, the projected growth in water demand exceeds the water supply currently available to existing generation facilities. Because growth in demand is not site-specific, strategies may include movement of demand to other locations as well as new supply development.

Potentially Feasible Strategies

Because of an overall lack of available new water supplies at existing generation facilities, Region F has limited water use for steam-electric power generation to current use. The expected growth in water demand reflects the expected need for additional electrical generation capacity in Texas, and that additional capacity can be met through a variety of approaches. Therefore meeting these shortages is not limited to water management strategies.

Strategies to meet steam-electric needs include:

- Moving the power generation need to another existing facility outside of Region F with sufficient water supplies;
- Construction of a new generation facility in an area where there are sufficient water supplies to meet projected demands, either inside or outside of Region F;
- Using an alternative source of water, including brackish water (either groundwater or surface water from chloride control projects such as Mitchell County Reservoir) or treated wastewater, either inside or outside of Region F;
- Voluntary redistribution of water supplies already dedicated to another use, including purchase of existing irrigation supplies; and
- Use of alternative cooling technologies that use less water.

Table 4.5-1
Comparison of Region F Steam-Electric Water Demand Projections
to Currently Available Supplies

	Name	County	2010	2020	2030	2040	2050	2060	Comments
Currently Available Supply	Oak Creek Reservoir	Coke	0	0	0	0	0	0	No supply in priority order WAM
Demand	AEP Oak Creek	Coke	310	247	289	339	401	477	
Surplus (Need)			*(310)*	*(247)*	*(289)*	*(339)*	*(401)*	*(477)*	
Currently Available Supply	Edwards-Trinity Plateau aquifer	Pecos	1,500	1,500	1,500	1,500	1,500	1,500	Supply based on recent use
Demand	AEP Rio Pecos	Crockett	973	776	907	1,067	1,262	1,500	Source in Pecos County
Surplus (Need)			*527*	*724*	*593*	*433*	*238*	*0*	
Currently Available Supply	Ogallala aquifer	Andrews	5,156	5,156	5,156	5,156	5,156	5,156	Supply limited to recent use
Demand	Panda Odessa-Ector	Ector	6,375	9,125	10,668	12,549	14,842	17,637	Source in Andrews County
Surplus (Need)			*(1,219)*	*(3,969)*	*(5,512)*	*(7,393)*	*(9,686)*	*(12,481)*	
Currently Available Supply	Champion/Colorado City System	Mitchell	0	0	0	0	0	0	No supply in priority order WAM
Demand	TXU Morgan Creek	Mitchell	5,023	4,847	4,670	4,493	4,317	4,140	
Surplus (Need)			*(5,023)*	*(4,847)*	*(4,670)*	*(4,493)*	*(4,317)*	*(4,140)*	
Currently Available Supply	Twin Buttes/Nasworthy	Tom Green	0	0	0	0	0	0	No supply in priority order WAM
Demand	AEP San Angelo	Tom Green	543	777	909	1,069	1,264	1,502	
Surplus (Need)			*(543)*	*(777)*	*(909)*	*(1,069)*	*(1,264)*	*(1,502)*	
Currently Available Supply	Pecos Valley	Ward	4,914	4,223	4,937	5,807	6,189	6,189	Supply limited to recent use
Demand	TXU Permian Basin	Ward	4,914	4,223	4,937	5,807	6,868	8,162	
Surplus (Need)			*0*	*0*	*0*	*0*	*(679)*	*(1,973)*	
	Total Currently Available Supply		*11,570*	*10,879*	*11,593*	*12,463*	*12,845*	*12,845*	
	Total Demand		*18,138*	*19,995*	*22,380*	*25,324*	*28,954*	*33,418*	
	Total Surplus (Need)		*(6,568)*	*(9,116)*	*(10,787)*	*(12,861)*	*(16,109)*	*(20,573)*	

Region F has identified only subordination of downstream water rights as a recommended strategy. Other strategies may be employed in Region F, including the voluntary redistribution of existing water supplies, moving demand to another location, desalination and use of alternative cooling technologies. However, the actual strategies are largely a business decision on the part of the power industry. An analysis of the potential costs of alternative cooling technologies is included in this plan. The other strategies have a large degree of uncertainty that makes it difficult to perform a meaningful analysis in the context of regional planning. Therefore, analyses of these strategies are not included in this plan.

Subordination of Downstream Senior Water Rights

TWDB requires the use of the TCEQ WAM for regional water planning. In the Colorado WAM, most reservoirs in Region F with a priority date after 1926 do not have a firm or safe yield. This result is largely due to the assumptions used in the Colorado WAM. Four reservoirs in Region F provide water for steam-electric power generation:

- Oak Creek Reservoir, which is owned by the City of Sweetwater;
- Champion Creek Reservoir and Lake Colorado City, which are owned by Luminant and operated as system; and
- Lake Nasworthy, which is owned by the City of San Angelo.

All of these reservoirs have priority dates after 1926, so these reservoirs have no yield.

In order to address water availability issues associated with the Colorado WAM model, Region F and the Lower Colorado Region (Region K) participated in a joint modeling effort to evaluate a strategy in which lower basin senior water rights do not make priority calls on major upstream water rights. This strategy also assumes that major water rights in Region F do not make priority calls on each other. The subordination strategy is discussed in Section 4.2.3.

Table 4.5-2 is a summary of the impacts of the subordination strategy on supplies used for steam-electric power generation.

The joint modeling between the two regions was conducted for planning purposes only. Neither Region F nor the Lower Colorado Region mandates the adoption of this strategy by individual water right holders. A subordination agreement is not within the authority of the

Region F Water Planning Group. Such an agreement must be developed by the water rights holders themselves, including steam-electric power generators.

Table 4.5-2
Impact of Subordination Strategy on Steam-Electric Water Supplies [a]
(Values in acre-feet per year)

Reservoir	Priority Date	Permitted Diversion	2010 Supply WAM Run 3	2010 Supply with Subord-ination	2060 Supply WAM Run 3	2060 Supply with Subord-ination
Oak Creek Reservoir	4/27/1949	10,000 [b]	0	2,118	0	1,760
Champion Creek Reservoir	4/08/1957	6,750 [c]	0	2,337	0	2,220
Lake Colorado City	11/22/1948	5,500	0	2,686	0	1,920
Lake Nasworthy [d]	3/11/1929	25,000 [e]	0	12,310 [f]	0	11,360 [f]
Total		*47,250*	*0*	*19,451*	*0*	*17,260*

a Water supply is defined as the safe yield of the reservoir.

b 4,000 acre-feet per year for industrial purposes and 6,000 acre-feet per year for municipal purposes, making the total authorized diversion from Oak Creek Reservoir 10,000 acre-feet per year. Steam-electric power generation is considered an industrial use.

c 2,700 acre-feet per year of the authorized diversions can be used for municipal purposes. However, at this time there is no municipal use from the reservoir, so the entire 6,750 acre-feet per year can be used for power generation.

d Diversions from Lake Nasworthy are backed up by storage in Twin Buttes Reservoir, which has a priority date of 5/06/1959.

e 7,000 acre-feet per year for industrial, 17,000 acre-feet per year for municipal and 1,000 acre-feet per year for irrigation, making the total authorized diversions from Lake Nasworthy 25,000 acre-feet per year.

f Yield from Twin Buttes Reservoir and Lake Nasworthy operating as a system.

Impacts of the subordination strategy are discussed in Section 4.2.3.

Alternative Cooling Technologies

Region F considers alternative cooling technologies on new power generation projects a likely method for developing new generation capacity within Region F. This technology, which uses air for cooling instead of water, can be utilized on any steam cycle based power generation project, for an incremental cost. This cost, calculated on a dollar per installed megawatt basis, would be above the cost of conventional cooling.

Quantity, Reliability and Cost

Table 4.5-3 shows the results of this analysis. Using the suggested technology up to 15,000 acre-feet per year of unmet needs can be met by 2060. This technology is currently in use and is very reliable. Capital costs, which are based on the incremental difference between more conventional cooling technologies and the alternative technology, are approximately $50.25 million in 2010, increasing to $201 million by 2060. These costs are based on the development of incremental capacities in units of 500 MW. Actual electric generating capacities will be determined on a facility basis.

Agricultural and Rural Issues

There are no agricultural or rural issues associated with this project.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

The implementation of this strategy is dependent upon a distribution of state-wide generation needs that may not represent the actual needs for generation within Region F. Location of new generation facilities within Region F is largely an economic issue that will be made by the power industry. Other technologies or strategies may be more attractive for meeting the need for new generation capacity.

Other Water Management Strategies Directly Affected

No other water management strategies are impacted by this project.

Recommended Water Management Strategies for Steam Electric Power Generation

Table 4.5-4 is a summary of supply and demand for steam-electric power generation with subordination of downstream water rights, the only recommended strategy in this plan. There are significant needs remaining. It is likely that other strategies may be implemented by the steam-electric power industry to meet these demands, including moving demand to other locations, use of alternative water sources such as desalination, and use of alternative generation technologies.

Table 4.5-3
Needed Generation Capacity on Incremental Cost of ACC Technology

	2010[a]	2020	2030	2040	2050	2060
Steam Electric Needs [b] (Ac-Ft)	1,219	3,969	5,512	7,441	10,608	14,935
Equivalent needs (GWh)	-	2,332	3,387	4,880	7,419	11,104
MW Capacity Needed (MW)	-	389	565	813	1,236	1,851
Incremental Capacity Installed (MW)	-	500	500	0	500	500
Total Capacity Installed (MW)	-	500	1,000	1,000	1,500	2,000
Capacity Factor of New Capacity (%)	-	53%	39%	56%	56%	63%
Incremental cost of ACC (million $)	-	$50.25	$50.25	$0.00	$50.25	$50.25
Total Capital Cost *(million $)*	-	$50.25	$100.50	$100.50	$150.75	$201.00
Debt Service (million $)	-	$4.38	$8.76	$4.38	$4.38	$8.76
O&M (million $) [c]	-	$1.26	$2.51	$2.51	$3.77	$5.03
Total Annual Cost *(million $)*	-	$5.64	$11.27	$6.89	$8.15	$13.79
Amount of Water Saved (af/y)		5,000	8,000	9,000	12,000	16,000
Cost/Ac-Ft	-	$1,127	$1,409	$766	$679	$862
Cost/1,000 Gal	-	$3.46	$4.32	$2.35	$2.08	$2.65

[a] Strategy assumed to be implemented after 2010.

[b] Does not include surplus supplies at other locations.

[c] Assuming 2.5 percent of construction for O&M.

Table 4.5-4
Recommended Strategies for Steam-Electric Power Generation

Category	Name	County	2010	2020	2030	2040	2050	2060
Supply	Oak Creek Reservoir	Coke	0	0	0	0	0	0
	Subordination		310	247	289	339	401	477
	Total		310	247	289	339	401	477
Demand	AEP Oak Creek	Coke	310	247	289	339	401	477
Surplus (Need)			0	0	0	0	0	0
Supply	Edwards-Trinity Plateau aquifer	Pecos	1,500	1,500	1,500	1,500	1,500	1,500
Demand	AEP Rio Pecos	Crockett	973	776	907	1,067	1,262	1,500
Surplus (Need)			527	724	593	433	238	0
Supply	Ogallala aquifer	Andrews	5,156	5,156	5,156	5,156	5,156	5,156
Demand	Panda Odessa-Ector	Ector	6,375	9,125	10,668	12,549	14,842	17,637
Surplus (Need)			(1,219)	(3,969)	(5,512)	(7,393)	(9,686)	(12,481)
Supply	Champion/Colorado City System	Mitchell	0	0	0	0	0	0
	Subordination		5,023	4,847	4,670	4,493	4,317	4,140
	Total		5,023	4,847	4,670	4,493	4,317	4,140
Demand	TXU Morgan Creek	Mitchell	5,023	4,847	4,670	4,493	4,317	4,140
Surplus (Need)			0	0	0	0	0	0
Supply	Twin Buttes/Nasworthy	Tom Green	0	0	0	0	0	0
	Subordination		1,021	1,021	1,021	1,021	1,021	1,021
	Total		1,021	1,021	1,021	1,021	1,021	1,021
Demand	AEP San Angelo	Tom Green	543	777	909	1,069	1,264	1,502
Surplus (Need)			478	244	112	(48)	(243)	(481)
Supply	Pecos Valley	Ward	4,914	4,223	4,937	5,807	6,189	6,189
Demand	TXU Permian Basin	Ward	4,914	4,223	4,937	5,807	6,868	8,162
Surplus (Need)			0	0	0	0	(679)	(1,973)
Total Supply			*17,924*	*16,994*	*17,573*	*18,316*	*18,584*	*18,483*
Total Demand			*18,138*	*19,995*	*22,380*	*25,324*	*28,954*	*33,418*
Total Surplus (Need)			*(214)*	*(3,001)*	*(4,807)*	*(7,008)*	*(10,370)*	*(14,935)*

4.6 Irrigation Needs

Sixteen of the thirty-two counties in Region F have identified irrigation needs. However, the adoption of advanced conservation technologies throughout the region will help preserve existing water resources for continued agricultural use and provide for other demands. Therefore, this analysis presents water savings for all counties in Region F. The counties with identified irrigation needs are listed in Table 4.6-1.

Table 4.6-1
Counties with Projected Irrigation Needs
(Values in Acre-Feet per Year)

County	Projected Irrigation Needs					
	2010	**2020**	**2030**	**2040**	**2050**	**2060**
Andrews	12,875	12,845	12,707	11,317	11,114	10,946
Borden	1,847	1,844	1,839	1,835	1,829	1,826
Brown	3,006	2,982	2,946	2,905	2,868	2,841
Coke	363	363	361	360	360	360
Coleman	1,348	1,348	1,348	1,348	1,348	1,348
Glasscock	27,784	27,381	26,972	26,552	26,131	25,722
Irion	1,302	1,241	1,181	1,120	1,060	1,000
Martin	788	564	322	-	-	-
Menard	2,441	2,421	2,402	2,383	2,361	2,342
Midland	16,233	16,359	16,348	16,254	16,112	15,993
Reagan	10,997	10,607	10,116	9,559	8,976	8,393
Reeves	14,253	13,401	12,543	11,681	10,820	10,003
Runnels	1,358	1,344	1,325	1,306	1,287	1,268
Tom Green	47,090	46,831	46,576	46,321	46,062	45,807
Upton	10,672	10,451	10,223	9,992	9,762	9,539
Ward	5,527	4,973	5,721	6,539	6,905	6,888
Total	*157,884*	*154,955*	*152,930*	*149,472*	*146,995*	*144,276*

Region F recommends improvements in the efficiency of irrigation equipment as the most effective water conservation strategy for irrigation within the region. The analysis presented in this plan is an update of the analysis performed for the 2001 *Region F Regional Water Plan.*[35] For this plan a review of the current irrigation practices was conducted through a special study for selected counties in Region F (see Volume II). The special study found that in two counties, Glasscock and Reagan Counties, the adoption rate of highly efficient irrigation equipment is greater than assumed in the 2006 plan. This means that the potential for incremental increases in irrigation conservation savings in these counties may be small. There was not sufficient data on the other counties to warrant changing the distribution of irrigation technologies. It was determined to retain the approach used in the *2006 Region F Water Plan* for irrigation conservation since the demands were developed prior to this observed increase in use of efficient irrigation equipment. Irrigation demands and adoption rates of irrigation equipment will be updated for the 2016 Region F Water Plan.

Six alternative irrigation systems were evaluated based on assumed use in Region F or the potential to improve water use efficiency. The alternative irrigation systems analyzed included furrow flood (FF), surge flow (SF), mid-elevation sprinkler application (MESA), low elevation spray application (LESA), low energy precision application (LEPA) and subsurface drip irrigation (drip). This analysis assumed an irrigation system was installed on a square quarter section of land (160 acres). Terrain and soil types were assumed to not limit the feasibility of adopting an irrigation system. Application efficiencies for the various irrigation technologies were assumed as follows:

- Furrow irrigation (FF) – 60 percent,
- Surge flow (SF) – 75 percent,
- MESA – 78 percent,
- LESA – 88 percent,
- LEPA – 95 percent, and
- Drip irrigation – 97 percent[36].

The system with the higher efficiency rating is considered more efficient because it uses less water.

Table 4.6-2 contains data on irrigated acreage by crop type from the Texas Water Development Board (TWDB). As shown in Table 4.6-2, there were 226,444 irrigated acres within Region F in 2006.[37] Cotton was the most significant irrigated crop with 50 percent of the irrigated acreage. Wheat and hay-pasture represented 11 percent and 8 percent, respectively, of the irrigated acreage. Seven counties (Andrews, Glasscock, Martin, Midland, Pecos, Reeves, and Tom Green) account for 71 percent of the region's irrigated acreage.

The procedure used to evaluate potential savings is dependent upon data regarding the current irrigation equipment types used in the region, which are summarized in Table 4.6-3. These data were from the 2006 Region F Plan and were not updated in this round of planning.

Based on this methodology, 42 percent of the region's irrigated crop production used some form of advanced irrigation technology (surge, sprinkler or drip) in 2002. Accelerated adoption of advanced irrigation technologies, and in particular, adoption of the most feasible advanced technologies could potentially reduce irrigation demands while maintaining the highest level of irrigated acreage possible. To examine the impact of an aggressive rate of water-conserving technology implementation, one half of the necessary adoption of advanced irrigation technologies was assumed to take place by the year 2020, with 100 percent adoption by the year 2030.

