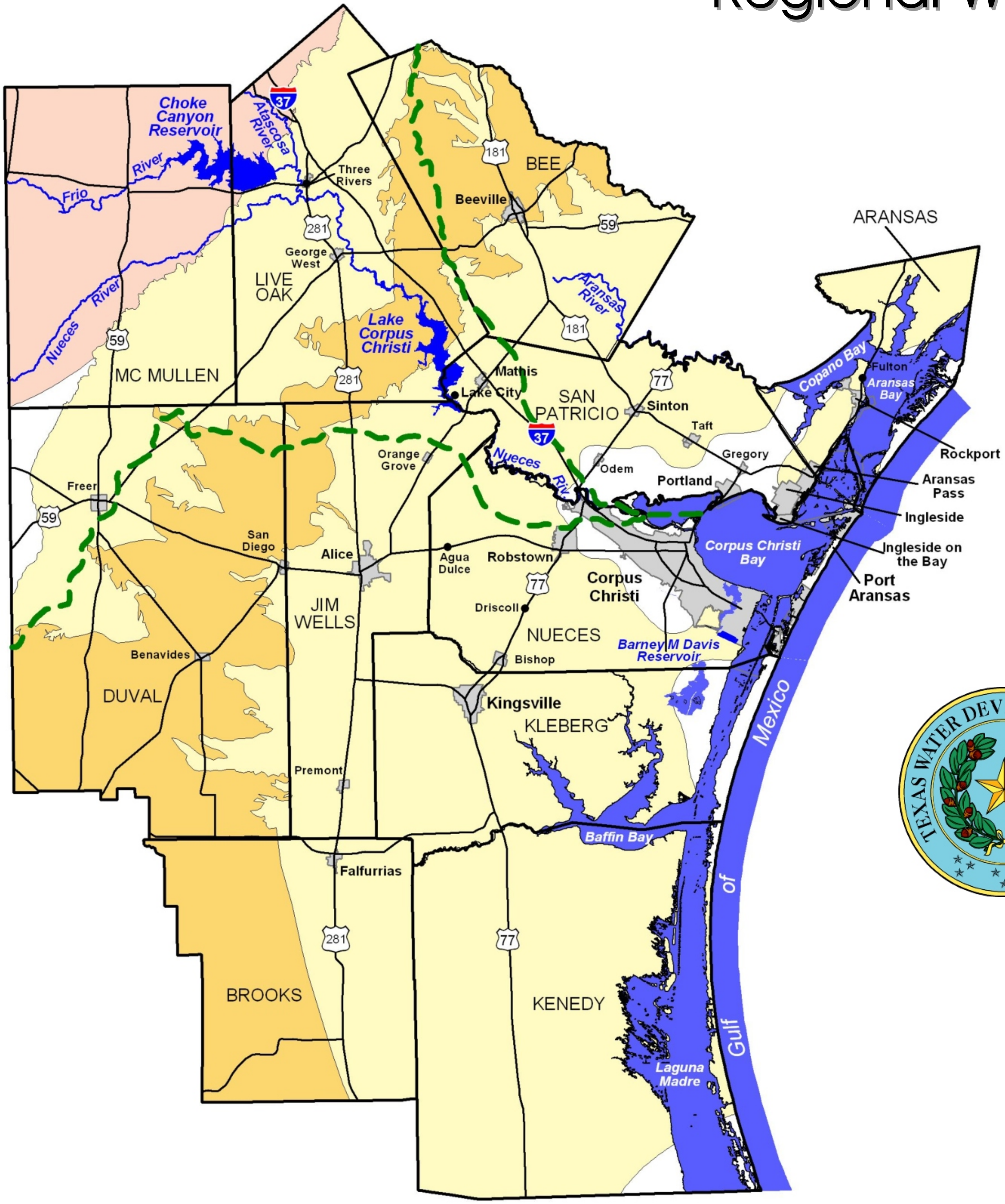
Coastal Bend
Regional Water Planning Area
Region N



Regional Water Plan

Volume II
Water Management Strategies

January 2006

Prepared for:

Texas Water Development Board

Prepared by:

Coastal Bend
Regional Water Planning Group

With administration by:

Nueces River Authority

With technical assistance by:

HDR Engineering, Inc.

In association with:

The Rodman Company

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Coastal Bend
Regional Water Planning Area

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Volume II
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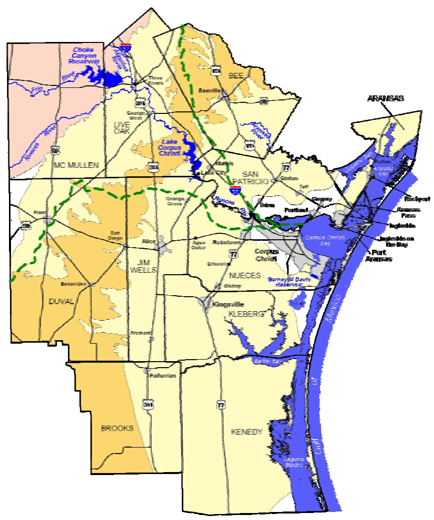

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Coastal Bend Regional Water Planning Area
2006 Regional Water Plan

Acknowledgements

The thoughtful consideration, input, public service, and direction of the members of the Coastal Bend Regional Water Planning Group is gratefully acknowledged in producing the water plan for this diverse planning area.