The selection of the most feasible advanced irrigation technology for each crop within a county was based on several assumptions and constraints relating to crop type, water source, and water quality considerations. The following guidelines were used:

- Furrow and surge acres were moved to drip or sprinkler whenever feasible.
- Existing sprinkler acres were moved to the most efficient sprinkler technology whenever feasible.
- Surface water supplies were assumed to remain as furrow or flood due to problems associated with the use of sprinkler or drip technologies with surface supplies. While there may be ways to make more efficient use of surface water supplies, this would involve a county by county assessment, which was beyond the scope of this analysis.
- The shift of furrow to drip was considered feasible for cotton and grain sorghum.
- Other crops such as wheat, alfalfa, peanuts, forage crops, and hay-pasture were shifted from furrow to the most feasible sprinkler technology.
- Orchard and vineyard crops currently using flood irrigation were not changed to alternative technologies.
- The application efficiency of drip and LEPA in Reeves, Ward, Loving, and Pecos counties was reduced to 93 percent and 91 percent, respectively, to allow for a flood irrigation at least once every 3 years to flush any buildup of salts in the upper soil profile.
- No additional sprinkler acreage was included in Glasscock, Midland, Upton, and Reagan counties due to the low water well yields in those counties. This strategy would involve using multiple wells per system and was deemed unlikely.

Table 4.6-2
Irrigated Acreage by Crop Type in 2006
(Values in Acres)

County/Crop	Cotton	Grain Sorghum	Wheat	Alfalfa	Forage Crops	Hay Pasture	Veg Deep	Veg Shallow	Peanuts	Pecans	Vineyards	Corn	Other	County Total
Andrews	10,460	0	6,094	0	0	158	20	0	2,170	20	0	0	2,016	*20,938*
Borden	1,135	0	202	50	100	9	0	0	0	12	0	0	200	*1,708*
Brown	0	0	259	136	172	1,385	39	0	0	2,250	0	623	155	*5,019*
Coke	138	0	0	10	250	18	0	0	0	0	0	0	111	*527*
Coleman	0	0	0	0	50	350	0	0	0	0	0	0	0	*400*
Concho	2,030	394	1,479	400	535	306	0	0	0	0	0	315	76	*5,535*
Crane	0	0	0	0	0	0	0	0	0	0	0	0	0	*0*
Crockett	0	0	231	69	0	0	0	0	0	0	0	0	0	*300*
Ector	0	0	0	0	0	300	0	0	0	200	0	0	0	*500*
Glasscock	24,033	359	764	56	0	153	114	0	0	422	0	68	262	*26,231*
Howard	2,498	0	250	82	22	50	0	0	0	28	0	0	50	*2,980*
Irion	0	0	100	0	400	100	0	0	0	0	0	0	0	*600*
Kimble	0	0	250	18	108	2,000	0	0	0	44	0	0	0	*2,420*
Loving	0	0	0	0	0	0	0	0	0	0	0	0	0	*0*
McCulloch	0	0	0	0	150	2,500	0	0	0	0	6	0	150	*2,806*
Martin	11,541	0	1,144	800	27	549	50	0	0	0	0	0	827	*14,938*
Mason	0	58	783	600	751	1,530	256	0	0	10	34	22	392	*4,436*
Menard	98	0	243	0	202	750	0	0	0	158	200	0	164	*1,815*
Midland	5,644	0	535	1,058	150	2,500	353	0	0	127	28	0	2,000	*12,395*
Mitchell	3,386	14	1,535	129	0	48	27	0	0	17	3	36	100	*5,295*
Pecos	5,561	568	886	6,000	778	2,000	1,500	1,500	0	3,000	1,000	0	1,662	*24,455*
Reagan	10,000	0	72	38	317	9	0	0	0	94	0	473	43	*11,046*
Reeves	2,673	0	2,000	2,491	1,750	1,145	1,000	500	0	375	0	0	11,347	*23,281*
Runnels	1,158	66	231	0	221	300	0	0	0	62	0	109	236	*2,383*
Schleicher	0	0	170	0	0	300	0	0	0	50	0	0	0	*520*
Scurry	2,173	0	400	347	1,500	500	0	0	52	0	0	0	63	*5,035*
Sterling	0	0	500	0	100	100	0	0	0	0	0	0	25	*725*
Sutton	0	0	551	0	100	90	0	0	0	154	0	0	127	*1,022*
Tom Green	24,189	2,585	5,089	230	1,597	469	100	106	0	100	0	3,170	1,494	*39,129*
Upton	4,980	0	50	0	0	0	184	0	0	100	0	212	100	*5,626*
Ward	677	0	0	0	0	1,000	0	0	0	0	0	0	80	*1,757*
Winkler	608	0	735	20	0	150	109	0	0	0	0	0	1,000	*2,622*
Crop Totals	*112,982*	*4,044*	*24,553*	*12,534*	*9,280*	*18,769*	*3,752*	*2,106*	*2,222*	*7,223*	*1,271*	*5,028*	*22,680*	*226,444*

Irrigated crops as reported by the TWDB in 2006. Acreages and/or crop types may have changed since 2006, but such changes are not reflected in this table.

Table 4.6-3
Estimated Distribution of Irrigation Equipment in 2002

County	Irrigated Acres	Acres by Equipment Type						Percentage of Acreage		
		Furrow	Surge	MESA	LESA	LEPA	Drip	% Furrow & Surge	% Sprinkler	% Drip
Andrews	20,326	12,183	177	0	5,046	2,800	120	60.8	38.6	0.6
Borden	2,149	861	0	640	648	0	0	40.1	59.9	0.0
Brown	7,642	6,012	0	691	909	0	31	78.7	20.9	0.4
Coke	564	289	0	224	51	0	0	51.2	48.9	0.0
Coleman	188	188	0	0	0	0	0	100.0	0.0	0.0
Concho	4,478	3,937	0	212	329	0	0	87.9	12.1	0.0
Crane	0	0	0	0	0	0	0	0.0	0.0	0.0
Crockett	96	9	0	23	64	0	0	9.2	90.5	0.0
Ector	1,632	1,052	0	0	402	0	179	64.4	24.6	11.0
Glasscock	26,598	16,650	41	80	80	1,190	8,555	62.8	5.1	32.2
Howard	2,315	1,308	0	36	272	628	72	56.5	40.4	3.1
Irion	1,245	884	0	361	0	0	0	71.0	29.0	0.0
Kimble	922	548	0	39	335	0	0	59.4	40.6	0.0
Loving	100	100	0	0	0	0	0	100.0	0.0	0.0
McCulloch	2,258	310	0	1,821	102	0	25	13.7	85.2	1.1
Martin	14,502	5,574	0	1,509	2,090	4,845	486	38.4	58.2	3.4
Mason	6,610	1,606	0	4,230	704	0	68	24.3	74.6	1.0
Menard	3,188	2,567	0	360	49	0	212	80.5	12.8	6.6
Midland	15,954	5,832	0	3,067	6,476	0	579	36.6	59.8	3.6
Mitchell	4,837	4,061	150	213	394	0	20	87.1	12.5	0.4
Pecos	23,848	8,800	10,165	0	2,447	57	2,379	79.5	10.5	10.0
Reagan	10,716	9,480	2	68	46	85	1,035	88.5	1.9	9.7
Reeves	22,078	5,843	12,726	0	2,021	20	1,467	84.1	9.2	6.6
Runnels	3,646	3,298	161	0	186	0	1	94.9	5.1	0.0
Schleicher	820	757	0	62	1	0	0	92.3	7.7	0.0
Scurry	3,490	2,929	42	72	432	0	15	85.1	14.4	0.4
Sterling	647	187	0	460	0	0	0	28.9	71.1	0.0
Sutton	851	776	0	10	67	0	0	91.1	9.0	0.0
Tom Green	30,820	25,004	1,567	261	3,419	0	568	86.2	11.9	1.8
Upton	6,301	5,029	0	0	0	0	1,272	79.8	0.0	20.2
Ward	1,426	1,414	0	12	0	0	0	99.1	0.9	0.0
Winkler	1,029	409	375	47	11	0	188	76.2	5.6	18.2
Crop Totals	*221,276*	*127,896*	*25,405*	*14,497*	*26,581*	*9,624*	*17,272*	*69.3*	*22.9*	*7.8*

Estimated irrigated crops in 2002 are from the 2006 Region F plan. Recent information provided by the GCDs indicate the distributions in some counties may be different than shown here.

Utilizing these assumptions, the projected percentages of use for different irrigation equipment are shown in Table 4.6-4.

The methodology for calculating annual water savings in acre-feet was to shift acreages of furrow irrigated crops to LEPA or drip, from Surge to LEPA or drip, from MESA to LEPA and from LESA to LEPA when an advanced technology was considered feasible. The gross irrigation application rate per acre for each crop in a given county using a furrow system was used as the base water application rate. This base rate was then compared to the required equivalent irrigation application rate with advanced irrigation technology. The difference in application rates was the assumed water savings. For example, the total per acre applied irrigation water for cotton using a furrow system was 16 acre-inches in Glasscock County. Using the 60 percent application efficiency for furrow resulted in an effective application rate of 9.6 acre-inches. If a drip system were used with an application efficiency of 97 percent, the resulting total application rate would be 9.9 acre-inches. Therefore, the potential water savings for a shift from furrow to drip would be 6.1 acre-inches.

Quantity, Reliability and Cost of Irrigation Conservation

Table 4.6-5 presents the estimates of water savings by decade from accelerated adoption of water-efficient technology for all counties in Region F. With partial adoption (50%) completed by 2020, the annual water savings for the region is 40,470 acre-feet. Following full adoption in 2030, these annual water savings increase to 81,112 acre-feet. For the counties with irrigation needs, 22 percent of the initial deficit was recovered by 2020 and 44 percent was recovered by 2030. As shown on Table 4.6-5, all of the projected irrigation need can be met by advanced conservation for Brown and Martin Counties. The large irrigation counties, including Andrews, Glasscock, Midland, Reeves and Tom Green, still have considerable unmet irrigation demands. No specific alternative strategies were identified for these needs. It is anticipated that in the counties with unmet irrigation demands, some portion of the irrigated acreage will shift to non-irrigated crop production or to other uses. While it is difficult to predict what crops will likely be removed from production, the crops with the lower relative value of water will most likely be removed first. Table 4.6-6 presents the revised projected irrigation needs after accounting for advanced irrigation technologies. Also shown are estimates of the number of irrigated acres that

Table 4.6-4
Estimated Percentage of Projected Adoption of Advanced Irrigation Technology in Region F

County	Irrigated Acres	2002 (current)			2020			2030 - 2060		
		% Furrow & Surge	% Sprinkler	% Drip	% Furrow & Surge	% Sprinkler	% Drip	% Furrow & Surge	% Sprinkler	% Drip
Andrews	20,326	60.8	38.6	0.6	37.9	54.5	7.6	15.0	70.4	14.6
Borden	2,149	40.1	59.9	0.0	22.1	70.4	7.4	4.2	80.9	14.9
Brown	7,642	78.7	20.9	0.4	78.7	20.9	0.4	78.7	20.9	0.4
Coke	564	51.2	48.9	0.0	51.2	48.9	0.0	51.2	48.9	0.0
Coleman	188	100.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0
Concho	4,478	87.9	12.1	0.0	47.2	39.4	13.4	6.5	66.7	26.8
Crane	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crockett	96	9.2	90.5	0.0	9.2	90.5	0.0	9.2	90.5	0.0
Ector	1,632	64.4	24.6	11.0	40.1	48.9	11.0	15.8	73.2	11.0
Glasscock	26,598	62.8	5.1	32.2	35.9	5.1	59.0	9.1	5.1	85.8
Howard	2,315	56.5	40.4	3.1	33.2	51.5	15.3	9.8	62.7	27.5
Irion	1,245	71.0	29.0	0.0	71.0	29.0	0.0	71.0	29.0	0.0
Kimble	922	59.4	40.6	0.0	40.1	59.9	0.0	20.8	79.2	0.0
Loving	100	100.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0
McCulloch	2,258	13.7	85.2	1.1	9.8	89.1	1.1	5.8	93.1	1.1
Martin	14,502	38.4	58.2	3.4	19.9	61.7	18.4	1.4	65.2	33.4
Mason	6,610	24.3	74.6	1.0	14.8	84.1	1.0	5.4	93.5	1.0
Menard	3,188	80.5	12.8	6.6	80.5	12.8	6.6	80.5	12.8	6.6
Midland	15,954	36.6	59.8	3.6	25.3	59.8	14.9	14.1	59.8	26.1
Mitchell	4,837	87.1	12.5	0.4	47.0	26.2	26.8	7.0	39.8	53.1
Pecos	23,848	79.5	10.5	10.0	46.3	31.4	22.3	13.1	52.3	34.5
Reagan	10,716	88.5	1.9	9.7	51.9	1.9	46.3	15.3	1.9	82.9
Reeves	22,078	84.1	9.2	6.6	45.9	36.4	17.7	7.7	63.6	28.7
Runnels	3,646	94.9	5.1	0.0	94.9	5.1	0.0	94.9	5.1	0.0
Schleicher	820	92.3	7.7	0.0	63.9	36.1	0.0	35.5	64.5	0.0
Scurry	3,490	85.1	14.4	0.4	47.3	42.6	10.1	9.5	70.8	19.7
Sterling	647	28.9	71.1	0.0	28.9	71.1	0.0	28.9	71.1	0.0
Sutton	851	91.1	9.0	0.0	61.0	39.1	0.0	30.8	69.3	0.0
Tom Green	30,820	86.2	11.9	1.8	58.8	25.9	15.3	30.5	40.2	29.2
Upton	6,301	79.8	0.0	20.2	50.6	0.0	49.4	21.4	0.0	78.6
Ward	1,426	99.1	0.9	0.0	58.7	41.3	0.0	18.3	81.7	0.0
Winkler	1,029	76.2	5.6	18.2	50.1	31.7	18.2	23.9	57.8	18.2
System Totals	*221,276*	*69.3*	*22.9*	*7.8*	*44.2*	*34.2*	*21.6*	*19.0*	*45.6*	*35.4*

would need to be converted to dryland farming or taken out of production to remain within the available supplies in each decade.

The actual amount of water saved by using advanced irrigation conservation is dependent upon a large number of factors, including weather, crop prices, funding, technical assistance, and individual preference. Therefore the reliability of this strategy is expected to be medium because of the uncertainty involved in the actual savings associated with this strategy.

Table 4.6-5
Projected Water Savings with Advanced Irrigation Technologies

County	Irrigation Need	Projected Water Savings (acre-feet/year)		% Reduction of 2010 Need	
	2010	2020	2030-2060	2020	2030-2060
Andrews	12,875	2,727	5,455	21.2%	42.4%
Borden	1,847	230	460	12.5%	24.9%
Brown	3,006	93	185	3.1%	6.2%
Coke	363	0	0	0.0%	0.0%
Coleman	1,348	0	0	0.0%	0.0%
Concho		748	1,496		
Crane		0	0	0.0%	0.0%
Crockett		0	0		
Ector		245	490		
Glasscock	27,784	3,631	7,262	13.1%	26.1%
Howard		327	653		
Irion	1,302	37	73	2.8%	5.6%
Kimble		74	147		
Loving		0	0		
McCulloch		197	394		
Martin	788	1,751	3,502	100%	100%
Mason		746	1,491		
Menard	2,441	23	46	0.9%	1.9%
Midland	16,233	1,800	3,600	11.1%	22.2%
Mitchell		865	1,729		
Pecos		6,300	12,600		
Reagan	10,997	1,968	3,936	17.9%	35.8%
Reeves	14,253	5,824	11,648	40.9%	81.7%
Runnels	1,358	0	0	0.0%	0.0%
Schleicher		107	214		
Scurry		571	1,143		
Sterling		45	89		
Sutton		142	284		
Tom Green	47,090	5,774	11,548	12.1%	24.5%
Upton	10,672	920	1,840	8.6%	17.2%
Ward	5,527	785	1,570	14.2%	28.4%
Winkler		195	389		
Total	*157,884*	*36,125*	*72,244*	*22.9%*	*45.8%*

Table 4.6-6
Revised Irrigation Needs Incorporating Advanced Irrigation Technologies

County	Projected Irrigation Need (ac-ft/yr)						Projected Irrigation Need with Conservation (ac-ft/yr)					
	2010	**2020**	**2030**	**2040**	**2050**	**2060**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Andrews	12,875	12,845	12,707	11,317	11,114	10,946	12,875	10,118	7,252	5,862	5,659	5,491
Borden	1,847	1,844	1,839	1,835	1,829	1,826	1,847	1,614	1,379	1,375	1,369	1,366
Brown	3,006	2,982	2,946	2,905	2,868	2,841	3,006	2,889	2,761	2,720	2,683	2,656
Coke	363	363	361	360	360	360	363	363	361	360	360	360
Coleman	1,348	1,348	1,348	1,348	1,348	1,348	1,348	1,348	1,348	1,348	1,348	1,348
Glasscock	27,784	27,381	26,972	26,552	26,131	25,722	27,784	23,750	19,710	19,290	18,869	18,460
Irion	1,302	1,241	1,181	1,120	1,060	1,000	1,302	914	528	467	407	347
Martin	788	564	322	0	0	0	788	0	0	0	0	0
Midland	2,441	2,421	2,402	2,383	2,361	2,342	2,441	2,398	2,356	2,337	2,315	2,296
Midland	16,233	16,359	16,348	16,254	16,112	15,993	16,233	14,559	12,748	12,654	12,512	12,393
Reagan	10,997	10,607	10,116	9,559	8,976	8,393	10,997	8,639	6,180	5,623	5,040	4,457
Reeves	14,253	13,401	12,543	11,681	10,820	10,003	14,253	7,577	895	33	0	0
Runnels	1,358	1,344	1,325	1,306	1,287	1,268	1,358	1,344	1,325	1,306	1,287	1,268
Tom Green	47,090	46,831	46,576	46,321	46,062	45,807	47,090	41,057	35,028	34,773	34,514	34,259
Upton	10,672	10,451	10,223	9,992	9,762	9,539	10,672	9,531	8,383	8,152	7,922	7,699
Ward	5,527	4,973	5,721	6,539	6,905	6,888	5,527	4,188	4,151	4,969	5,335	5,318
Totals	*157,884*	*154,955*	*152,930*	*149,472*	*146,995*	*144,276*	*157,884*	*130,289*	*104,405*	*101,269*	*99,620*	*97,718*

* Values are for each decade and do not represent incremental reductions in irrigated acreage.

Estimated costs for implementing this strategy are based on the analysis performed in the 2001 Region F plan. Assuming a static pumping lift of 350 feet, the cost of implementing a furrow flood system is $557/acre, a surge flow system $581/acre, MESA system $876/acre, LESA system $920/acre, LEPA system $936/acre and drip system $1,354/acre.

The costs of implementing advanced irrigation technologies in Region F are presented in Appendix 4E. The additional investment for converting a furrow irrigation system to LEPA and drip is $380 and $800 per acre respectively; from Surge to LEPA and drip is $360 and $780 per acre respectively; from MESA to LEPA and from LESA to LEPA is $60 and $20 per acre respectively. The corresponding annualized cost per acre for each strategy amortized over 30 years at 6 percent interest is $27.61, $58.12, $26.15, $56.67, $4.36 and $1.45, respectively.

The estimated per acre water savings achieved with shifts from one irrigation technology to another varies by county. Therefore, the costs to adopt alternative irrigation systems are given by county. In general, the highest cost per acre-foot of water savings is for shifts from furrow or surge to drip. However, this represents only capital costs associated with equipment changes. Cost savings associated with reduced labor requirements for the more advanced irrigation technologies (sprinkler and drip) are not included in this analysis. To fully assess the economic feasibility of a strategy, a more complete economic evaluation is required.

Environmental Issues Associated with Irrigation Conservation

This strategy is expected to have minimal impact on the environment, either positive or negative. Most of the areas in Region F with significant irrigation needs rely on groundwater for irrigation, and most of the conservation strategies developed in this analysis are specifically for groundwater-based irrigation. In areas where conserved groundwater is discharged as springs or base flow, conservation will have a positive impact. However, in many cases projected irrigation demand exceeds available supply even with implementation of advanced irrigation technologies.

Agricultural and Rural Issues Associated with Irrigation Conservation

Irrigated agriculture is vital to the economy and culture of Region F. Implementation of water-conserving irrigation practices may be necessary to retain the economic viability of many areas that show significant water supply needs throughout the planning period.

Other Natural Resource Issues Associated with Irrigation Conservation

None identified.

Significant Issues Affecting Feasibility of Irrigation Conservation

The most significant issue associated with implementation of this strategy is the lack of a clear sponsor for the strategy. Although the TWDB and other state and federal agencies sponsor many excellent irrigation conservation programs, the actual implementation is the responsibility of individual irrigators. Because this strategy relies largely on individual behavior, it is difficult to quantify the actual savings that can be achieved.

Another significant factor is the lack of detailed data on both irrigation equipment in use and the quantity of water used for individual crops. The conservation calculations included in this analysis were hampered by a lack of current data for these two items.

Other Water Management Strategies Directly Affected by Irrigation Conservation

None identified.

4.7 Mining Needs

There are four counties in Region F with mining needs: Coke, Coleman and Howard Counties. Table 4.7-1 compares supplies to demands for these counties. These mining needs are the result of using the Colorado WAM for water supplies and can be met by the implementation of a subordination strategy.

Potentially Feasible Strategies

Region F has identified subordination of downstream water rights and use of non-potable water to meet mining needs. Most of the water used for mining purposes in Region F is for enhanced oil and gas production. According to §27.0511 of the Texas Water Code, the oil and gas industry is required by law to use non-potable supplies whenever possible for enhanced production.[38] As a result, it is unclear to what extent the water demand projections for the region actually represent direct competition with other types of use that require better water quality. The actual amount of mining needs may be considerably less than indicated.

Table 4.7-1
Mining Needs in Region F
(Values in Acre-Feet per Year)

	Source	2010	2020	2030	2040	2050	2060
Coke County							
Supply	CRMWD diverted water	232	239	378	378	380	372
	Other aquifer	170	170	170	170	170	170
	Total	*402*	*409*	*548*	*548*	*550*	*542*
Demand	*Mining*	*488*	*528*	*550*	*572*	*593*	*614*
Surplus (Need)		*(86)*	*(119)*	*(2)*	*(24)*	*(43)*	*(72)*
Coleman County							
Supply	Lake Coleman	0	0	0	0	0	0
	Other aquifer	1	1	1	1	1	1
	Total	*1*	*1*	*1*	*1*	*1*	*1*
Demand	*Mining*	*18*	*19*	*19*	*19*	*19*	*19*
Surplus (Need)		*(17)*	*(18)*	*(18)*	*(18)*	*(18)*	*(18)*
Howard County							
Supply	Edwards-Trinity Plateau	82	82	82	82	82	82
	Ogallala	119	119	119	119	119	119
	Dockum	106	106	106	106	106	106
	CRMWD diverted water	1,076	1,053	1,608	1,555	1,523	1,460
	Total	*1,383*	*1,360*	*1,915*	*1,862*	*1,830*	*1,767*
Demand	*Mining*	*1,783*	*1,883*	*1,924*	*1,963*	*2,001*	*2,052*
Surplus (Need)		*(400)*	*(523)*	*(9)*	*(101)*	*(171)*	*(285)*
Total Needs		*(503)*	*(660)*	*(29)*	*(143)*	*(232)*	*(375)*

Subordination of Downstream Water Rights

TWDB requires the use of the TCEQ WAM for regional water planning. In the Colorado WAM, most reservoirs in Region F with a priority date after 1926 do not have a firm or safe yield. This result is largely due to the assumptions used in the Colorado WAM. Mining water in Coke and Howard Counties is from the CRMWD system. Mining water in Coleman County comes from Lake Coleman. All of these sources have reduced supplies because of the WAM.

In order to address water availability issues resulting from the Colorado WAM model, Region F and the Lower Colorado Region (Region K) participated in a joint modeling effort to evaluate a strategy in which lower basin senior water rights do not make priority calls on major upstream water rights. This strategy also assumes that major water rights in Region F do not make priority calls on each other. The subordination strategy is discussed in Section 4.2.3. With implementation of the subordination strategy there are sufficient supplies in these counties to meet demands.

The joint modeling between the two regions was conducted for planning purposes only. Neither Region F nor the Lower Colorado Region mandates the adoption of this strategy by individual water right holders. A subordination agreement is not within the authority of the Region F Water Planning Group. Such an agreement must be developed by the water rights holders themselves, including CRMWD and the City of Coleman. Impacts of the subordination strategy are discussed in Section 4.2.3.

Recommended Strategies

Table 4.7-2 is a summary of the recommended strategies to meet mining needs in Coke, Coleman, and Howard Counties. Meaningful costs for these strategies are difficult to develop because of the uncertainty regarding the magnitude of the shortages and the actual way that these strategies will be implemented.

Table 4.7-2
Strategies to Meet Mining Needs
(Values in Acre-Feet per Year)

Category	2010	2020	2030	2040	2050	2060
Coke County						
Existing supplies	402	409	548	548	550	542
Subordination	86	119	2	24	43	72
Total Supply	*488*	*528*	*550*	*572*	*593*	*614*
Demand	*488*	*528*	*550*	*572*	*593*	*614*
Surplus (need)	*0*	*0*	*0*	*0*	*0*	*0*
Coleman County						
Existing supplies	1	1	1	1	1	1
Subordination	17	18	18	18	18	18
Total Supply	*18*	*19*	*19*	*19*	*19*	*19*
Demand	*18*	*19*	*19*	*19*	*19*	*19*
Surplus (need)	*0*	*0*	*0*	*0*	*0*	*0*
Howard County						
Existing Supplies	1,383	1,360	1,915	1,862	1,830	1,767
Subordination	400	523	9	101	171	285
Total Supply	*1,783*	*1,883*	*1,924*	*1,963*	*2,001*	*2,052*
Demand	*1,783*	*1,883*	*1,924*	*1,963*	*2,001*	*2,052*
Surplus (need)	*0*	*0*	*0*	*0*	*0*	*0*

Note: The subordination strategy will be implemented by CRMWD and the City of Coleman.

4.8 Strategies for Wholesale Water Providers

Strategies have been developed for the Colorado River Municipal Water District and the City of San Angelo. For the purposes of this plan, contracts between University Lands and CRMWD, the City of Andrews and the City of Midland are expected to be renewed when they expire. If these contracts are not renewed, the timing of recommended strategies for the City of Midland and CRMWD may be impacted. The City of Andrews may not have sufficient supplies even with the contract renewal and may require a new source of water.

4.8.1 Colorado River Municipal Water District

The Colorado River Municipal Water District (CRMWD), the largest water supplier in Region F, provides raw water from both groundwater and surface water sources. CRMWD owns and operates three major reservoirs, Lake J.B. Thomas, E.V. Spence Reservoir, and O.H. Ivie Reservoir, as well as several chloride control reservoirs. Groundwater sources include well fields in Ward, Scurry and Martin Counties. CRMWD member cities include Big Spring, Odessa and Snyder. CRMWD also supplies water to Midland, San Angelo and Abilene (through West Central Texas MWD) as well as several smaller cities in Ward, Martin, Howard and Coke Counties.

Table 4.8-1 compares supplies to projected demands for CRMWD customers. As shown in Table 4.8-1, CRMWD has needs throughout the planning period. These needs are the result of the use of the Colorado WAM as the basis for water availability.

Potentially Feasible Strategies for CRMWD

The following potentially feasible strategies have been identified for CRMWD:

- Subordination of downstream senior water rights
- Water conservation
- Drought management
- Reuse

Table 4.8-1
Comparison of Supply and Demand for CRMWD
(Values in Acre-Feet per Year)

Supplies	2010	2020	2030	2040	2050	2060
Thomas	0	0	0	0	0	0
Spence	560	560	560	560	560	560
Ivie	66,350	65,000	63,650	62,300	60,950	59,600
Ward County Well Field (Pecos Valley) *	5200	0	0	0	0	0
Scurry County Well Field (Dockum)	900	900	900	900	900	900
Ector County Well Field (Edwards-Trinity)	440	440	440	440	440	440
Martin County Well Field (Ogallala)	1,035	1,035	1,035	1,035	1,035	1,035
Total	*74,485*	*67,935*	*66,585*	*65,235*	*63,885*	*62,535*
Demands	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Member Cities	33,425	34,764	35,761	36,782	38,081	39,637
Others	55,787	56,867	37,982	37,347	35,618	35,007
Total	*89,212*	*91,631*	*73,743*	*74,129*	*73,699*	*74,644*
Surplus (Need)	*-14,727*	*-23,696*	*-7,158*	*-8,894*	*-9,814*	*-12,109*

* The contract with University Lands for the Ward County Well Field expires in 2019.

- Voluntary redistribution
  - Roberts County groundwater
  - Renew contract with University Lands for groundwater in Ward County, including replacement of lost capacity
  - New contracts to provide water
- New groundwater
  - Winkler County Well Field
  - Groundwater from southwestern Pecos County
- Groundwater Desalination

Precipitation enhancement and brush control are discussed in Section 4.9.

With subordination agreements CRMWD will have sufficient water to meet projected demands throughout the planning period. However, new supplies are needed to increase the reliability of the CRMWD system and to improve water quality. Water quality considerations often prevent CRMWD from operating its system at full capacity. The total dissolved solids (TDS) concentration of water varies among CRMWD's sources of water, ranging from less than 500 mg/l in Lake Thomas to up to 4,000 mg/l in Lake Spence. The CRMWD system is operated so that all of its customers receive water of approximately the same quality. To fully utilize the yield of Spence Reservoir and maintain water quality, additional low TDS water is needed.

Subordination of Downstream Senior Water Rights

TWDB requires the use of the TCEQ WAM for regional water planning. In the Colorado WAM, most reservoirs in Region F with a priority date after 1926 do not have a firm or safe yield. This result is largely due to the assumptions used in the Colorado WAM. The priority dates for CRMWD reservoirs are 1946 for Lake Thomas, 1964 for Spence Reservoir and 1978 for Ivie Reservoir. However, TCEQ modeled the Ivie Reservoir so that it can impound water at a 1926 priority date to represent the subordination with the Highland Lakes included in the water rights for those sources. As a result, Thomas and Spence have little or no yield, while Lake Ivie has a safe yield of over 66,000 acre-feet.

In order to address water availability issues resulting from the Colorado WAM model, Region F and the Lower Colorado Region (Region K) participated in a joint modeling effort to evaluate a strategy in which lower basin senior water rights do not make priority calls on major upstream water rights. This strategy also assumes that major water rights in Region F do not make priority calls on each other. The subordination strategy is discussed in Section 4.2.3. Table 4.8-2 is a summary of the impacts of the subordination strategy on CRMWD supplies.

Table 4.8-2
Impact of Subordination Strategy on CRMWD Water Supplies [a]
(Values in acre-feet per year)

Reservoir	Priority Date	Permitted Diversion	2010 Supply WAM Run 3	2010 Supply with Subord-ination	2060 Supply WAM Run 3	2060 Supply with Subord-ination
Lake Thomas	5/08/1946	23,000	0	10,013	0	10,130
Spence Reservoir	8/17/1964	41,573	560	38,472	560	37,330
Ivie Reservoir	2/21/1978 [b]	113,000	66,350	66,452	59,600	56,260
Total		*177,573*	*66,910*	*114,937*	*60,160*	*103,720*

a Water supply is defined as the safe yield of the reservoir.

b Although Ivie Reservoir has a junior priority date, in the Colorado WAM TCEQ assumed that the reservoir could store water at a 1926 priority date because of the subordination of Ivie to the Highland Lakes.

The joint modeling between the two regions was conducted for planning purposes only. Neither Region F nor the Lower Colorado Region mandates the adoption of this strategy by individual water right holders. A subordination agreement is not within the authority of the Region F Water Planning Group. Such an agreement must be developed by the water rights holders themselves, including CRMWD.

Impacts of the subordination strategy are discussed in Section 4.2.3.

CRMWD Reclamation Project

Wastewater reuse is becoming an increasingly important source of water across the state, especially in West Texas where there are few new water sources. Reuse provides a reliable source that remains available in a drought. The quantity of available reuse increases as water demands increase. This strategy also represents an effective means of conserving existing water sources, which can defer development of new water sources.

CRMWD serves several large municipal areas that could potentially benefit from wastewater reuse, reducing the demand for water from CRMWD's existing sources. To evaluate a regional reclamation project, three reuse projects were studied to serve the District's primary customers: Snyder, Big Spring and Odessa-Midland. Each of these projects could be implemented independently or collectively as a regional wastewater reuse plan for the District. A discussion of each proposed reuse project is presented in the following sections. Additional information on these projects may be found in the report *Regional Water Reclamation Project Feasibility Study.*[39]

Snyder Reuse Project

The City of Snyder is a CRMWD member city and obtains most of its water from Lake J.B. Thomas. During times of drought and low water levels in the lake CRMWD moves water from its other sources through Lake Thomas to serve Snyder. This operation is less than desirable due to increased water losses and higher TDS concentrations of the transferred water. The proposed Snyder Reclamation Project would provide additional water to the city and minimize the transfer of water from other sources.

The proposed Snyder Reclamation Project would blend the city's treated effluent, which is currently discharged to Deep Creek, with raw water from Lake Thomas. Approximately 0.9 MGD of wastewater effluent would be subjected to advanced treatment using membrane filtration, reverse osmosis and ultraviolet oxidation, and then blended with raw surface water in a new 15 million gallon terminal storage facility.

Treated effluent that is not needed during wet seasons or periods of low demand would be stored underground at a suitable site with an aquifer storage and recovery (ASR) system. An 8-inch transmission pipeline would be constructed to move the treated effluent to and from the ASR facility. Two new wells would be used for injection and extraction of the water.

Quantity, Reliability and Cost of Snyder Reuse Project

This strategy would provide approximately 726 acre-feet per year of additional supply to Snyder, or about 22 percent of the maximum expected demand for the city and its customers during the planning period. The reliability of this water source is high. Table 4.8-3 is a summary of the costs of the project. Capital costs are estimated at $9.6 million, with a unit cost of $4.67 per 1,000 gallons of reclaimed water.

Table 4.8-3
Snyder Reuse Project

Supply from Strategy	**726 acre-feet per year**
Total Capital Costs (2008 Prices)	$ 9,643,000
Annual Costs	$ 1,104,000
Unit costs (during amortization)	$ 1,521 per acre-foot
	$ 4.67 per 1,000 gallons
Unit Costs (after amortization)	$ 362 per acre-foot
	$ 1.11 per 1,000 gallons

Environmental Issues Associated with Snyder Reuse Project

Wastewater reuse will reduce low flows in Deep Creek and, to a much lesser extent, flows in the Colorado River below Lake Thomas. The advanced treatment will produce a reject stream that will be blended with other wastewater effluent and discharged to Deep Creek, which may increase TDS levels. However, TDS levels in Deep Creek and this portion of the Colorado River are already very high, and downstream impacts will be mitigated by diversion of high TDS water at the existing chloride control project near Colorado City and stored in Barber Reservoir.