Coastal Bend Regional Water Planning Group

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Co-Chair	Mr. Scott Bledsoe III, Live Oak UWCD	Water Districts Representative
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The efforts, long hours, and diligence is specially noted and appreciated of these individuals:

Ms. Rocky Freund, Deputy Executive Director	Nueces River Authority
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Regional Water Plan

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As adopted by the Coastal Bend Regional Water Planning Group on this date December 8, 2005

Coastal Bend Regional Water Planning Area
Regional Water Plan

For HDR Engineering, Inc.

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Table of Contents

Section **Page**

Table of Contents (Continued)

Section **Page**

Table of Contents (Continued)

Section **Page**

Table of Contents (Continued)

Section **Page**

List of Figures

List of Figures (Continued)

List of Figures (Continued)

Figure **Page**

List of Figures (Concluded)

List of Tables

List of Tables (Continued)

List of Tables (Continued)

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4C.1 Municipal Water Conservation (N-1)

4C.1.1 Description of Strategy

Water conservation refers to those methods and practices that either reduce the demand for water supply or increase the efficiency of the supply or use facilities so that available supply is conserved and made available for future use. Water conservation is typically a low-capital intensive alternative that water supply entities can pursue. All water supply entities and some major water right holders are required by Senate Bill 1 regulations to submit a Drought Contingency and Water Conservation Plan to the TCEQ for approval. These plans must detail the water supply entities' plans to reduce water demand at times when the demand threatens the total capacity of the water supply delivery system or overall supplies are low.

In 2001, the Texas Legislature amended the Texas Water Code to require Regional Water Planning Groups to consider water conservation and drought management measures for each water user group with a need (projected water shortage). The Water Conservation Implementation Task Force was created by Senate Bill 1094 to identify and describe Water Conservation Best Management Practices (BMPs) and provide a BMP Guide for use by Regional Water Planning groups in the development of the 2006 Regional Water Plans. Additional water conservation guidance reports include a TWDB report entitled, "Quantifying Effectiveness of Various Water Conservation Techniques in Texas," and a document entitled, "Strategies to Enhance Water Conservation in the Coastal Bend," specifically prepared to assist communities with water conservation in the Coastal Bend Area.

For regional water planning purposes, municipal water use is defined as residential and commercial water use. Municipal water is primarily for drinking, sanitation, cleaning, cooling, fire protection, and landscape watering for residential, commercial, and institutional establishments. A key parameter of municipal water use within a typical city or water service area is the number of gallons used per person per day (per capita water use). The objective of water conservation is to decrease the amount of water – measured in gallons per person per day (gpcd) – that a typical person uses.

The Water Conservation Implementation Task Force recommends that a standardized methodology be used for determining per capita per day (gpcd) municipal water use so as to allow consistent evaluations of effectiveness of water conservation measures among Texas cities that are located in the different climates and parts of Texas. The Task force further recommends gpcd targets and goals that should be considered by retail public water suppliers when developing water conservation plans required by the state, as follows:

- All public water suppliers that are required to prepare and submit water conservation plans should establish targets for water conservation, including specific goals for per capita water use and for water loss programs using appropriate water conservation BMPs.
- Municipal Water Conservation Plans required by the state shall include per capita water-use goals, with targets and goals established by an entity giving consideration to a minimum annual reduction of 1 percent in total gpcd, based upon a 5-year moving average, until such time as the entity achieves a total gpcd of 140 gpcd or less, or
- Municipal water use (gpcd) goals approved by regional water planning groups.

Per capita water use was calculated using TWDB-approved population and water demand estimates based on water user surveys for each decade from 2000 to 2060. The per capita water use in 2000 and projected per capita water use in 2010, 2020, 2030, 2040, 2050, and 2060 include expected effects of low flow plumbing fixtures upon per capita water use and are shown for each municipal entity located in the Coastal Bend Region in Table 4C.1-1. The projected municipal water demands assume a 100 percent replacement of existing plumbing fixtures to water efficient fixtures by 2045 (assumed 2 percent per year replacement).[1] The 51 municipal entities of Region N are listed in Table 4C.1-1, in the order of low to high per capita water use, in year 2000 in four groupings as follows:

- Less than 140 gpcd,
- 140 to 164 gpcd,
- 165 to 199 gpcd, and
- 200 and greater gpcd.

The projected municipal water needs (shortages) were calculated for each municipal entity by subtracting projected municipal water demands, with plumbing fixture water conservation taken into account, from existing municipal water supplies. The purpose of the municipal water conservation water management strategy is to evaluate the potentials of additional municipal water conservation for inclusion in the Regional Water Plan to meet a part of the projected water needs (shortages) of each municipal entity.