Because of the relatively small volume of effluent currently discharged, the impact on overbanking flows is expected to be minimal. There is no impact on bays and estuaries because all of the current discharge is lost, impounded or used before reaching the Colorado estuary or Matagorda Bay.

This strategy should have a positive impact on water quality in Lake Thomas because the need to pass water from other sources through the reservoir during drought will be reduced or eliminated.

The project does not require a bed-and-banks permit because the reuse occurs prior to discharge.

Agricultural and Rural Issues Associated with Snyder Reuse Project

There are no agricultural or rural issues associated with this project.

Other Natural Resource Issues Associated with Snyder Reuse Project

This strategy will provide an alternative source of water for Snyder, which will conserve water from CRMWD sources that otherwise would be needed to meet Snyder's water needs.

Significant Issues Affecting Feasibility of Snyder Reuse Project

Public acceptability of wastewater reuse for municipal use may affect the feasibility of this project.

Other Water Management Strategies Directly Affected by Snyder Reuse Project

No other water management strategies are impacted by this project.

Big Spring Reuse Project

Similar to the Snyder Reclamation Project, the Big Spring Reclamation Project would blend treated wastewater effluent from Big Spring with raw water from Spence Reservoir. This project proposes to treat 2.3 MGD of wastewater effluent with advanced treatment (membrane filtration, reverse osmosis and UV oxidation) and blend the treated water directly with raw water in the District's Spence Pipeline that runs along the northeast side of Big Spring. The raw water/effluent blend would then be treated at the city's water treatment plant for municipal and industrial use. Pilot testing of the project was initiated in 2008 and is on-going (2009). Based on the findings of this study the project could be on-line within the next several years. Water from Spence Reservoir has historically been high in TDS and the reclaimed water should improve the quality of the water from this source.

The reject water from the reverse osmosis treatment would be discharged to Beals Creek and subsequently re-diverted at the existing Beals Creek chloride control project and stored in Red Draw Reservoir.

An alternative to the proposed project is to use all or a portion of the reclaimed water for industrial purposes. The industrial water will require less treatment.

Quantity, Reliability and Cost of the Big Spring Reuse Project

The annual yield of the project is estimated at 1,855 acre-feet per year, which is approximately 25 percent of the maximum projected municipal demand for the city and its customers. The reliability of the water source is high. Capital costs are estimated at $9.9 million, with unit costs for the reclaimed water at $2.53 per 1,000 gallons. Table 4.8-4 summarizes the costs for the project.

Table 4.8-4
Big Spring Reuse Project

Supply from Strategy	**1,855 acre-feet per year**
Total Capital Costs (2008 Prices)	$ 9,911,000
Annual Costs	$ 1,529,000
Unit costs (during amortization)	$ 824 per acre-foot
	$ 2.53 per 1,000 gallons
Unit Costs (after amortization)	$ 358 per acre-foot
	$ 1.10 per 1,000 gallons

Environmental Issues Associated with the Big Spring Reuse Project

Currently almost all of the treated wastewater discharge from the City of Big Spring is re-diverted at the Beals Creek chloride control project, and this operation is not expected to change with the proposed project. Except for the short reach between the existing discharge point and the diversion project, there should be little impact on instream flows. The water quality of this stream reach is already high in TDS and the discharge is expected to have little impact on water quality. The existing chloride control project will mitigate any impacts on downstream water quality.

Because of the relatively small volume of effluent currently discharged, the impact on overbanking flows is expected to be minimal. There will be no impact on bays and estuaries because all of the water currently discharged is lost, diverted or stored in reservoirs before reaching the Colorado estuary or Matagorda Bay. The project does not require a bed-and-banks permit because the reuse occurs prior to discharge.

Agricultural and Rural Issues Associated with the Big Spring Reuse Project

There are no agricultural or rural issues associated with this project.

Other Natural Resource Issues Associated with the Big Spring Reuse Project

This strategy will provide an alternative source of water for Big Spring, which will conserve water from CRMWD sources that would be needed to meet the city's water needs.

Significant Issues Affecting Feasibility of the Big Spring Reuse Project

Public acceptability of wastewater reuse for municipal use may affect the feasibility of this project.

Other Water Management Strategies Directly Affected by the Big Spring Reuse Project

No other water management strategies are impacted by this project.

Odessa-Midland Reuse Project

The proposed Odessa-Midland Reuse Project would utilize wastewaters from both cities and reclaim approximately 10.8 MGD of treated wastewater. The effluent would undergo advanced treatment at a Regional Reclamation Facility prior to blending with raw water at the District's 100 million gallon terminal storage reservoir between the two cities. The City of Odessa already has an extensive water reclamation system which could be used as part of this project. Treatment will consist of membrane filtration, reverse osmosis and ultraviolet oxidation. This strategy includes ASR using the City of Midland's abandoned McMillan well field for underground storage.

Handling and disposal of the brine reject from the treatment process is a large part of the cost of this project. The disposal process includes a combination of disposal wells, storage and evaporation reservoirs, and transfers to oil operations at the Mabee Oil Field. The strategy also calls for construction of secondary treatment facilities at the City of Midland's existing treatment plant.

Quantity, Reliability and Cost of the Odessa/Midland Reuse Project

The annual yield of the project is estimated at 9,799 acre-feet per year, or about 17 percent of the combined demand for the cities of Odessa and Midland and their municipal customers.

The reliability of the water source is high. Capital costs are estimated at $109 million, with unit costs for the reclaimed water at $4.16 per 1,000 gallons. Table 4.8-5 summarizes the costs for the project.

Table 4.8-5
Odessa-Midland Reuse Project

Supply from Strategy	**9,799 acre-feet per year**
Total Capital Costs (2008 Prices)	$ 109,194,000
Annual Costs	$ 13,272,000
Unit costs (during amortization)	$ 1,354 per acre-foot
	$ 4.16 per 1,000 gallons
Unit Costs (after amortization)	$ 383 per acre-foot
	$ 1.18 per 1,000 gallons

Environmental Issues Associated with the Odessa/Midland Reuse Project

Currently the City of Midland disposes of treated effluent using land application; none of the treated effluent is discharged. The City of Odessa also uses a large part of its treated effluent for irrigation, with some water contracted for industrial use. Unused treated wastewater is discharged into Monahans Draw. Almost all of the flow in Monahans Draw is treated wastewater, and during the summer very little treated wastewater is discharged. Although reuse will reduce current flows in Monahans Draw, most of the current discharge is lost due to evapotranspiration and infiltration before reaching Beals Creek just above Big Spring. Therefore downstream impacts will be negligible.

Reuse is expected to have minimal impacts on overbank flows and no impact on bays and estuaries.

The proposed project does not call for discharge of the waste stream from treatment, so implementation will not cause a degradation of water quality because of the waste stream. The project does not require a bed-and-banks permit.

Agricultural and Rural Issues Associated with the Odessa/Midland Reuse Project

The City of Midland currently irrigates with treated effluent. Therefore, this project may make less water available for irrigation in Midland County.

Other Natural Resource Issues Associated with the Odessa/Midland Reuse Project

This strategy will provide an alternative source of water for the cities of Odessa and Midland, which will conserve water from CRMWD sources.

Significant Issues Affecting Feasibility of the Odessa/Midland Reuse Project

Public acceptability of wastewater reuse for municipal use may affect the feasibility of this project.

Other Water Management Strategies Directly Affected by the Odessa/Midland Reuse Project

CRMWD Winkler County Well Field project.

New Groundwater Development - Winkler Well Field

CRMWD owns groundwater rights to an undeveloped well field in southern Winkler County. The well field will produce water from the Pecos Valley aquifer. For the purposes of this plan it has been assumed that water from the well field would be pumped approximately 43 miles directly to the City of Odessa. At Odessa the water could be blended with other sources and distributed to CRMWD's customers.

For this plan, it is assumed that the CRMWD Winkler well field will be developed as a stand-alone project. However, the CRMWD Winkler well field is near the City of Midland's undeveloped T-Bar Well Field. As an alternative, these two projects could use the same transmission facilities. This project could also be developed in conjunction with other supply projects from the Pecos Valley or other fresh or brackish groundwater sources. Region F considers co-development of these projects to be consistent with this plan. A discussion of potential co-development of supply from the Pecos Valley with the CRMWD Winkler well field and the Midland T-Bar project may be found in *Special Study No. 1: Refinement of Groundwater Supplies and Identification of Potential Projects* in Volume II. This study found that although there is some potential cost savings by developing these projects together, the initial capital costs are much higher. Cost savings due to co-development depend on the timing of the need for the water. If all of the water is needed in a short time period there may be some savings from co-development. However, if the projects will be phased over time then cost savings may not be realized from co-development.

Quantity, Reliability and Cost of Winkler County Well Field

CRMWD estimates that the Winkler County Well Field could provide 6,000 acre-feet per year. Water from this source is considered to be very reliable. Table 4.8-6 summarizes the expected costs of developing the well field.

Table 4.8-6
Costs for CRMWD Winkler County Well Field

Supply from Strategy	**6,000 acre-feet per year**
Total Capital Costs (2008 Prices)	$ 76,268,000
Annual Costs	$ 8,666,000
Unit costs (during amortization)	$ 1,444 per acre-foot
	$ 4.43 per 1,000 gallons
Unit Costs (after amortization)	$ 336 per acre-foot
	$ 1.03 per 1,000 gallons

Environmental Issues Associated with Winkler County Well Field

Winkler County has no flowing water. Therefore development of this source has very little potential of impacting springflow, baseflow in rivers, or habitats. Based on the available data, it is unlikely that pumping limits will be needed to prevent impacts on aquatic or terrestrial ecosystems. It is not anticipated that groundwater development will cause subsidence.

Agricultural and Rural Issues Associated with Winkler County Well Field

The Region F water supply analysis shows sufficient water supply in Winkler County to meet local agricultural and municipal needs and support well field development by CRMWD and the City of Midland. Therefore, this strategy should have minimal effects on agriculture and rural areas. The right of way for the transmission line may temporarily affect a small amount of agricultural acreage during construction.

Other Natural Resource Issues Associated with Winkler County Well Field

None identified.

Significant Issues Affecting Feasibility of Winkler County Well Field

None identified.

Other Water Management Strategies Directly Affected by Winkler County Well Field

Odessa-Midland Reuse project.

Water Marketing – Water from Southwestern Pecos County

A group of landowners in southwestern Pecos County has proposed selling groundwater from an unclassified aquifer in southwestern Pecos County. Initial estimates indicate that this area can produce a large quantity of water of acceptable quality.

Quantity, Reliability and Cost of Water from Pecos County

The sustainable quantity of water from Southwestern Pecos County has not been established, although preliminary estimates indicate that 50,000 to 100,000 acre-feet per year could be available from this source. This strategy assumes that CRMWD would take up to 15,000 acre-feet per year from this source. Because of the uncertainty associated with the sustained availability of water from this source, the reliability of supply is medium. Table 4.8-7 shows the estimated costs associated with this strategy.

Table 4.8-7
Costs for Water from Southwestern Pecos County

Supply from Strategy	**15,000 acre-feet per year**
Total Capital Costs (2008 Prices)	$ 183,321,000
Annual Costs	$ 22,279,000
Unit costs (during amortization)	$ 1,485 per acre-foot
	$ 4.56 per 1,000 gallons
Unit Costs (after amortization)	$ 420 per acre-foot
	$ 1.29 per 1,000 gallons

Environmental Issues Associated with Water from Pecos County

Information provided by the sponsors of this project indicates possible impacts on flow in the Pecos River from development of this strategy,[40] which should be investigated if this strategy is pursued. If linkage between groundwater development and flows in the Pecos River can be established, the local groundwater conservation district may wish to impose pumping limits if needed to protect endangered and threatened species and environmental flows. It is unlikely that development of water from this source will cause subsidence.

Agricultural and Rural Issues Associated with Water from Pecos County

According to information provided by the developers of this project, the supply in the immediate area is primarily used for cattle ranching and development of the project will have minimal impact on existing uses. However, it is possible that large-scale production from this source could impact irrigation supplies in the Belding Farms area. Additional studies may be needed to quantify this impact.

Other Natural Resource Issues Associated with Water from Pecos County

None identified.

Significant Issues Affecting Feasibility of Water from Pecos County

The most significant issue facing this project is the lack of site-specific studies regarding supplies from this source and the potential impacts of large-scale groundwater development. These studies will be needed before this source can be recommended as a strategy. Also, the source is located more than 100 miles from the nearest potential user and will require a significant investment in infrastructure to make the water available.

Other Water Management Strategies Directly Affected by Water from Pecos County

Winkler Well Field, Odessa-Midland Reuse.

Water Marketing – Water from Roberts County

In the year 2000, Mesa Water, Inc., published a study that included an evaluation of delivery of Ogallala aquifer water from Roberts County in the Texas Panhandle to CRMWD and other users in Texas.[41] Delivery of water from this source requires construction of over 300 miles of pipeline. Since the initial study, Mesa Water has acquired water rights in four counties in the Panhandle (referenced as Roberts County Area for this plan).

Quantity, Reliability and Cost of Water from Roberts County Area

According to previous studies, there is a substantial amount of water available in Roberts County Area and this supply is very reliable.[42] For the purposes of this plan, this strategy assumes that CRMWD would take up to 25,000 acre-feet per year from this source. Table 4.8-8 shows the estimated costs associated with this strategy. Capital costs include the estimated development fee for this project. Costs are dependent upon the amount of water assumed to be used from this project. If other entities would participate in the project, costs could be lower.

Table 4.8-8
Costs for Water from Roberts County Area

Supply from Strategy	25,000 acre-feet per year
Total Capital Costs (2008 Prices)	$ 775,401,000
Annual Costs	$ 82,982,000
Unit costs (during amortization)	$ 3,319 per acre-foot
	$ 10.19 per 1,000 gallons
Unit Costs (after amortization)	$ 615 per acre-foot
	$ 1.89 per 1,000 gallons

Environmental Issues Associated with Water from Roberts County

There is some concern that large-scale groundwater use from the Roberts County Area could impact baseflow of the Canadian River, potentially impacting habitat of the Arkansas River Shiner, a threatened species. If this strategy is implemented, mitigation may be required. It is unlikely that development of water from this source will cause subsidence.

Agricultural and Rural Issues Associated with Water from Roberts County

According to previous studies, only a small amount of water from this portion of Roberts County Area is currently being used for local purposes. There is little irrigated agriculture in the area.

Other Natural Resource Issues Associated with Water from Roberts County

None identified.

Significant Issues Affecting Feasibility of Water from Roberts County

The most significant issue facing this project is the significant investment in infrastructure needed to deliver water from the Roberts County Area. Without the participation of other large water users it may not be cost-effective to deliver water from Roberts County to Region F.

Other Water Management Strategies Directly Affected by Water from Roberts County

Other CRMWD strategies.

Water Conservation

Potential water savings due to implementation of the recommended Region F conservation practices has been evaluated for the CRMWD member cities: Big Spring, Odessa and Snyder. Water conservation savings for the cities of Midland and San Angelo may be found in the

Section 4.3.6 and 4.8.3, respectively. Water conservation for smaller customer cities which have needs that are met through subordination and contract renewal have not been evaluated because of the small quantity of water used by these entities.

Region F recognizes that it has no authority to implement, enforce or regulate water conservation practices. The water conservation practices in this plan are guidelines. Region F considers water conservation strategies determined and implemented by the CRMWD, the CRMWD member cities and CRMWD customers to supersede the recommendations in this plan and to meet regulatory requirements for consistency with this plan.

Quantity, Reliability and Cost

Table 4.8-9, Table 4.8-10 and Table 4.8-11 show potential water conservation savings and costs of water conservation programs for the cities of Snyder, Big Spring and Odessa, respectively. Potential savings range from approximately 14 percent to 18 percent of the demand with no conservation. The reliability of this supply is classified as medium because of the uncertainty involved in the analysis used to calculate the savings. Site specific data regarding residential, commercial, industrial and other types of use would give a better estimate of the reliable supply from this strategy.

Environmental Issues

Most of the CRMWD's water supply comes from reservoirs which spill infrequently. Therefore water conservation could result in more water remaining in reservoir storage, and will have minimal impact on downstream flows. Much of the conserved water in storage will be used for other purposes or lost to evaporation. The additional water in storage may result in a minimal positive impact on recreation use and environmental water needs associated with those reservoirs.

Much of the new water supply development for CRMWD is driven by water quality concerns. CRMWD needs additional high-quality water sources to blend with existing water of lesser quality. As a result, water conservation may not delay or eliminate the need for new water supply development.

Table 4.8-9
Potential Water Conservation Summary for the City of Snyder [a]

Per Capita Demand (gpcd)								
		2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
No Conservation	Projections	194	227	227	227	227	227	227
Plumbing Code	Projections	227 [b]	223	219	216	213	212	212
	Savings	0	4	8	11	14	15	15
Region F Estimate	Projections	227 [b]	217	207	201	197	195	194
	Savings (Region F practices)	0	6	12	15	16	17	18
	Savings (Total)	0	10	20	26	30	32	33
Water Demand (Ac-Ft/Yr)								
		2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
No Conservation	Projections	2,343	2,843	2,938	2,988	3,015	3,033	3,033
Plumbing Code	Projections	2,742	2,792	2,834	2,844	2,829	2,832	2,832
	Savings	0	51	104	144	186	201	201
Region F Estimate	Projections	2,742	2,722	2,680	2,653	2,624	2,612	2,598
	Savings (Region F practices)	0	70	154	191	205	220	234
	Savings (Total)	0	121	258	335	391	421	435
Costs								
Annual Costs			$56,052	$61,357	$59,809	$57,823	$55,694	$54,185
Cost per Acre-Foot [c]			$801	$398	$313	$282	$253	$232
Cost per 1,000 Gal [c]			$2.46	$1.22	$0.96	$0.87	$0.78	$0.71

a Costs and water saving are based on data from TWDB *Report 362 Water Conservation Task Force Water Conservation Best Management Practices Guide*, November 2004.

b Year 2000 water use is based on a per capita water use of 227 gpcd. Actual year 2000 use was 2,343 acre-feet, equivalent to a per capita water demand of 194 gpcd.

c Costs for implementing recommended practices. Costs of implementing plumbing code savings not included in unit cost calculations.