[1] Correspondence with Kevin Kluge, TWDB, September 2004.

Table 4C.1-1.
Municipal Water User Groups Projected Per Capita Water Use
(TWDB Projections)

No.	Water User	County	Per Capita Water Use with Low Flow Plumbing Fixtures						
			2000	2010	2020	2030	2040	2050	2060
1	County-Other	Bee	77	74	72	70	68	67	67
2	Ingleside	San Patricio	83	77	75	73	72	72	72
3	Gregory	San Patricio	96	92	89	86	83	81	81
4	County-Other	Kenedy	100	96	94	91	89	88	88
5	Ingleside On The Bay	San Patricio	100	96	93	91	90	89	89
6	McCoy WSC	Live Oak	101	98	95	93	93	92	92
7	River Acres WSC	Nueces	102	97	94	92	91	90	90
8	County-Other	Brooks	103	99	96	93	90	89	89
9	Driscoll	Nueces	105	100	97	95	94	93	93
10	County-Other	San Patricio	105	101	98	95	92	91	91
11/12	San Diego[1]	Duval/Jim Wells	107	103	99	96	93	92	92
13	County-Other	Aransas	109	104	101	98	96	95	95
14	Odem	San Patricio	114	109	106	103	100	99	99
15	Ricardo WSC	Kleberg	115	107	105	104	103	103	103
16	County-Other	Jim Wells	117	114	111	108	105	104	104
17	Lake City	San Patricio	119	114	111	108	106	105	105
18	Portland	San Patricio	119	114	111	108	107	106	106
19	Mathis	San Patricio	119	115	112	109	106	104	104
20	Bishop	Nueces	124	120	117	114	111	109	109
21	Agua Dulce	Nueces	139	136	133	130	127	125	125
1	Choke Canyon WSC	McMullen	143	141	139	138	137	136	136
2	Choke Canyon WSC	Live Oak	143	141	139	138	137	136	136
3	County-Other	Live Oak	145	142	139	137	135	134	134
4	Taft	San Patricio	147	143	140	137	134	133	133
5	Aransas Pass	San Patricio	150	145	141	139	137	136	136
6	Fulton	Aransas	150	148	146	145	144	143	143
7	Aransas Pass	Aransas	150	145	141	139	137	136	136
8	Robstown	Nueces	151	148	145	142	139	137	137
9	Aransas Pass	Nueces	153	142	141	138	137	135	135
10	County-Other	Nueces	155	152	149	146	143	141	141
11	Kingsville	Kleberg	155	152	148	145	142	141	141
12	Sinton	San Patricio	163	160	156	153	150	149	149
13	Rockport	Aransas	164	161	158	156	154	153	153

Continued on next page

Table 4C.1-1 concluded

No.	Water User	County	Per Capita Water Use with Low Flow Plumbing Fixtures						
			2000	2010	2020	2030	2040	2050	2060
1	County-Other	Kleberg	165	161	158	156	154	153	153
2	Benavides	Duval	167	163	159	156	153	152	152
3	El Oso WSC	Bee	169	165	162	159	157	156	156
4	Live Oak El Oso WSC	Live Oak	169	165	162	159	157	156	156
5	Freer	Duval	172	168	164	161	158	157	157
6	Beeville	Bee	172	168	164	161	158	157	157
7	Corpus Christi	Nueces	179	175	171	168	166	165	165
8	Nueces County WCID #4	Nueces	187	181	179	178	177	177	177
9	County-Other	Duval	191	188	185	182	179	178	178
1	County-Other	McMullen	201	196	193	190	188	186	187
2	Three Rivers	Live Oak	202	198	195	192	189	188	188
3	George West	Live Oak	227	223	220	217	214	213	213
4	Orange Grove	Jim Wells	245	240	237	234	231	230	230
5	Alice	Jim Wells	248	244	241	238	235	234	234
6	Premont	Jim Wells	260	256	253	250	247	246	246
7	Falfurrias	Brooks	280	273	270	268	266	265	265
8	Port Aransas	Nueces	424	418	416	414	413	413	413

[1] San Diego is located in both Duval and Jim Wells Counties.

The City of Corpus Christi, the largest municipal water user in the Coastal Bend Region, has demonstrated significant water savings attributable to water conservation efforts over the last decade. The City's municipal water use was nearly 220 gpcd in 1990[2] and was reduced to 179 gpcd by 2000, a decrease of 41 gpcd (or 19 percent). According to TWDB water use projections, the City of Corpus Christi water use is anticipated to decline to 165 gpcd by 2060 (Table 4C.1-1).

Based on the success of the City's water conservation program, the Coastal Bend Regional Water Planning Group recommends that water user groups, with and without shortages, exceeding 165 gpcd should reduce consumption by 15 percent by 2060. For entities with projected water use equal or less than 165 gpcd in 2060, TWDB projections are recommended.

[2] City of Corpus Christi Water Conservation Plan, 1999.

In year 2000, in the Coastal Bend Water Planning Region, 34 municipal water users had per capita water use of less than 165 gpcd (Table 4C.1-1). Water users with less than 165 gpcd represented 36.03 percent of the population of the Region in 2000, and used 27.14 percent of the quantity of municipal water used in the Region in 2000 (Table 4C.1-2). In 2000, in the Region, 17.65 percent of the municipal entities had per capita water use of 165 to 199 gpcd. This group represented 57.18 percent of the region's population in 2000, and accounted for 61.95 percent of the municipal water used in the Region in 2000 (Table 1.1-2). Of the 51 municipal entities located in the region, eight (or 15.69 percent) had per capita water use greater than 200 gpcd, representing 6.79 percent of the Region's year 2000 population, and accounted for 10.91 percent of the municipal water use in the Region in 2000 (Table 4C.1-2).

Table 4C.1-2.
Municipal Water User Groups Number, Population, and Water Use by Per Capita Water Use Levels
Coastal Bend Water Planning Region

Per Capita Water Use in 2000 (gpcd)	Number of Municipal Entities	Percent of Municipal Entities	Population		Water Use	
			2000	Percent of Total	2000 (acft)	Percent of Total
Less than 140	21	41.18%	116,105	21.45%	13,527	13.53%
140 to 164	13	25.49%	78,912	14.58%	13,603	13.61%
165 to 199	9	17.65%	309,427	57.18%	61,915	61.95%
200 and above	8	15.69%	36,740	6.79%	10,905	10.91%
Totals	51	100.00%	541,184	100.00%	99,950	100.00%

4C.1.2 Available Yield

Of the 51 municipal entities in Region N, 17 had per capita water use rates in year 2000 higher than the 165 gpcd goal established by the CBRWPG. Of these 17 municipal entities, ten had per capita water use rates higher than 165 gpcd in 2060. All municipal entities in the Coastal Bend Region are encouraged to conserve water, regardless of per capita consumption. However, a 15 percent reduction in per capita water use was recommended by the CBRWPG for those municipal entities with per capita use in 2060 greater than 165 gpcd. This conservation can be achieved in a variety of ways, including using these BMPs identified by the Water Conservation Implementation Task Force:

1. System Water Audit and Water Loss,
2. Water Conservation Pricing,
3. Prohibition on Wasting Water,
4. Showerhead, Aerator, and Toilet Flapper Retrofit,
5. Residential Toilet Replacement Programs with Ultra-Low-Flow toilets,
6. Residential Clothes Washer Incentive Program,
7. School Education,
8. Water Survey for Single-Family and Multi-Family Customers,
9. Landscape Irrigation Conservation and Incentives,
10. Water-Wise Landscape Design and Conversion Programs,
11. Athletic Field Conservation,
12. Golf Course Conservation,
13. Metering of all New Connections and Retrofitting of Existing Connections,
14. Wholesale Agency Assistance Programs,
15. Conservation Coordinator,
16. Reuse of Reclaimed Water,
17. Public Information,
18. Rainwater Harvesting and Condensate Reuse,
19. New Construction Graywater,
20. Park Conservation, and
21. Conservation Programs for Industrial, Commercial, and Institutional Accounts.

The water conservation water management strategy for municipal entities of the Coastal Bend Region is based upon BMPs listed above, quantities and costs of water conservation measures as reported in TWDB and TCEQ guidance documents,[3,4] and the Water Conservation Implementation Task Force guidelines for water-use targets and goals listed previously. Since costs and savings presented in the Task Force Draft Report are general and have limited applicability, the list of specific BMPs is significantly reduced, as presented in Table 4C.1-3. Specific conservation measures are not assigned to each municipal entity to provide flexibility for entities to identify practical conservation strategies that fit their individual situation the best. It is also important to note that the list in Table 4C.1-3 has been identified primarily to estimate costs and water savings. A city may choose other BMPs not included in Table 4C.1-3 to reduce their per capita water use.

[3] TWDB, GDS Associates, "Quantifying the Effectiveness of Various Water Conservation Techniques in Texas," July 2003.
[4] TCEQ Water Audit, August 26, 2002.