Table 4.8-10
Potential Water Conservation Summary for the City of Big Spring [a]

Per Capita Demand (gpcd)								
		2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
No Conservation	Projections	198	210	210	210	210	210	210
Plumbing Code	Projections	210	207	204	201	198	197	197
	Savings	0	3	6	9	12	13	13
Region F Estimate	Projections	210	199	184	178	175	173	172
	Savings (Region F practices)	0	8	20	23	23	24	25
	Savings (Total)	0	11	26	32	35	37	38
Water Demand (Ac-Ft/Yr)								
		2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
No Conservation	Projections	5,596	6,103	6,255	6,305	6,305	6,305	6,305
Plumbing Code	Projections	5,936	6,016	6,077	6,035	5,945	5,915	5,915
	Savings	0	87	178	270	360	390	390
Region F Estimate	Projections	5,936	5,775	5,474	5,359	5,247	5,190	5,161
	Savings (Region F practices)	0	241	603	676	698	725	754
	Savings (Total)	0	328	781	946	1,058	1,115	1,144
Costs								
Annual Costs			$130,084	$134,880	$130,163	$124,565	$119,088	$115,696
Cost per Acre-Foot [c]			$540	$224	$193	$178	$164	$153
Cost per 1,000 Gal [c]			$1.66	$0.69	$0.59	$0.55	$0.50	$0.47

a Costs and water saving are based on data from TWDB *Report 362 Water Conservation Task Force Water Conservation Best Management Practices Guide*, November 2004.

b Year 2000 water use is based on a per capita water use of 210 gpcd. Actual year 2000 use was 5,596 acre-feet, equivalent to a per capita water demand of 198 gpcd.

c Costs for implementing recommended practices. Costs of implementing plumbing code savings not included in unit cost calculations.

Table 4.8-11
Potential Water Conservation Summary for the City of Odessa [a]

Per Capita Demand (gpcd)								
		2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
No Conservation	Projections	208	208	208	208	208	208	208
Plumbing Code	Projections	208	205	202	198	195	194	194
	Savings	0	3	6	10	13	14	14
Region F Estimate	Projections	208	200	191	185	181	179	178
	Savings (Region F practices)	0	5	11	13	14	15	16
	Savings (Total)	0	8	17	23	27	29	30
Water Demand (Ac-Ft/Yr)								
		2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
No Conservation	Projections	21,189	22,248	23,361	24,528	25,755	27,043	28,394
Plumbing Code	Projections	21,189	21,927	22,687	23,350	24,145	25,222	26,484
	Savings	0	321	674	1,178	1,610	1,821	1,910
Region F Estimate	Projections	21,189	21,376	21,487	21,814	22,430	23,302	24,335
	Savings (Region F practices)	0	551	1,200	1,536	1,715	1,920	2,149
	Savings (Total)	0	872	1,874	2,714	3,325	3,741	4,059
Costs								
Annual Costs			$478,790	$497,510	$499,438	$500,957	$501,922	$511,229
Cost per Acre-Foot [c]			$869	$415	$325	$292	$261	$238
Cost per 1,000 Gal [c]			$2.67	$1.27	$1.00	$0.90	$0.80	$0.73

a Costs and water saving are based on data from TWDB *Report 362 Water Conservation Task Force Water Conservation Best Management Practices Guide*, November 2004.
b Year 2000 water use is based on a per capita water use of 208 gpcd, which is the actual per capita water use in that year.
c Costs for implementing recommended practices. Costs of implementing plumbing code savings not included in unit cost calculations.

Agricultural and Rural Issues

None identified.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

This strategy is based on a generalized assessment of water conservation practices and may not accurately reflect the actual costs or water savings that can be achieved by the CRMWD and its member cities. Site-specific data will be required for a better assessment of the potential for water conservation by the city. Technical assistance and funding by the state may be required to implement this strategy.

Other Water Management Strategies Directly Affected

Timing and quantity from other CRMWD strategies.

Drought Management

Drought management strategies are designed to temporarily reduce water demand during extreme drought periods. The CRMWD Drought Contingency Plan (May 2009), drought contingency plans developed by CRMWD customers, and subsequent revisions of these plans determine drought management strategies for CRMWD and its customers. Region F has not identified additional drought management strategies.

Voluntary Redistribution – Renew Contract with University Lands

CRMWD's Ward County Well Field is leased from University Lands, the managing agency for properties belonging to the University of Texas System. The contract expires in 2019. For the purposes of this plan it is assumed that CRMWD and University Lands will renew the contract without change in the quantity of water available from the source. Actual quantities and costs will be determined at the time of renewal. To maintain the same amount of groundwater supplies from Ward County, CRMWD will need to develop replacement wells and/or acquire additional water rights. CRMWD has recently received funding to acquire additional water rights and drill 14 additional water wells to maintain the long-term capacity of the Ward County well field. Rehabilitation and replacement of existing wells will be on-going for this well field and other CRMWD groundwater sources. Generic costs for replacement wells are discussed in another subsection of this chapter.

It is assumed that the supply from the additional wells will simply replace the contract amount with University Lands. Renewals of existing contracts for the same quantity of water are not evaluated for impacts. An estimate of the capital cost for constructing the 14 new wells is shown below. Actual costs will be determined during design.

Supply from Strategy	**5,200 acre-feet per year***
Total Capital Costs (2008 Prices)	$ 8,964,000
Annual Costs	$ 847,000
Unit costs (during amortization)	Not Applicable
Unit Costs (after amortization)	Not applicable

* This supply is for the same amount as the current contract.

Voluntary Redistribution – New Contracts to Provide Water

The planning process has identified several new CRMWD contracts to provide water, which are shown in Table 4.8-12. All of these contracts are the result of expiration of existing customer contracts. The amounts shown in Table 4.8-12 are for planning purposes. The actual amount of water and cost for the water will be negotiated between the contracting parties.

Other CRMWD contracts do not expire during the planning period.

Table 4.8-12
New CRMWD Contracts to Supply Water

Water User	**Amount (Acre-Feet per Year)**						**Comments**
	2010	**2020**	**2030**	**2040**	**2050**	**2060**	
Midland			10,000	9,800	9,600	9,400	8.45 percent of system yield
Stanton	392	422	429	430	415	393	Set to demands
Millersview-Doole WSC					500	500	
Ballinger					600	600	Set to existing amt
Total	*392*	*422*	*10,429*	*10,230*	*11,115*	*10,893*	

Groundwater Desalination

CRMWD intends to develop supplies from brackish groundwater. The Capitan Reef aquifer has been identified as a potential source. In Region F, the Capitan Reef aquifer extends from the New Mexico border in Winkler County, through Ward County and into Pecos County. The Region F water supply analysis shows about 27,000 acre-feet of water per year available from this source. Development of this aquifer could occur concurrently with development of the CRMWD well field in Winkler County, the City of Midland T-Bar well field or supplies from other sources. Brackish water production from the Dockum or Pecos Valley aquifer could also be developed as an alternative to or in conjunction with brackish water from the Capitan Reef aquifer. Additional information on the Capitan Reef aquifer may be found in Section 3.1.11.

Quantity, Reliability and Cost of Capitan Reef Desalination Project

For the purposes of this plan it is assumed that a 10 MGD desalination plant delivering up to 9,500 acre-feet of water per year would be constructed in Winkler County near the proposed Winkler County Well Field. A parallel pipeline would be constructed to deliver the water to CRWMD customers. Disposal of brine reject would be through deep well injection. Because of the uncertainty involved with development of this source for municipal water use, the reliability of this source is considered to be moderate. Table 4.8-13 summarized the expected costs for the project.

Table 4.8-13
CRMWD Brackish Water Desalination Project

Supply from Strategy	**9,500 acre-feet per year**
Total Capital Costs (2008 Prices)	$ 131,603,990,000
Annual Costs	$ 17,814,378
Unit costs (during amortization)	$ 1,875 per acre-foot
	$ 5.75 per 1,000 gallons
Unit Costs (after amortization)	$ 667 per acre-foot
	$ 2.05 per 1,000 gallons

Environmental Issues Associated with CRMWD Desalination Project

This strategy relies on brackish groundwater from formations which have no surface outflow in the vicinity of the proposed project. It is unlikely that pumping from these formations will result in any alteration of terrestrial habitats. The conceptual design for the project uses deep well injection for brine disposal. A properly designed and maintained facility should have minimal environmental impact. Well field development and construction of the treatment facility should have minimal environmental impact as well.

Agricultural and Rural Issues of CRMWD Desalination Project

Water from the Capitan Reef aquifer is currently used only for oil field flooding. No competition is expected with municipal or agricultural water users. Therefore agricultural and rural impacts are expected to be minimal.

Other Natural Resource Issues Associated with CRMWD Desalination Project

None identified.

Significant Issues Affecting Feasibility

Because this source of water is only used for oil field flooding, very little is known about the suitability of this source for municipal water supply. Additional studies will be required to evaluate the merit of this source.

Other Water Management Strategies Directly Affected by CRMWD Desalination Project

Winkler County Well Field.

Supplemental Wells

The CRMWD operates groundwater systems for four existing well fields located in Ward, Scurry, Ector and Martin Counties. The supplies from each of these well fields are expected to produce a total of 7,558 acre-feet per year through 2060 (assuming renewal of the University Lands contract). In order to maintain this level of production, it is likely that new wells will be needed to replace diminished capacities of existing wells. These supplemental wells will be needed over time to ensure a continued adequate supply for CRMWD. The depth and capacity of each supplemental well will need to be determined on a case by case basis. For this plan, a typical cost was developed based on average well depths and productions capacities.

Since the supplemental wells do not provide additional water supplies but rather replace existing supplies, this strategy is not evaluated for impacts.

Table 4.8-14
Generic Cost for Supplemental Well

Supply from Strategy	**0 acre-feet per year**
Total Capital Costs (2008 Prices)	$522,000
Annual Costs	$ 50,000
Unit costs (during amortization)	Not Applicable
Unit Costs (after amortization)	Not applicable

Recommended Strategies for CRMWD

Recommended strategies for CRMWD include:

- Subordination of downstream senior water rights
- New groundwater – Winkler Well Field
- Reuse – CRMWD Reclamation Project
- Renew contract with University Lands and maintain capacities of Ward County well field
- Groundwater Desalination
- Water conservation
- Supplemental Wells

Table 4.8-15 compares the supply from the strategies to demands with these strategies in place, and Table 4.8-16 summarizes the capital costs for the recommended strategies. For the purposes of this plan, it has been assumed that water conservation activities will be financed by the member cities, so costs for water conservation do not appear in Table 4.8-16.

Table 4.8-15
Recommended Water Management Strategies for CRMWD
(Values in Acre-Feet per Year)

Supplies	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Existing Supplies	*74,485*	*67,935*	*66,585*	*65,235*	*63,885*	*62,535*
Subordination	48,027	47,134	46,240	45,347	44,453	43,560
Winkler County Well Field	0	0	6,000	6,000	6,000	6,000
CRMWD Reclamation Project	0	12,380	12,380	12,380	12,380	12,380
Renew Contract with University Lands and Maintain Capacity	0	5,200	5,200	5,200	5,200	5,200
Desalination				9,500	9,500	9,500
Supplemental Wells		0	0	0	0	0
Total Supplies	*122,512*	*132,649*	*136,405*	*143,662*	*141,418*	*139,175*
Conservation	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Potential Savings [a]	862	1,957	2,403	2,618	2,865	3,137
Demands	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Existing customers	89,212	91,631	73,743	74,129	73,699	74,644
New Contracts	392	422	10,429	10,230	11,115	10,893
Total Demand	89,604	92,053	84,172	84,359	84,814	85,537
Surplus (Need) without Conservation	*32,908*	*40,596*	*52,233*	*59,303*	*56,604*	*53,638*
Surplus (Need) with Conservation	*33,770*	*42,553*	*54,636*	*61,921*	*59,469*	*56,775*

a Savings for member cities only, and does not include plumbing code savings, which are already included in the water demand projections.

Table 4.8-16
Capital Costs for Recommended Strategies [a]

Strategy	Capital Costs	Annual Costs					
		2010	2020	2030	2040	2050	2060
Winkler County Well Field	$76,268,000	$-	$-	$8,666,000	$8,666,000	$2,017,000	$2,017,000
CRMWD Reclamation Project	$128,748,000	$-	$15,905,000	$15,905,000	$4,680,000	$4,680,000	$4,680,000
Subordination [b]	$-	$-	$-	$-	$-	$-	$-
University Lands Contract	$8,964,000	$-	$847,000	$847,000	$65,000	$65,000	$65,000
Desalination	$131,603,990	$-	$-	$-	$17,814,378	$17,814,378	$6,340,378
Supplemental Wells [c]	$10,440,000	$-	$200,000	$400,000	$416,000	$432,000	$448,000
Total	*$356,023,990*	*$0*	*$16,952,000*	*$25,818,000*	*$31,641,378*	*$25,008,378*	*$13,550,378*

a. Water conservation would be implemented by individual member cities and would not be a CRMWD cost.
b. Costs were not determined for the subordination strategy.
c. It is assumed that 4 wells per decade would be replaced. The actual number and cost will be based on operations and specific well fields.

4.8.2 City of San Angelo

The City of San Angelo is located in Tom Green County near the center of Region F. As one of the largest cities in the region, it is a major center of employment, trade and cultural activities in the region. The city receives water from six sources: Lake Nasworthy, Twin Buttes Reservoir, the Concho River, O.C. Fisher Reservoir, Ivie Reservoir, and Spence Reservoir. The water rights for Lake Nasworthy, Twin Buttes Reservoir and the Concho River are owned by the city. The rights for O.C. Fisher are owned by the Upper Colorado River Authority (UCRA). Ivie and Spence Reservoirs are owned by the Colorado River Municipal Water District (CRMWD). The city also owns an undeveloped groundwater well field in McCulloch County.

Table 4.8-17 is a comparison of the Region F supply and demand for the City of San Angelo for municipal and industrial use. For this analysis it is assumed that the city will provide all of the water for the City of San Angelo, approximately 250 acre-feet per year to connections outside of the city (County-Other), all of the manufacturing demand in Tom Green County, and up to 1,021 acre-feet of raw water for steam electric power generation. Steam-electric demand is limited to recent historical use. According to historical data from the TWDB, 1,021 acre-feet of water was used for steam-electric generation in Tom Green County in 1999. More recent use has been less. The city also supplies treated O.C. Fisher water to the City of Miles through an agreement with UCRA.

Table 4.8-17 contains the Region F supplies for the City of San Angelo based on the TCEQ Colorado WAM.[43] TWDB requires use of the Colorado WAM Run 3 in regional water planning. In this model, all of San Angelo's local reservoir supplies and Spence Reservoir have little or no firm yield. Ivie Reservoir is the only significant source of water with a reliable yield. The model shows a small reliable supply from three of the city's run-of-the-river permits, namely CA 1325 (Lone Wolf), CA 1333 and CA 1337. (Note: CA 1357 was not included in the version of the Colorado WAM used for this analysis). Using these supplies, the City of San Angelo has needs for over 12,000 acre-feet of water in 2010 which increases to over 16,000 acre-feet by 2060.

Table 4.8-17
Comparison of Supply and Demand for the City of San Angelo
(Values in Acre-Feet per Year)

Supplies	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**Comment**
Twin Buttes/Nasworthy	0	0	0	0	0	0	WAM supply
O.C. Fisher	0	0	0	0	0	0	WAM supply
Concho River	642	642	642	642	642	642	WAM supply
Spence Contract	0	0	0	0	0	0	Currently not available
Ivie Contract	10,974	10,751	10,528	10,304	10,081	9,858	Supply limited to 16.54 % of safe yield
Total	*11,616*	*11,393*	*11,170*	*10,946*	*10,723*	*10,500*	
Demand	**2,010**	**2,020**	**2,030**	**2,040**	**2,050**	**2,060**	**Comment**
City of San Angelo	20,800	21,418	21,734	21,744	21,907	21,969	
City of Miles	200	200	200	200	200	200	
Municipal Sales	250	250	250	250	250	250	Assumed
Manufacturing	2,226	2,498	2,737	2,971	3,175	3,425	100% of demand
Steam-Electric	543	777	909	1,021	1,021	1,021	Limited to recent use
Total	*24,019*	*25,143*	*25,830*	*26,186*	*26,553*	*26,865*	
Surplus (Need)	*(12,403)*	*(13,750)*	*(14,660)*	*(15,240)*	*(15,830)*	*(16,365)*	

Note: San Angelo also provides 8,500 ac-ft/yr of treated wastewater for irrigation in exchange for supplies from Twin Buttes Reservoir. This table does not include irrigation demands on Twin Buttes Reservoir.