Table 4C.1-3.
Possible Water Conservation Techniques (BMPs)

	Rural		***Suburban***		***Urban***	
	Water Savings (gpcd)		***Water Savings (gpcd)***		***Water Savings (gpcd)***	
	Maximum	***Typical****	***Maximum***	***Typical****	***Maximum***	***Typical****
Indoor Conservation						
Toilet Retrofit[1]	10.5	4.2	10.5	4.3	10.5	4.4
Showerheads and Aerators[1]	5.5	2.2	5.5	2.2	5.5	2.3
Clothes Washer Rebate[1]	5.4	4.8	5.3	4.8	4.7	4.2
Outdoor Conservation						
Irrigation Audit-High User[1]	19.4	0.8	19.1	0.8	14.9	0.7
Rainwater Harvesting[1]	12.0	0.6	11.7	0.6	10.4	0.5
Rain Barrels[1]	1.3	0.4	1.3	0.4	1.3	0.4
Landscape Irrigation & Incentives[2]	62.3	12.4	105.5	12.4	32.0	12.4
Seasonal water use reduction[3]	5.0	1.8	5.0	1.8	5.0	1.8
General Conservation						
Unaccounted for losses[3]	7.8	—	7.8	—	7.8	—
Public Education Programs[3]	7.8	3.1	7.8	3.1	7.8	3.1
Total	**136.9**	**30.3**	**179.4**	**30.3**	**99.8**	**29.8**

1 GDS Associates, July 2003.
2 Water Conservation Implementation Task Force, typical based on 15 percent reduction of outdoor water use and maximum based on 30 percent reduction of outdoor water use. Outdoor water use = Total Water Use - 72.5 gpcd (indoor).
3 TCEQ Water Audit, August 2002.
* Typical water savings calculated based on potential savings identified by GDS Associates divided by number of people potentially affected as reported in “Quantifying the Effectiveness of Various Water Conservation Techniques in Texas,” TWDB, GDS Associates, Austin, TX, July 2003.

A description of water conservation BMPs listed in Table 4C.1-3 to assist municipal entities exceeding 165 gpcd in 2060 achieve a 15 percent reduction in water use or 165 gpcd by 2060 is presented below, and includes indoor, landscape irrigation, and general water conservation methods.

Indoor Water Conservation: An average demand reduction of 13 gpcd for Coastal Bend municipal entities is included in the TWDB per capita water use projections associated with replacing plumbing fixtures. The TWDB water use projections have a maximum built-in per capita reduction of 16 gpcd from 2000 to 2060, which assumes 100 percent participation in low flow plumbing fixture programs. The amount of additional indoor water conservation is calculated based upon the potential typical water conservation of 11 gpcd, which assumes

50 percent participation in toilet retrofit/showerhead programs and 45 percent participation in clothes washer rebate. The potential amount of "additional" indoor conservation beyond the savings included in the TWDB projections was determined for the projected population at the respective projection dates, by subtracting the plumbing fixtures effects already in the water demand projections. For municipal entities that already have a built-in reduction exceeding 11 gpcd in TWDB per capita water use projections, no additional savings would be expected from indoor water conservation.

Landscape Irrigation Water Conservation: In addition to the indoor water conservation measures described above, the water conservation water management strategy for municipal entities for the Coastal Bend Region includes landscape irrigation. The estimated potentials are based upon the following conditions and assumptions:

1. For those municipal entities having year 2060 water use of 165 to 200 gpcd, landscape irrigation potential can be 15 percent of water use above 75 gpcd.
2. For those WUGs having year 2060 water use greater than 200 gpcd, landscape irrigation potential can be as much as 30 percent of water use greater than 75 gpcd.

General Water Conservation: A municipality can determine unaccounted for water losses by performing a water audit, which includes collecting information that can then be used to calculate unaccounted for water loss using the following equation:

Unaccounted for water = Water production/purchased (gallons) – Water Sales (gallons)

To maximize the benefits of this conservation strategy, the utility uses this audit information to revise meter testing and repairs, reduce unmetered use, improve accuracy of the utility's metering system, and implement effective water loss management strategies. Factors that affect the amount of unaccounted for water include density of the system, age of the system, construction quality of the system, and accuracy of the water metering.[5]

The TCEQ reports that unaccounted for water losses of 15 percent or less are acceptable for communities greater than 5,000 people. Losses above 15 percent may be an area of concern and provide conservation potentials. Rural communities in the Coastal Bend may experience as high as 20 percent unaccounted for losses,[6] which presents an opportunity to conserve at least 5 percent of per capita water use by taking measures to reduce unaccounted for losses.

[5] Naismith Engineering, Inc., "Strategies to Enhance Water Conservation in the Coastal Bend," April 1999.
[6] Conversation with Carl Crull, HDR, January 2005.

In addition to unaccounted for water losses, public information programs can be an important and key element to having water users save water inside homes and commercial structures, in landscaping and lawn watering, and in recreation uses. Public information and education can work in two ways to accomplish water conservation. One way is to inform and convince water users to obtain and use water-efficient plumbing fixtures and appliances, to adopt low water use landscaping plans and plants, to find and repair plumbing leaks, to use gray water for permissible uses (e.g., lawn and shrubbery watering where regulations allow), and to take advantage of water conservation incentives where available.

A second way public information and education can work to conserve water is to inform water users of ways to manage and operate existing and new fixtures and appliances so that less water is used. This includes ideas and practices such as washing full loads of clothes and dishes; using a pail of water instead of a flowing hose to wash automobiles; turning the water off while brushing one's teeth, washing one's hands, or shaving; and watering lawns, gardens, and shrubs during evening—as opposed to daytime—hours.

To assist communities and water supply entities with their conservation planning, the TWDB has prepared a publication entitled *Water Loss Manual*. Additionally a document entitled *Strategies to Enhance Water Conservation in the Coastal Bend* was specifically prepared to assist communities in the Coastal Bend Area with water conservation (included in Appendix E of 2001 Plan). Both the TWDB and Coastal Bend Area documents include a water audit to assist each community in assessing their system.

After subtracting demand reductions already incorporated into the TWDB demand projections, a 15 percent reduction in per capita water use for those cities and county-others using greater than 165 gpcd in 2060 would result in savings—less water used—of 721 acft in 2030 and 2,415 acft in 2060, as seen in Table 4C.1-4. Note: Water savings are only included for 10 of the 17 municipal entities, since seven of the entities have a projected water use equal or less than 165 gpcd in 2060. As can be seen in Table 4C.1-5, the average per capita water use for cities exceeding 165 gpcd in 2000 with additional conservation is approximately 7 percent lower than without additional conservation.

Table 4C.1-4.
Potential Additional Water Conservation Savings for Water User Groups having 2060 Per Capita Water Use Greater than 165 gpcd

Water User	County	Housing Area	Water Demand Reduction via Additional Water Conservation											
			2010		2020		2030		2040		2050		2060	
			gpcd	acft/yr	gpcd	acft/yr	gpcd	acft/yr	gpcd	acft/yr	gpcd	acft/yr	gpcd	acft/yr
Nueces County WCID #4	Nueces	Suburban	0	0	0	0	3	56	5	135	9	261	12	384
County-Other	Duval	Rural	1	6	3	13	4	21	5	27	8	44	12	63
County-Other	McMullen	Rural	1	1	2	2	5	3	8	5	10	7	16	10
Three Rivers	Live Oak	Rural	1	3	3	8	5	14	7	18	11	27	16	34
George West	Live Oak	Rural	1	5	4	14	7	25	10	33	14	45	20	57
Orange Grove	Jim Wells	Rural	2	3	5	8	8	14	11	18	16	28	22	38
Alice	Jim Wells	Rural	2	50	5	133	9	219	12	306	17	438	23	585
Premont	Jim Wells	Rural	3	9	6	22	10	36	13	49	19	70	25	92
Falfurrias	Brooks	Rural	0	1	4	38	9	95	14	156	20	228	27	309
Port Aransas	Nueces	Suburban	5	28	13	115	22	238	31	406	42	615	52	843
Total			—	**104**	—	**353**	—	**721**	—	**1,155**	—	**1,764**	—	**2,415**

Table 4C.1-5.
Coastal Bend Region Average Per Capita Water Use for Expected and Advanced Conservation (gpcd)

Type of Conservation	Region Average		Average for Water Users >165 gpcd in 2000	
	2030	2060	2030	2060
TWDB projections	145	142	205	202
TWDB plus additional conservation	143	137	200	188

4C.1.3 Environmental Issues

Environmental impacts from water conservation measures in the Coastal Bend Region are not associated with direct physical impacts to the natural environment. Some of the indoor conservation measures recommended could reduce the amount of treated wastewater available to send to the Nueces Bay and estuary during low flow times, which could be offset by possible positive impact resulting from higher reservoir levels.

4C.1.4 Engineering and Costing

Of all the indoor water conservation activities, clothes washer rebates are the most costly, ranging in cost from $677/acft to $726/acft, as seen in Table 4C.1-6. For outdoor conservation activities, rain barrels are the most costly program. Costs varied significantly for reducing seasonal water use, unaccounted for loss, and public education programs, and therefore were not presented. For example, a city's cost of a meter replacement and leak detection program, generally part of the utilities' operation and maintenance budget, would vary based on size and age of utility operation and will increase the cost per acft of water conservation activities.

The costs for various water conservation strategies are presented in Table 4C.1-6. Those strategies with costs less than $500/acft were averaged to calculate program costs. The average cost of municipal water conservation for suburban entities is $342/acft water saved and $323/acft water saved for rural entities and includes toilet retrofit, installation of low flow showerhead and aerators, irrigation audits, and landscape incentives. The total program costs for municipal entities having per capita use greater than 165 gpcd in 2060 are presented in Table 4C.1-7. Total conservation potential costs for Region N are estimated at $34,227 in 2010 and increasing to $803,457 by 2060. The CBRWPG has expressed a desire to offer BMPs to encourage conservation while maintaining flexibility for municipal users to adopt strategies that suit them the best.