The supplies from CRMWD reservoirs (Spence and Ivie) have been adjusted to reflect yields determined with the Colorado WAM. The city's contracts with CRMWD are currently set at 3,000 acre-feet per year from Spence Reservoir and 15,000 acre-feet per year from Ivie

Reservoir. These contracts also specify that, at the option of CRMWD, the contracted amount from these reservoirs can be reduced to 6 percent of the safe yield of Spence Reservoir and 16.54 percent of the safe yield of Ivie Reservoir. For the purposes of this plan, it was assumed that CRMWD will reduce available supplies to San Angelo based on the Region F safe yield of each source. Also, the city's pipeline to Spence Reservoir is not usable at this time and requires extensive rehabilitation. Therefore supplies from Spence Reservoir are considered to be unavailable until the pipeline has been repaired. This plan includes the repair of the pipeline as a water management strategy.

Potentially Feasible Strategies

In accordance with TWDB rules, the Region F Water Planning Group has adopted a standard procedure for identifying potentially feasible strategies. This procedure classifies strategies using the TWDB's standard categories developed for regional water planning.

In addition to the Region F analysis, the city used an extensive public process to evaluate potential strategies to meet the City's future needs. In February of 2004, the San Angelo City Council, the Citizen's Water Advisory Board, and the City Staff published the results of this process in the report *San Angelo Water Preparing for the Next 50 Years.*[44] In this report five preferred strategies were identified:

- Develop and communicate public and private conservation and drought management programs
- Develop reclamation, reuse and water storage alternatives
- Protect and enhance existing surface water resources
- Expand cooperative efforts and agreements to increase water availability for both urban and rural areas
- Identify and develop fresh and brackish groundwater alternatives

Combining these strategies with standard categories results in the following list of potentially feasible strategies for the City of San Angelo:

- Water conservation
- Drought management
- Subordination of downstream senior water rights
- Desalination of brackish groundwater
- New groundwater – development of the McCulloch County well field

- New groundwater – water from Edwards-Trinity aquifer
- Reuse
- System Optimization through system operation and conjunctive use
- Voluntary redistribution through purchase of additional water rights or contracts for additional supplies
- Other – Rehabilitation of the Spence pipeline

Precipitation enhancement and brush control are discussed in Section 4.9.

Water Conservation

During the recent drought the City of San Angelo succeeded in significantly reducing per capita water demand. Between 1980 and 2000, the average per capita water demand for the city was 196 gallons per person per day (gpcd). In 2006, the latest year for which data are available, the per capita water demand was 149 gpcd.[45] Some of this reduction is the result of implementation of water use restrictions and other drought management strategies. Water conservation activities conducted by the city include public awareness and education programs, inclining rate structure to discourage high water use, outdoor watering restrictions and infrastructure improvements to reduce water loss.

Quantity, Reliability and Cost

Municipal conservation activities that the City of San Angelo has implemented are consistent with the recommended strategies for Region F. The water use restrictions that the city has implemented are considered part of the drought management strategies. These restrictions were put into place in response to the current drought and it is uncertain whether they will remain in place during non-drought periods. Therefore, for this plan, the potential water savings associated with municipal water conservation is based on the Region F package of water conservation practices.

Table 4.8-18 compares projected demands for the City of San Angelo with no conservation, with the expected conservation due to plumbing code (the default projections used in regional water planning), and with Region F water conservation criteria (see the Appendix 4G).

Based on these data, savings due to conservation could be about 1,000 acre-feet per year in 2010, increasing to about 4,000 acre-feet per year by 2060. The reliability of these supplies has been determined to be medium due to the lack of site-specific data regarding the long-term savings associated with implementing these strategies. Costs range from $565 per acre-foot in 2010 to $158 per acre-foot in 2060.

Table 4.8-18
Potential Water Conservation Summary for the City of San Angelo [a]

Per Capita Demand (gpcd)								
		2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
No Conservation	Projections	162	200	200	200	200	200	200
Plumbing Code	Projections	162	197	193	190	187	186	186
	Savings	0	3	7	10	13	14	14
Region F Estimate [b]	Projections	200 [c]	190	178	172	169	167	166
	Savings (Region F Practices)	0	7	15	18	18	19	20
	Savings (total)	0	10	22	28	31	33	34
Water Demand (Ac-Ft/Yr)								
		2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
No Conservation	Projections	19,813	21,117	22,195	22,878	23,256	23,556	23,623
Plumbing Code	Projections	19,813	20,800	21,418	21,734	21,744	21,907	21,969
	Savings	0	317	777	1,144	1,512	1,649	1,654
Region F Estimate [b]	Projections	19,813	20,099	19,713	19,725	19,617	19,652	19,598
	Savings (Region F Practices)	0	701	1,705	2,009	2,127	2,255	2,371
	Savings (total)	0	1,018	2,482	3,153	3,639	3,904	4,025
Costs								
Annual Costs			$230,014	$250,370	$256,256	$259,652	$261,609	$261,721
Cost per Acre-Foot [d]			$328	$147	$128	$122	$116	$110
Cost per 1,000 Gal [d]			$1.01	$0.45	$0.39	$0.37	$0.36	$0.34

a Costs and water saving are based on data from TWDB *Report 362 Water Conservation Task Force Water Conservation Best Management Practices Guide,* November 2004, and data provided by the City of San Angelo, 2008.
b Includes plumbing code savings.
c Year 2000 water use is based on a per capita water use of 200 gpcd. Actual year 2000 use was 16,048 acre-feet, equivalent to a per capita water demand of 162 gpcd.
d Costs for implementing recommended practices. Plumbing code savings not included in unit cost calculations.

Recent experience in the City of San Angelo has shown that per capita water demand can be even lower than estimated using these techniques. There are several possible explanations for this:

- The base per capita demand of 200 gpcd used to develop the projections may be high
- Replacement of old 2-inch pipes and other leak reduction and water accounting activities implemented by the city
- Drought contingency measures implemented by the city (these measures are assumed to be temporary and water demand would increase as these restrictions are removed)
- Public awareness of the city's water supply problems, creating a 'culture of conservation'

Region F recognizes that it has no authority to implement, enforce or regulate water conservation practices. The water conservation practices in this plan are guidelines. Region F considers water conservation strategies determined and implemented by the City of San Angelo to supersede the recommendations in this plan and to meet regulatory requirements for consistency with this plan.

Environmental Issues

Most of the City of San Angelo's water supply comes from reservoirs which spill infrequently. Therefore water conservation could result in more water remaining in reservoir storage, and will have minimal impact on downstream flows. Much of the conserved water in storage will be used for other purposes or lost to evaporation. The additional water in storage may result in a minimal positive impact on recreation use and environmental water needs associated with those reservoirs.

Agricultural and Rural Issues

Conservation is expected to have a small positive impact on agricultural resources because some of the conserved water may be available for irrigation.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

This strategy is based on a generalized assessment of water conservation practices and may not accurately reflect the actual costs or water savings that can be achieved by the City of San Angelo. Site-specific data will be required for a better assessment of the potential for water conservation by the city. Technical assistance and funding by the state may be required to implement this strategy.

Other Water Management Strategies Directly Affected

None identified.

Drought Management

Drought management strategies are designed to temporarily reduce water demand during drought periods. The San Angelo Drought Contingency Plan, the CRMWD Drought Contingency Plan and subsequent revisions of these plans determine drought management for the City of San Angelo. Some of the recent reduction in water demand by the city may be attributable to practices that result in temporary reductions in water use. Examples include landscape watering or car washing restrictions that may be discontinued once the area is out of critical drought conditions. Until additional data are available after these restrictions have been lifted, it is uncertain how much water has been saved by implementation of these practices.

During the current drought, use of Lake Nasworthy water for power generation was reduced. No irrigation water has been used from Twin Buttes Reservoir because the irrigation pool is empty. During part of the drought Twin Buttes ceased impounding water in order to pass water for downstream senior water rights. All of these activities could be considered drought management strategies.

Subordination of Downstream Senior Water Rights

TWDB requires the use of the TCEQ WAM for regional water planning. In the Colorado WAM, reservoirs in Region F with a priority date after 1926 do not have a firm or safe yield. This result is largely due to the assumptions used in the Colorado WAM. In order to address water availability issues in the Colorado Basin associated with the WAM model, Region F and the Lower Colorado Region (Region K) participated in a joint modeling effort to evaluate a strategy in which lower basin senior water rights do not make priority calls on major upstream water rights. This strategy also assumes that major water rights in Region F do not make priority calls on each other. The subordination strategy is discussed in detail in Section 4.2.3. Table 4.8-19 is a summary of the impacts of the subordination strategy on supplies for the city.

The joint modeling between the two regions was conducted for planning purposes only. Neither Region F nor the Lower Colorado Region mandates the adoption of this strategy by individual water right holders. A subordination agreement is not within the authority of the Region F Water Planning Group. Such an agreement must be developed by the water rights holders themselves, including the City of San Angelo and CRMWD.

Impacts of the subordination strategy are discussed in Section 4.2.3.

Table 4.8-19
Impact of Subordination Strategy on San Angelo Water Supplies
(Values in acre-feet per year)

Reservoir	Priority Date	Permitted Diversion	2010 Supply WAM Run 3	2010 Supply Subord-ination	2060 Supply WAM Run 3	2060 Supply Subord-ination	Comments
San Angelo System							
Twin Buttes Reservoir	5/6/1959	29,000	0	12,310	0	11,360	
Lake Nasworthy	3/11/1929	25,000					
O.C. Fisher Reservoir	5/27/1949	80,400	0	3,862	0	3,270	
San Angelo System Total		*134,400*	*0*	*16,172*	*0*	*14,630*	
Spence Reservoir	8/17/1964	41,573					
CRMWD system portion			526	36,164	526	35,090	
San Angelo contract			34	2,308	34	2,240	6% of safe yield
Spence Reservoir Total			*560*	*38,472*	*560*	*37,330*	
Ivie Reservoir	2/21/1978	113,000					
CRMWD, Midland, Abilene			55,376	55,461	49,742	46,955	
San Angelo contract			10,974	10,991	9,858	9,305	16.54% of safe yield
Ivie Reservoir Total			*66,350*	*66,452*	*59,600*	*56,260*	

Voluntary Redistribution through Lease or Purchase of Existing Water Rights

Voluntary redistribution through purchase or lease of existing water rights is a feasible strategy that is complementary to subordination. The City of San Angelo has already purchased several water rights in the vicinity, and will continue to consider purchase of other water rights on a willing-buyer willing-seller basis. Diversions for these rights could be moved to one of San Angelo's existing diversion points, or the rights could simply not be exercised, eliminating the possibility of a priority call.

Region F has not identified specific rights for purchase, so no quantity, costs or impacts can be developed at this time.

Reuse

The City of San Angelo has historically disposed of its treated effluent through land application. In the past few years the city has sold treated effluent to the local irrigation district as a substitute for Twin Buttes water. The city has recently initiated a reuse study to investigate alternative uses for its treated effluent. The results of this study are not available at this time.

Potential reuse strategies include:

- In-city landscape irrigation (parks, cemeteries, golf courses, Angelo State University, air base, etc.)
- Manufacturing purposes
- Steam-electric power generation
- Blending with other sources of water for indirect reuse
- Aquifer storage and recovery (ASR) in conjunction with one or more of the above strategies

Under current rules, ASR would require treatment of wastewater to drinking water standards before injection. This strategy would most likely use reverse osmosis or a similar membrane process.

An analysis of quantity and impacts will be completed once specific strategies have been identified in the reuse study.

Desalination

The Region F Water Planning Group, in association with the City of San Angelo and UCRA, has identified several potential brackish groundwater sources north and west of the city. An initial investigation into one of these sources, the Whitehorse formation, did not yield water of sufficient quality or quantity and has been dropped from consideration. A test of the Clear Fork formation was more promising and merits additional investigation.[46] The city plans to continue investigating sources of saline water for future water supplies. For the purposes of this plan, a conceptual design was developed for phased development of a facility with an initial capacity of 5 MGD and an ultimate capacity of 10 MGD. The most likely location for desalination facility is on the northwest side of the city. The conceptual design for this strategy calls for disposal of brine reject through deep-well injection.

Quantity, Reliability and Cost

Since a specific source for this strategy has not been identified, at this time the amount of water available from the formation and the quality of the water is largely unknown. For the purposes of this plan, it will be assumed that sufficient water is available from these sources to provide up to 11,200 acre-feet of water per year and that a source of water will be located within 30 miles of the city. The reliability of this source is considered to be medium due to the uncertainty associated with the available water from the source. Table 4.8-20 is a summary of costs for the project. It is assumed that the facilities will be built with an initial capacity of 5 MGD and upgraded to 10 MGD at a later date.

Environmental Issues

This strategy relies on brackish groundwater for its source. These formations have no surface outflow in the vicinity of the proposed project. It is unlikely that pumping from these formations will result in any alteration of terrestrial habitats. The conceptual design for the project uses deep well injection for brine disposal. A properly designed and maintained facility should have minimal environmental impact. Well field development and construction of the treatment facility should have minimal environmental impact as well.

Table 4.8-20
Desalination Facility for San Angelo

Initial Capacity (5 MGD)	
Supply from Strategy	5,600 acre-feet per year
Total Capital Costs (2008 Prices)	$ 75,440,000
Annual Costs	$ 9,223,930
Unit costs (during amortization)	$ 1,647 per acre-foot
	$ 5.05 per 1,000 gallons
Unit Costs (after amortization)	$ 473 per acre-foot
	$ 1.45 per 1,000 gallons
Ultimate Capacity (10 MGD)	
Supply from Strategy	11,200 acre-feet per year
Total Expansion Capital Costs (2008 Prices)	$ 40,424,000
Annual Costs	$ 12,047,500
Unit costs (during amortization)	$ 1,076 per acre-foot
	$ 3.30 per 1,000 gallons
Unit Costs (after amortization)	$ 445 per acre-foot
	$ 1.37 per 1,000 gallons

Agricultural and Rural Issues

One of the most productive agricultural areas in the region is located east of the City of San Angelo. Some of this area is irrigated with surface water from Twin Buttes Reservoir and the Concho River, resulting in direct competition for water during dry periods. One of the chief benefits of this strategy is that there is no competition for this source of water with other interests; at present water from these formations is not used for any beneficial purpose.

Therefore this strategy has a positive impact on agricultural interests by reducing the competition for water supplies.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

The most significant factor affecting feasibility is the lack of data on water quality and quantity from these formations. It has been demonstrated that there is water in these formations and geophysical logs indicate favorable formation conditions. However, specific data on chemistry and quantity of water are not available at this time. Water chemistry could have a significant impact on the cost and feasibility of this project.

Other Water Management Strategies Directly Affected

Other San Angelo strategies

New Groundwater Development - McCulloch County Well Field

The City of San Angelo owns an undeveloped well field on the border of McCulloch and Concho Counties. This well field produces water from the Hickory aquifer. Water from this well field may not meet current drinking water standards for radium. The city is currently conducting a study evaluating the water quality of the aquifer, options to meet drinking water standards for radionuclides, well field layout and alternatives to deliver the water to the city.

The results of the study are not complete and are not available for this plan update. Preliminary cost estimates provided by the City of San Angelo from the current study show the total estimated capital cost, including treatment using ion exchange, at $173 million.[47] The schedule shows the initial new supply to be on line by 2014, with subsequent expansions in 2026 and 2036.

Quantity, Reliability and Cost

The quantity of water available from the McCulloch well field is limited by an agreement with the Hickory Underground Water Conservation District to 6,700 acre-feet per year when the well field is brought on line in about 2014, increasing to 10,000 acre-feet in 2026. By 2036, the maximum amount of water available will be 12,000 acre-feet per year. The reliability of water from the well field is high. Table 4.8-21 shows the costs associated with this strategy.

Table 4.8-21
Costs for the McCulloch County Well Field

Supply from Strategy	**12,000 acre-feet per year**
Total Capital Costs (2008 Prices)	$173,307,000
Annual Costs*	$18,215,000
Unit costs (during amortization)	$ 2,719 per acre-foot
	$ 8.34 per 1,000 gallons
Unit Costs (after amortization)	$ 1,083 per acre-foot
	$ 3.32 per 1,000 gallons

* Annual costs vary with the different phases. The annual and unit costs reported in this table are for Phase 1.

Environmental Issues

Previous studies of the McCulloch County Well Field have not assessed the potential for impacts on springflows.[48, 49] The well field will produce water from the down-dip portion of the Hickory aquifer. Faulting may have caused portions of the well field to be cut off from the recharge zone of the aquifer, and most of the supply is expected to come from water in storage. Based on this information, it is unlikely that development of this well field will have a significant impact on springflow and streamflows, or cause subsidence. Therefore environmental impacts are expected to be minimal.

Based on the available data, it is unlikely that pumping limits other than those already imposed by the Hickory Underground Water Conservation District will be required to protect the environment. There are no subsidence districts in Region F.

Agricultural and Rural Issues

The Hickory aquifer is used extensively for irrigation and for municipal water supply in the area. There is concern that other users of the Hickory aquifer, particularly the cities of Eden, Brady and Melvin, may be affected by lowering of the water table caused by pumping for San Angelo. It is recommended that additional investigations be performed prior to implementation of this strategy to assess the impacts on other users.

This strategy should have minimal impacts on agriculture since most of the irrigated acreage using the Hickory aquifer is located upgradient of the well field in the recharge zone or shallower areas of the aquifer. San Angelo's holdings are in the deeper portion of the aquifer. The right of way for the transmission line may affect a small amount of agricultural acreage that will need to be determined once the pipeline route has been finalized.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

Much of the water from the Hickory aquifer has radium levels that exceed the maximum contaminant level (MCL) for drinking water. It is assumed that the water from the McCulloch County well field will be treated using ion exchange.