Table 4C.1-6.
Costs of Possible Water Conservation Techniques (BMPs)

	Rural	*Suburban1*	*Urban*
	Water Costs (per acft supply realized)	*Water Costs (per acft supply realized)*	*Water Costs (per acft supply realized)*
	Typical	*Typical*	*Typical*
Indoor Conservation			
Toilet Retrofit[2]	$390	$457	$367
Showerheads and Aerators[2]	$69	$78	$64
Clothes Washer Rebate[2]	$725	$726	$677
Outdoor Conservation			
Irrigation Audit-High User[2]	$434	$434	$434
Rainwater Harvesting[2]	$640	$640	$591
Rain Barrels[2]	$1,248	$1,248	$1,153
Landscape Irrigation & Incentives[3]	$400	$400	$400
Seasonal water use reduction[3]	N/A	N/A	N/A
General Conservation			
Unaccounted for losses[4]	N/A	N/A	N/A
Public Education Programs[4]	N/A	N/A	N/A

[1] Suburban costs typically higher than rural costs since more multi-family dwellings are in suburban communities and have higher costs to implement indoor conservation programs.
[2] GDS Associates, July 2003.
[3] Water Conservation Implementation Task Force, typical based on 15 percent reduction of outdoor water use and maximum based on 30 percent reduction of outdoor water use. Outdoor water use= Total Water Use- 72.5 gpcd (indoor).
[4] TCEQ Water Audit, August 2002.

4C.1.5 Implementation Issues

There are several issues that may slow down the efforts of water conservation activities. The most crucial is to get water customers to change their water use habits. Effective public outreach and education can go a long way to reducing water use, but in the end the effectiveness of any program is dependent upon the individual. A key element to the Drought Contingency and Water Conservation Plan that each city has been required to submit to the TCEQ is the curtailment of water use during drought. Enforcement of these restrictions—usually ones that limit lawn watering—is often difficult. Lastly, retrofit programs can be expensive, and may not be a budget priority for many cities.

Table 4C.1-7.
Costs of Water Conservation for Selected Water Conservation Techniques for Water User Groups having 2060 Per Capita Water Use Greater than 165 gpcd

Water User	County	Housing Area	Cost per acft	Cost of Water Savings via Additional Water Conservation					
				2010 (dollars)	2020 (dollars)	2030 (dollars)	2040 (dollars)	2050 (dollars)	2060 (dollars)
Nueces County WCID #4	Nueces	Suburban	$342	$0	$0	$19,183	$46,189	$89,333	$131,206
County-Other	Duval	Rural	$323	$1,856	$4,336	$6,746	$8,792	$14,096	$20,204
County-Other	McMullen	Rural	$323	$208	$564	$1,085	$1,704	$2,209	$3,255
Three Rivers	Live Oak	Rural	$323	$815	$2,666	$4,425	$5,938	$8,650	$11,075
George West	Live Oak	Rural	$323	$1,497	$4,632	$7,974	$10,707	$14,510	$18,447
Orange Grove	Jim Wells	Rural	$323	$830	$2,461	$4,385	$5,974	$9,088	$12,114
Alice	Jim Wells	Rural	$323	$16,214	$42,833	$70,811	$98,923	$141,513	$189,080
Premont	Jim Wells	Rural	$323	$2,911	$7,078	$11,675	$15,955	$22,645	$29,830
Falfurrias	Brooks	Rural	$323	$216	$12,179	$30,550	$50,480	$73,770	$99,910
Port Aransas	Nueces	Suburban	$342	$9,681	$39,430	$81,488	$138,823	$210,465	$288,337
	Total			**$34,227**	**$116,179**	**$238,321**	**$383,484**	**$586,279**	**$803,457**

4C.1.6 Evaluation Summary

An evaluation summary of this water management option is provided in Table 4C.1-8.

Table 4C.1-8.
Evaluation Summary of Municipal Water Conservation

Impact Category	***Comment(s)***
a. Water Supply 1 Quantity 2. Reliability	 1. Firm Yield: 2,415 per acft/yr 2. Cost: Ranges from $69 to $1,248 per acft water saved (based on BMP selected.)
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. Some impact due to decreased return flows, which could be offset by possible positive impact resulting from higher reservoir levels. 2. Some impact due to decreased return flows, which could be offset by possible positive impact resulting from higher reservoir levels. 3. Some impact due to decreased return flows, which could be offset by possible positive impact resulting from higher reservoir levels. 4. Some impact due to decreased return flows, which could be offset by possible positive impact resulting from higher reservoir levels. 5. None. 6. No cultural resources affected. 7. None or low impact.
c. Impacts to State water resources	• No apparent negative impacts on water resources
d. Threats to agriculture and natural resources in region	• None
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Standard analyses and methods used
g. Interbasin transfers	• None

Continued on next page.