Other Water Management Strategies Directly Affected

Other San Angelo strategies.

System Optimization

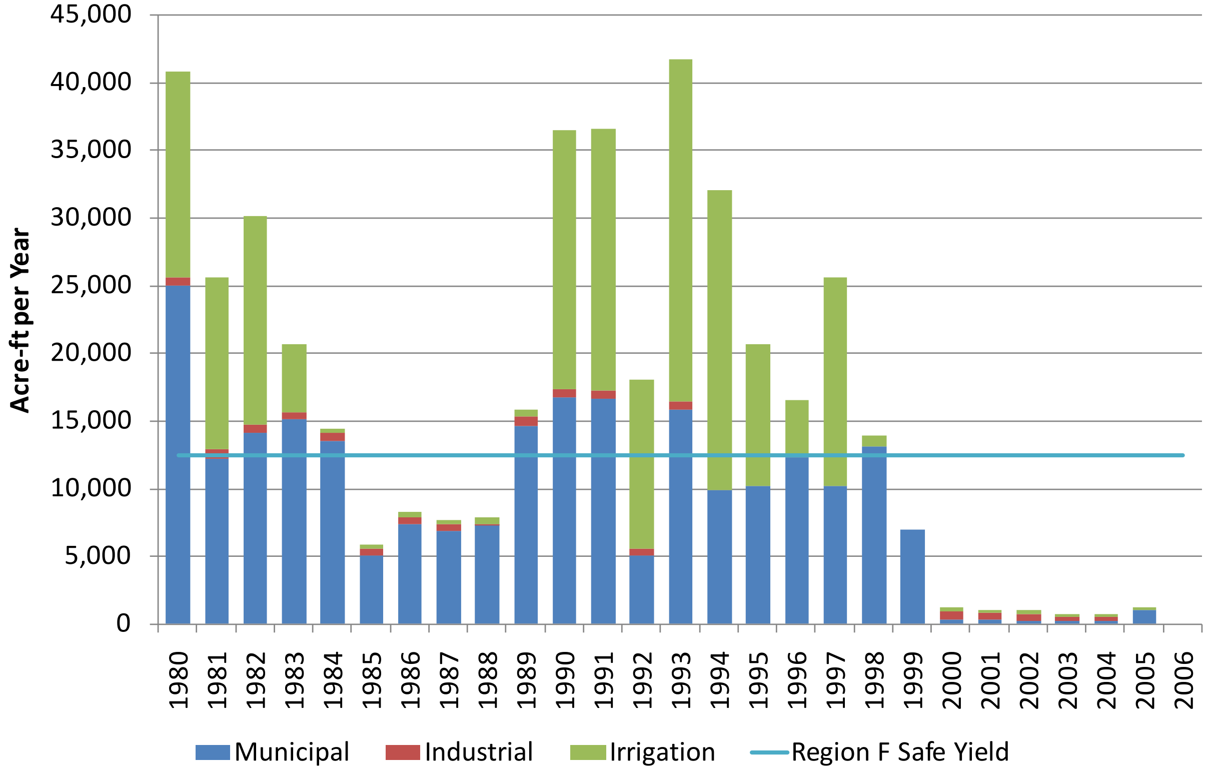
The City of San Angelo uses multiple sources of water. Previous studies have shown some increased yield from operating these sources in a coordinated fashion. In the first round of planning, it was estimated that an additional 2,100 acre-feet of water could be generated by operating Twin Buttes, Lake Nasworthy and O.C. Fisher in a coordinated fashion. If other existing and potential sources are added, additional supplies may be generated.

As part of system optimization, the city is pursuing changes to its water rights in O.C. Fisher Reservoir to allow storage of water pumped from Ivie Reservoir, Spence Reservoir or other sources in the reservoir. Water from these sources could be stored in the reservoir during lower-demand winter months for use later in the year.

Another issue associated with system optimization is the overdrafting of Twin Buttes Reservoir and Lake Nasworthy. The contract between the city and the Tom Green County Water Control and Improvement District (Tom Green County WCID) specifies a pool accounting system that reserves the lower 50,000 acre-feet of storage in the reservoir for municipal use. The remaining storage may be used for irrigation supplies. The amount of water in each storage pool is tracked over time based on an accounting system defined in the contract. During an extended drought, the reservoir may drop below 50,000 acre-feet of storage and no water from the irrigation pool will be available.

Figure 4.8-1 shows historical water use from the two reservoirs between 1980 and 2006. Between 1980 and 2000 as much as 41,000 acre-feet of water has been used from the two reservoirs, which greatly exceeds the safe supply of the two reservoirs of 12,400 acre-feet per year. Recent use has been considerably less than the safe supply.

Figure 4.8-1
Historical Water Use from the Twin Buttes Reservoir/Lake Nasworthy System



Quantity, Reliability and Cost

The 2001 Region F plan estimated that an additional 2,100 acre-feet of water could be made available by operating Twin Buttes, Nasworthy and O.C. Fisher as a coordinated system. However, the 2001 Region F plan did not consider the impact of this type of operation on senior water rights. Also, with the current drought the reliable supply cannot be determined. Additional studies will be required to determine potential supplies taking into account priority of other water rights, subordination of major water rights, additional sources of water and the impact of recent drought. Until further studies have been performed, no water should be considered available from this strategy.

Impacts

Impacts cannot be determined until the amount of water available from this strategy has been defined.

Rehabilitation of the Spence Pipeline

Currently the city's pipeline from Spence Reservoir is not operational. Rehabilitation of the pipeline will be required for the city to access this source.

Quantity, Reliability and Cost

For the purposes of this plan it was assumed that the supply from Spence Reservoir is limited to 6 percent of the safe yield. With subordination, the 2010 supply is 2,308 acre-feet per year and the 2060 supply is 2,240 acre-feet per year. The reliability of this source is medium because of the water rights issues associated with subordination. Table 4.8-22 shows the expected costs of this strategy.

Table 4.8-22
Costs for Rehabilitation of the Spence Pipeline *

Supply from Strategy	**2,300 acre-feet per year**
Total Capital Costs (2008 Prices)	$6,157,000
Annual Costs *	$716,000
Unit costs (during amortization)	$ 311 per acre-foot
	$ 0.96 per 1,000 gallons
Unit Costs (after amortization)	$ 78 per acre-foot
	$ 0.24 per 1,000 gallons

* Costs do not include purchase of water from CRMWD

Impacts

Because this is an existing source for the City of San Angelo, an impact analysis was not conducted.

Water Marketing – Water from Southwestern Pecos County

A group of landowners in southwestern Pecos County has proposed selling groundwater from the Edwards-Trinity (Plateau) aquifer in southwestern Pecos County. Initial estimates indicate that this area can produce a large quantity of water of reasonable quality.

Quantity, Reliability and Cost

The sustainable quantity of water from Southwestern Pecos County has not been established, although preliminary estimates indicate that 50,000 to 100,000 acre-feet per year could be provided from this source. For this analysis, we are assuming that the City of San Angelo could take up to 12,000 acre-feet per year from Pecos County. Because of the uncertainty associated with this source, the reliability of the supply is medium. Table 4.8-23 shows the costs associated with this strategy.

Table 4.8-23
Costs for water from Southwestern Pecos County
City of San Angelo

Supply from Strategy	**12,000 acre-feet per year**
Total Capital Costs (2008 Prices)	$ 277,730,000
Annual Costs	$ 31,725,000
Unit costs (during amortization)	$ 2,644 per acre-foot
	$ 8.11 per 1,000 gallons
Unit Costs (after amortization)	$ 626 per acre-foot
	$ 1.92 per 1,000 gallons

Environmental Issues

Information provided by the sponsors of this project indicates possible impacts on flow in the Pecos River from development of this strategy,[50] which should be investigated if this strategy is pursued. If linkage between groundwater development and flows in the Pecos River can be established, the local groundwater conservation district may wish to impose pumping limits. There are no subsidence districts in Region F.

Agricultural and Rural Issues

According to information provided by the developers of this project, the supply in the immediate area is primarily used for cattle ranching and development of the project will have minimal impact on existing uses. However, it is possible that large-scale production from this source could impact irrigation supplies in the Belding Farms area. Additional studies may be needed to quantify this impact.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

The most significant issue facing this project is the lack of funds to perform studies to verify the potential supplies from this source. Also, the source is located over 175 miles from the City of San Angelo.

Other Water Management Strategies Directly Affected

Other San Angelo strategies.

New Groundwater – Water from the Edwards-Trinity (Plateau) Aquifer

In 1985 the City of San Angelo investigated the possibility of developing a water supply from the Edwards-Trinity (Plateau) aquifer in northern Schleicher County.[51] This study concluded the following:

- Water from the Edwards limestones was of good quality. The water quality of the Trinity sands was somewhat poorer in quality.
- Water production from the Edwards limestones appears to be from cavernous porosity and could provide sufficient water for municipal supply. The Trinity sand is poorly developed, contains a high percentage of clay and is less attractive for large-scale water development.
- Drought conditions from 1962 to 1967 caused water levels in the Edwards to drop by 15 to 20 feet.
- Models of production from a proposed well field near Hulldale had a significant impact on the Anson springs. These springs provide much of the base flow of the South Concho River, which flows into Twin Buttes Reservoir.

Other areas in the Edwards-Trinity (Plateau) aquifer south of the city may provide water in sufficient quantities for municipal supplies. However, the quantity of water can vary greatly depending on the presence of porosity in the Edwards limestones. An exploration program would be required to find other suitable areas for municipal development.

Quantity, Reliability and Cost

According to the Region F water supply analysis, over 62,000 acre-feet of water per year are available from the Edwards-Trinity in Crockett, Schleicher and Sutton Counties. However, most of the water is contained in caverns or fractures in the Edwards limestone. This type of porosity tends to be highly localized, making it difficult to find areas with sufficient production for municipal supplies. Studies have also indicated that production from the aquifer may be significantly impacted by drought. Therefore the reliability of the supply has been classified as medium.

The 1985 San Angelo study proposed construction of a 30-mile 30-inch pipeline with a capacity of 15 MGD. The proposed well field had 10 wells. Table 4.8-24 is a cost estimate based on this study. If this strategy is pursued, additional engineering studies will be required to refine these estimates.

Table 4.8-24
Costs for Water from Edwards-Trinity (Plateau) Aquifer
City of San Angelo

Supply from Strategy	**12,000 acre-feet per year**
Total Capital Costs (2008 Prices)	$47,982,000
Annual Costs	$7,920,500
Unit costs (during amortization)	$ 660 per acre-foot
	$ 2.02 per 1,000 gallons
Unit Costs (after amortization)	$ 311 per acre-foot
	$ 0.96 per 1,000 gallons

Environmental Issues

Previous studies have indicated that groundwater development from the Edwards-Trinity aquifer may significantly impact springflow. If this strategy is pursued, a detailed study of the potential impacts of groundwater development should be conducted. If necessary, pumping limits in addition to those already imposed by the local groundwater conservation districts may be necessary to protect the environment. Development of water from this source is unlikely to cause subsidence.

Agricultural and Rural Issues

Springflows from the Edwards-Trinity supply much of the base flow of the South Concho and other flowing streams in the area. Many of these streams are used extensively for irrigation. Wells provide water for ranching, domestic and municipal supplies throughout the area. Studies will be required to evaluate potential impacts on the area.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

Local groundwater district rules in the area discourage the large-scale development of groundwater. Rule changes may be necessary for development of water from these counties.

Other Water Management Strategies Directly Affected

Other San Angelo strategies.

Recommended Strategies for the City of San Angelo

The recommended strategies for the City of San Angelo include:

- Subordination of downstream senior water rights
- Voluntary Redistribution through lease or purchase of existing water rights
- Rehabilitation of the Spence pipeline
- Development of the McCulloch County Well Field by 2020
- Development of a 5 MGD brackish groundwater desalination facility by 2040
- Water Conservation

Table 4.8-25 compares the supply from recommended strategies to projected demands for the City of San Angelo. Alternative strategies such as reuse and other water sources may be required if studies currently being conducted by the City of San Angelo prove that one or more of these strategies is more costly, produces less water or has greater impacts than determined in this analysis.

Table 4.8-25
Recommended Water Management Strategies for the City of San Angelo

Supplies	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Existing Supplies	11,616	11,393	11,170	10,946	10,723	10,500
Subordination – municipal and industrial only	12,787	12,468	12,149	11,831	11,512	11,192
Lease or Purchase of Existing Water Rights [a]	0	0	0	0	0	0
Rehabilitation of Spence Pipeline	0	0	2,281	2,267	2,254	2,240
Desalination Facility	0	0	0	5,600	5,600	5,600
McCulloch County Well Field	0	6,700	10,000	12,000	12,000	12,000
Total Supplies	24,403	30,561	35,600	42,644	42,089	41,532
Conservation	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Potential Savings [b]	701	1,705	2,009	2,127	2,255	2,371
Demands	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
City of San Angelo	20,800	21,418	21,734	21,744	21,907	21,969
Outside Sales	3,219	3,725	4,096	4,442	4,646	4,896
Total Demand	24,019	25,143	25,830	26,186	26,553	26,865
Surplus (Need) without Conservation	384	5,418	9,770	16,458	15,536	14,667
Surplus (Need) with Conservation	1,085	7,123	11,779	18,585	17,791	17,038

a A specific quantity of water has not been identified for this strategy.
b Does not include plumbing code savings, which are already included in the water demand projections.

Recommended Alternative Strategies for the City of San Angelo

The recommended alternative strategies include for the City of San Angelo include:

- Wastewater reuse
- Development of alternative groundwater sources

4.9 Other Strategies

4.9.1 Weather Modification

Weather modification is a water management strategy currently used in Texas to increase precipitation released from clouds over a specified area typically during the dry summer months. The most common form of weather modification or rainfall enhancement is cloud seeding. Early forms of weather modification began in Texas in the 1880s by firing cannons to induce convective cloud formation. Current cloud seeding techniques are used to enhance the natural process for the formation of precipitation in a select group of convective clouds.

Convective clouds, also known as cumulus clouds, are responsible for producing the bulk of rainfall during any given year in Texas.[52] The cloud seeding process increases the availability of ice crystals, which bond with moisture in the atmosphere to form raindrops, by injecting a target cloud with artificial crystals, such as silver iodide. Specially equipped aircraft release the seeding crystals into clouds as flares that are rich in supercooled droplets. The silver iodide crystals form water droplets from available moisture in the air. Droplets then collide with droplets transforming the ice crystal into a raindrop.

Weather modification is most often utilized as a water management strategy during the dry summers in West Texas. The water produced by weather modification augments existing surface and groundwater supplies. It also reduces the reliance on other supplies for irrigation during times of normal and slightly below normal rainfall. However, not all of this water is available for water demands. Some of this precipitation is lost to evaporation, evapotranspiration, and local ponds. During drought years the amount of additional rainfall produced by weather modification may not be significant.

The amount of water made available to a specific entity from this strategy is difficult to quantify, yet there are regional benefits. Three major benefits associated with weather modification include:

- Improved rangeland and agriculture due to increased precipitation
- Greater runoff to streams and rivers due to higher soil moisture
- Groundwater recharge

Weather Modification Programs in Region F

In Region F, there are two ongoing weather modification programs: the West Texas Weather Modification Association (WTWMA) project and the Trans Pecos Weather Modification Association (TPWMA) program.

West Texas Weather Modification Association (WTWMA) Project

The WTWMA began weather modification efforts in 1995. The intent of the rainfall enhancement program was to increase ground water recharge, spring flow, and runoff resulting in increased agricultural productivity and reduction in ground water withdrawals. WTWMA operates in eight counties covering an area of 10 thousand square miles. The City of San Angelo, Emerald Underground Water Conservation District (UWCD), Glasscock County UWCD, Irion County Water Conservation District (WCD), Plateau Underground Water Conservation and Supply District (UWC & SD), Santa Rita UWCD, Sterling County UWCD and Sutton County UWCD are the current participants in the rainfall enhancement effort. In 2008, a total of 77 clouds were seeded as part of WTWMA's rain enhancement efforts in 38 operational days. WTWMA's estimates a 20-percent increase in rainfall in the target area because of their operations.[53]

Table 4.9-1 shows a breakdown by county of the estimated increase in rainfall for the year 2008 from the annual report of the Texas Weather Modification Association.[54]

Table 4.9-1
Estimated Precipitation Increase for the Year 2008 due to WTWMA Activities

County	Inches (Increase)	Rain Gage (season value)	% Increase
Glasscock	0.99	9.55	10.4
Sterling	3.12	13.75	22.7
Reagan	3.94	11.1	35.5
Irion	2.96	11.69	25.3
Tom Green	3.11	12.24	25.4
Crockett	1.92	12.93	15.0
Schleicher	2.71	12.06	22.5
Sutton	0.68	13.29	5.1
Total	19.43	96.61	20.1

Data are from the Texas Weather Modification Association

Trans Pecos Weather Modification Association (TPWMA) Program

The TPWMA began operation in 2003. The TPWMA consists of the Ward County Irrigation District and other political entities from a 4-county area, including Culberson, Loving, Reeves, and Ward counties. The program's target area covers over 5.1 million acres along and to the west of the Pecos River from El Paso to Midland. The program is currently funded by local ranchers, farmers, and landowners, Loving County, the Ward County Irrigation District, and a grant from the Texas Department of Agriculture. In 2008, TPWMA had 17 seeding days.[55]

Quantity, Reliability and Cost

Benefits of the weather modification programs are widespread and are difficult to quantify in the context of regional water planning. To precisely estimate the benefit of weather modification requires an estimate of how much precipitation would have occurred naturally without weather modification, and an estimate of how much of the increase in precipitation becomes directly available to a water user. Research indicates that rainfall can increase by 15 percent or more in areas participating in weather modification. Some locations have shown rainfall increases of as much as 27 percent. Other methods of measuring the effects of rainfall enhancement have shown positive benefits of weather modification. Dry land farm production, a common measurement, has increased in regions participating in rainfall enhancement. However, because there is no direct method to quantify the benefits to individual water user groups, no specific quantity will be assigned by Region F for this planning cycle.

The reliability of water supplies from precipitation enhancement is considered to be low for two reasons. First, it is uncertain how much water is made directly available per water user. Second, during drought conditions precipitation enhancement may not result in a significant increase in water supply. (The guidelines for regional water planning in TAC §357.5(a) specifies that regional water planning evaluate supplies from water management strategies during critical drought conditions.) Cloud formations suitable for seeding may not occur frequently during drought, so benefits during drought may be negligible.

The cost of operating the weather modification program is approximately nine to ten cents per acre. Additional data collection may be vital in determining if weather modification could be used as a long-term water management strategy in the region.

Environmental Issues

Weather modification should have a positive impact on the environment due to the increased rainfall from storms. The chemicals used in weather modification should be sufficiently diluted to minimize any threat of contamination.

Agricultural and Rural Issues

Weather modification has a positive impact on agriculture and ranching by increasing productivity. Another benefit of weather modification is hail suppression, which helps minimize damage from severe weather.

Other Natural Resource Issues

None identified.

Significant Issues Affecting Feasibility

The most significant issue facing existing weather modification programs is funding. In many cases these programs rely on the cooperation of several entities and the availability of outside funding to continue operations. In addition, local opposition to weather modification programs has caused some programs to be discontinued.

Other Water Management Strategies Directly Affected

None identified.

4.9.2 Brush Control

Brush control has been identified as a potentially feasible water management strategy for Region F. It has the potential to create additional water supply that could be used for some of the unmet needs in the Region as well as enhance the existing supply from the Region's reservoirs.

Background

Prior to settlement, most of Texas was grassland. Along with settlement came grazing animals which, for a number of reasons, created an environment that favored shrubs and trees (brush) rather than grasslands. Brush not only increases the costs of land management and decreases the livestock carrying capacity of the land, but as shown in Table 4.9-2, certain species of brush can drastically reduce water yield in a watershed. For these reasons, an effort was bought forth to control this brush and convert land back to grasslands.

In 1985, the Texas Legislature authorized the Texas State Soil and Water Conservation Board (TSSWCB) to conduct a program for the "selective control, removal, or reduction of … brush species that consume water to a degree that is detrimental to water conservation." In 1999 the TSSWCB began the Brush Control Program. This is a voluntary program in which landowners may contract with the state for cost-share assistance. Working through local soil and water conservation districts, landowners develop resource management plans addressing brush control, soil erosion, water quality, wildlife habitat and other natural resource issues.

Table 4.9-2
Plant Water Use Rates

Plant	Water Loss (in/yr)	Water Loss (ac-ft/ac/yr)
Cottonwood	43.5 – 64.5	3.63 – 5.38[56, 57]
Crops	30.8 – 37.0	2.57 – 3.08[58]
Fourwing Saltbush	28.5 – 68.8	2.38 – 5.73[59]
Grass	6.0	0.50[60]
Honey Mesquite	13.7 – 25.4	1.14 – 2.12[61]
Juniper	23.3 – 25.0	1.94 – 2.08[62]
Mesquite	19.2 – 26.3	1.60 – 2.19
Salt cedar	27.3 – 234	2.28 – 19.52[56,63,64,65]
Salt grass	11.9 – 44.8	0.99 – 3.73[66]

The TSSWCB has designated areas of critical need in the State in which to implement the Brush Control Program. Currently four watersheds have been designated as critical areas based on water needs and the results of the completed feasibility studies. Three of those four critical watersheds lie within Region F. They are the North Concho River Watershed, Twin Buttes Reservoir Watershed, and the Upper Colorado River Watershed.

Methods of Brush Control

A number of methods can be employed to control brush. They include: mechanical, chemical, prescribed burning, bio-control, and range management. Mechanical brush control methods can range from selective cutting with a hand axe and chain saw to large bulldozers. Moderate to heavy mesquite or cedar can be grubbed or plowed for $100 to $165/acre.[67]

Several herbicides are approved for chemical brush control. The herbicides may be applied from aircraft, from booms on tractor-pulled spray rigs, or from hand tanks. Some herbicides are also available in pellet form. The herbicides Triclopyr (Remedy®) and Clopyralid methyl (Reclaim®) are approved herbicides for on-going TSSWCB brush programs. Arsenal is the herbicide typically used for removal of salt cedar. These chemical were shown to achieve about 70 percent root kill in studies around the state and in adjacent states. Specific soil temperature and foliage conditions must be met in order for chemical brush control to be effective. Aerial spraying of brush such as mesquite costs the same regardless of the plant density or canopy cover, about $25 per acre.[67]

Prescribed burning is also used to control brush. Burning is conducted under prescribed conditions to specifically target desired effects. Prescribed burning is estimated at $15 per acre for the TSSWCB programs. There are some limitations however. Burning rarely affects moderate to heavy stands of mature mesquite. Burning only topkills the smooth-bark mesquite plants and they re-sprout profusely. In addition, for mesquite, fire only gives short-term suppression and it stimulates the development of heavier canopy cover than was present pre-burn. Fire is not usually an applicable tool in moderate to heavy cedar (juniper) because these stands suppress production of an adequate amount of grass for fine fuel. Fire can be excellent for controlling junipers over 4 feet tall, if done correctly. Prescribed burning is often not recommended for initial clearing of some heavy brush due to the concern that the fire could become too hot and sterilize the soil. Burning is often used for maintenance of brush removal that has been initially performed through some other method.

Bio-control of salt cedar is a relatively new technique to be used in Texas. It has been studied for nearly 20 years, and there have been pilot studies in the Lake Meredith watershed and most recently in the Colorado River Basin.[68] Research has shown that the Asian leaf beetle can consume substantial quantities of salt cedar in a relatively short time period, and generally does not consume other plants. Different subspecies of the Asian beetle appear to be sensitive to varying climatic conditions, and there is on-going research on appropriate subspecies for Texas. It is recommended that this control method be integrated with chemical and mechanical removal to best control re-growth. The cost per acre is unknown.

Range or grazing management should follow any type of upland brush control. It allows the regrowth of desirable grasses, maintaining good groundcover that hinders establishment of woody plant seedlings. Continued maintenance of brush is necessary to ensure the benefits of brush control.

Brush Control in Region F

Brush control is a potential water management strategy that could possibly create additional water supply within Region F. Predicting the amount of water that would be made available by implementing a brush control program is difficult, but some estimates have been made through ongoing pilot projects. Feasibility studies were conducted in many areas, and based on those feasibility studies, a number of brush control projects were initiated in Region F. Currently active projects sponsored by the Texas State Soil and Water Conservation Board (TSSWCB) include: O.C. Fisher Project, Twin Buttes Reservoir/Lake Nasworthy Projects, and the Lake Brownwood Project.[69]

O. C. Fisher Project

In 1999, the Legislature authorized the North Concho River Pilot Brush Control Project for the purpose of enhancing the amount of water flowing from the North Concho River watershed into O.C. Fisher Reservoir. O.C. Fisher Reservoir serves as a water supply source for the City of San Angelo. This project is a follow-on to the North Concho project, further enhancing potential watershed yield by removal of water-loving exotic species on approximately 15,860 acres owned by the Corps of Engineers above the existing lake level. The project area includes lake habitat, riverine habitat, intermittent riverine habitat and bottomland hardwoods. As of 2008 1,255 acres had been treated.

Twin Buttes Reservoir/Lake Nasworthy Brush Control Projects

In September 2002, brush control projects were initiated to enhance the amount of water flowing into the Twin Buttes Reservoir/Lake Nasworthy complex. Twin Buttes Reservoir is used to maintain sufficient water levels in Lake Nasworthy, which serves as a water supply for the City of San Angelo. TSSWCB has allocated $10.8 million for brush control cost-share in this watershed. As of December 2008, over 252,729 acres have already been treated using state funds. TSSWCB estimates that this project could increase water yield by approximately 198,000 acre-feet over the life of the project. Additional allocation of funds will be needed to complete the treatment of the more than 555,000 acres of eligible brush in the Twin Buttes Subbasin.

Lake Brownwood Project

In March 2008, the TSSWCB funded efforts to treat mesquite and juniper in the Lake Brownwood watershed. The program is being administered by the Pecan Bayou Soil and Water Conservation District. Lake Brownwood provides municipal, industrial and agricultural water supply to Brown County and surrounding areas. As of the end of 2008, TSSWCB $200,000 to the project and contracted to treat 701 acres. TSSWCB estimates an increase in water yield of approximately 1,900 acre-feet over the life of the project.

Quantity, Reliability and Cost

Although many studies have illustrated the benefits of brush control, until recently it has been difficult to quantify the benefits in the context of regional water planning. This quantification is very important because in most areas that the program is currently being implemented, hydrologic records indicate long term declines in reservoir watershed yields (some as much as 80%). Region F has been in critical drought conditions during most of the time that the current brush removal programs have been in place, so the monitoring programs associated with these projects may not have shown significant gains due to the lack of rainfall events. Also, the benefits from brush control are long term; it takes time for aquifers to recharge and for watersheds to return to pre-brush conditions. This fact was recognized by the various scientists during the initial planning for the Texas Brush Control Program and the preparation of numerous feasibility studies. Measuring success and hydrologic responses to brush control projects is going to be a long-term process, even under ideal conditions. Until recently, the projects have been implemented under less than ideal conditions due to the record drought. While the relatively short period of time these programs have been in place may not be indicative of the long term gains of the programs, evidence is beginning to manifest that should serve to offer some indications.

Considering the above facts as a point of reference, the measured hydrologic responses and ongoing research findings to date have been nothing short of spectacular. Some of the indications of water production successes observed to date are as follows:

- Following modest surface water inflows in November 2004, unprecedented base flows into Twin Buttes Reservoir essentially doubled reservoir capacity (to 47,500 acre feet by mid June) and is effectively mitigating summer evaporation losses from the reservoir. The Twin Buttes watershed has been the recent recipient of a major brush removal effort on targeted and high priority sub-basins.
- Base flows on Pecan Creek (a long dormant perennial tributary to Lake Nasworthy and the subject of a special brush control project) provided so much base flow to Lake Nasworthy that water had to be released downstream on several occasions during the winter and spring of 2004-2005. This condition has been unprecedented in recent history.
- Long dormant tributary springs throughout the region have begun to flow following brush removal. Most of these became active during the drought and without benefit of any rainfall.
- The East Fork of Grape Creek, which is a portion of a major tributary to O.C. Fisher Reservoir, has received extensive brush removal (approximately 70 percent of targeted brush in the sub-basin). This tributary has been measured to have produced hundreds of acre feet of water in base flows since November, 2004. A similarly sized adjacent watershed (West Fork

of Grape Creek) that has not received brush removal produced no downstream water base flows. Hydrologic calculations of data from the East Fork indicate that this watershed is producing in excess of 1.0 acre inch of water per year in base flows. Prior to brush removal, the hydrologic characteristics of this watershed were similar to that of the West Fork. An August, 2005 runoff event on both watersheds revealed a dramatic difference in the flood hydrographs from each stream. The untreated watershed produced a rapid short flow event, while the treated watershed produced a longer and sustained flow.

- For the first time since the mid 20th century, the North Concho River has experienced perennial base flows for an extended period of the year throughout the stream reach. As a result of this saturated stream condition, the watershed yield from an August, 2005 storm runoff event was undoubtedly increased.
- Regional groundwater monitoring within the North Concho watershed during the last 48 months is indicating a significant trend in increasing ground water levels. Much of this data has been collected during a period of record drought.
- Preliminary evapotranspiration data from on-going paired watershed studies conducted by the Texas Institute for Applied Environmental Research (TIAER) at Tarleton State University for the Upper Colorado River Authority (UCRA) is indicating a significant difference in water use between treated and untreated mesquite infested sites. This data, which is due to be published by TIAER by early 2006, will likely confirm existing watershed model predictions and other ongoing research and monitoring initiatives.

Based on anecdotal accounts and observations, almost everyone in the area from participating landowners to water supply and elected officials are recognizing the water producing value of the program. It would appear from preliminary observations and findings that brush control as a water producing strategy is viable and should be incorporated into water supply planning. Since the region appears to be moving out of the drought period of the last few years and reliable experimental data is emerging from monitoring efforts, accurate quantification of the hydrological effects of brush control may soon be possible. This quantification will likely be based on existing modeling output found in a completed watershed feasibility study and confirmation or adjustment of that modeling prediction. Also, since the program is based on voluntary participation by landowners, an analysis of the completed brush control work as to the extent within each sub-basin, location of each sub-basin in relationship to the overall watershed and anticipated water production from each sub-basin should be performed. The feasibility studies and models assume removal of all of the targeted brush, which will not often happen. A summary of each sub-basin within the Upper Colorado watershed by production and costs was published by the Upper Colorado River Authority (UCRA) in 2002 and is available for use in performing an analysis.

The UCRA document referenced above is also a good source of information regarding the cost of water produced through brush control. In consideration of the entire upper Colorado River basin, there is tremendous variability in sub-basin water yields and therefore tremendous variability in costs per acre-feet of water produced. According to existing feasibility studies, treating the entire upper Colorado River basin (nine reservoir watersheds) would result in a composite cost of slightly over $70 per acre foot of water produced. Treating only the most productive sub-basins, however, could produce a high percentage of the modeled water production and reduce the composite costs to less than $50 per acre foot. This (priority sub-basin) approach has been utilized in allocating initial funding available for brush control in the region. An assumption of water yields (from feasibility studies) based on 50 percent of high priority brush removal and 65 percent of modeled water yield will result in 191,817 acre feet of water being produced in ten (10) upper basin reservoirs, including 30,000 acre feet in the O.C. Fisher watershed and 49,856 acre feet in the Twin Buttes/Nasworthy watershed.

In order to be an effective and reliable long term water production strategy, areas of brush once removed, must be maintained. Follow –up treatment is essential to the program and has been built into the TSSWCB landowner contracts. During the 10-year contract period landowners must perform any needed follow- up treatment if state funding is available. Toward this end, the NRCS has made funding available for landowners in the O.C. Fisher and Twin Buttes watersheds for follow-up treatment through the EQIP program.

In 2003 the cost of the existing brush control program in Region F was $26,000,000. Near-term funding for brush control in the region would be at similar levels.

Environmental Issues

The Texas Parks and Wildlife Department (TPWD) list the potential environmental impacts of brush control as alteration of terrestrial habitat, increased sediment runoff and erosion, impacts from chemical control measures, potential for increase groundwater recharge, impacts to aquatic and terrestrial communities and ecosystem process, and influence on energy and nutrient inputs and processing[70]. Region F suggests coordinating with TPWD and other state and federal agencies regarding any brush control program.

Agricultural and Rural Issues

Invasive brush has altered the landscape of Region F and the rest of West Texas. Restoration of much of the landscape to natural grassland conditions will benefit the ranching economy of the region as well as enhance water supplies.

Other Natural Resource Issues

Although invasive brush has impacted water supplies and altered the natural landscape of the region and reduced runoff, in some cases the brush has provided habitat for wildlife. In addition to the environmental benefits of this habitat, some of this habitat is suitable for deer and other game. Hunting is an important part of the economy of Region F. Therefore it may be desirable to leave portions of a watershed with brush to maintain habitat.

Significant Issues Affecting Feasibility

The most significant factor regarding the feasibility of this strategy is on-going funding for brush control projects. Brush control is an on-going process that must be constantly maintained for the project to be successful. Existing programs provide funding for the initial clearing of brush but generally do not provide funding for on-going maintenance and monitoring. Without maintenance and monitoring, brush control will not be effective as either a range management or water management strategy.

Like other similar activities, brush control is dependent upon the on-going cooperation and financial contributions of individual landowners. Therefore each program should be tailored to local conditions.

Other Water Management Strategies Directly Affected

If the findings of the existing upper basin feasibility studies are verified and/or adjusted, and if the program is adequately implemented and maintained, brush control could delay or eliminate the need for new water supply projects. Currently, the major on-going brush removal projects are located above O.C. Fisher and the Twin Buttes/Nasworthy reservoirs. Both of these reservoirs are a part of the San Angelo water supply system. To date, approximately 300,000 acres have been completed on the O.C. Fisher watershed and 200,000 acres completed on the Twin Buttes/Nasworthy watershed. Neither of the projects are currently complete with an additional 10,000 acres targeted on the O.C. Fisher watershed and 25,000 acres targeted on the Twin Buttes/Nasworthy watershed during the FY 2006-2007 biennium. However, hydrologic observations and response monitoring on these watersheds previously reported herein, indicates a trend toward watershed restoration and partial return to pre-brush conditions. While this process is not complete, it is apparent that an improvement in watershed yields is occurring and should be recognized in planning.

With an intention of being prudent and in consideration of relevant factors, it is recommended that during the current planning period, an additional 8,362 acre feet of water per year should be recognized as available to San Angelo from local sources due to brush control. This estimate is based on the short term availability of approximately 20 percent of the ultimate increased watershed yield based on the current status of the brush removal program.