Table 4C.1-8 Concluded

h. Third party social and economic impacts from voluntary redistribution of water	• None
i. Efficient use of existing water supplies and regional opportunities	• Improvement over current conditions
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• None

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4C.2 Irrigation Water Conservation (N-2)

4C.2.1 Description of Strategy

Irrigation water use is the use of freshwater that is pumped from aquifers and/or diverted from streams and reservoirs of the planning area and applied directly to grow crops, orchards, and hay and pasture in the study area. Irrigated agriculture accounted for almost 60 percent of approximately 17 million acft of water used in the state in 2000.[1] Approximately 10 million acft of water were used in Texas to grow a variety of crops ranging from food and feed grains to fruits and vegetables to cotton. Of these 10 million acft, groundwater resources provide approximately 80 percent of the water used for irrigation purposes, with surface water supplies accounting for the remaining 20 percent.[2] Although irrigated agriculture accounts for only 30 percent of all harvested cropland acres in Texas, the value of irrigated crops account for nearly 50 percent of the total value of crop production in the State.[3]

In Texas, irrigated acreage development peaked in 1974 with 8.6 million acres of irrigated cropland. In 2000, irrigated acreage had declined statewide by approximately 2.25 million acres, with a corresponding decline in on-farm water use of more than 3.3 million acft, a reduction of 25 percent.[4] There are a number of factors associated with this declining trend, including more acreage being set aside for compliance with federal farm programs, poor economic conditions in the agricultural sector, a decline in the number and size of farms, technological advancements in crop production, advancement and implementation of more water efficient irrigation systems, and better irrigation management practices.

Irrigation water is supplied by groundwater and surface water and is typically applied to land by: (1) flowing or flooding water down the furrows; and (2) with the use of sprinklers. When groundwater is used, irrigation wells are usually located within the fields to be irrigated. For surface water supplies, typically water is diverted from the source and conveyed by canals and pipelines to the fields. In both the use of groundwater and surface water, the conservation objective is to reduce the quantity of water that is lost to deep percolation and evaporation between the originating points (wells in the case of groundwater, and stream diversion points in the case of surface water), and the irrigated crops in the fields. Thus, the focus is upon

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[1] Texas Water Development Board (TWDB) database, 2004.
[2] TWDB, "Surveys of Irrigation in Texas," Report 347, August 2001.
[3] 2002 Census of Agriculture.
[4] TWDB, Op. Cit., August 2001.

investments in irrigation application equipment, instruments, and conveyance facility improvements (canal lining and pipelines) to reduce seepage losses, deep percolation, and evaporation of water between the originating points of the water and the destination locations within the irrigated fields, and management of the irrigation processes to improve efficiencies of irrigation water use and reduce the quantities of water needed to accomplish irrigation.

Although the statewide trend in irrigated acreage is downward, irrigated acreage in the Coastal Bend Region does not reflect this trend. Crops grown on irrigated acres in the Coastal Bend Region included cotton, grain sorghum, corn, forage crops, peanuts, pecans, hay-pasture, Irish potatoes, vegetables, and other crops. Data collected for the Region by the TWDB in 1994 indicates that irrigated acreage totaled 10,628 acres. However, 2000 data indicates that irrigated acreage totaled about 25,810 acres, with over 60 percent of the acreage planted for cotton, corn, and hay-pasture.[5] Table 4C.2-1 summarizes the variety of crops grown in the Coastal Bend Region and number of irrigated crops for each county in 2000.

In 1994, the irrigators in the Coastal Bend Region used 10,588 acft of water, of which nearly 90 percent was from groundwater sources. In 2000, the TWDB estimated that the irrigators used 21,971 acft. Due to increased water application efficiencies, the irrigation use rate decreased from 1.00 acft/acre in 1994 to 0.85 acft/acre in 2000.

In the Coastal Bend Region, 10 of the 11 counties (except Nueces County) received a majority of their supply, in many cases full water supply, from groundwater sources. Nueces County irrigators receive most of their water supply from run-of-river water rights from the Nueces River, with water rights exceeding projected water demands.

The TWDB irrigation water demand projections for the Coastal Bend Region show significant decreases in irrigation usage in the future. For example, the TWDB estimate of irrigation water use is projected to decline to 17,077 acft by 2030 and 13,365 acft by 2060, representing a decrease of approximately 61 percent from 2000. Furthermore, each county has projected decreases in water demand over time. The county-wide decline in water use is likely due to expected reductions in irrigated land in the future, however this would imply a reversal of the trend observed in reported irrigated acreage from 1994 to 2000.

In the Coastal Bend Region, Live Oak County is projected to have irrigation needs (shortages) during the 2000 to 2060 planning period, as shown in Table 4C.2-2. Live Oak

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[5] Ibid.

Table 4C.2-1.
Irrigated Acres by Crop (2000)
Coastal Bend Region

County	Cotton	Grain Sorghum	Corn	Forage Crops	Peanuts	Pecans	Other Orchard	Hay – Pasture	Irish Potatoes	Vegetables (deep)	All other crops	Total
Aransas	0	0	0	0	0	0	0	0	0	0	0	0
Bee	1,070	1,480	575	0	0	0	0	608	0	0	62	3,795
Brooks	0	0	0	0	0	20	0	0	0	0	0	20
Duval	0	152	682	1,002	250	0	0	154	655	2, 760	200	5,855
Jim Wells	73	0	80	458	0	0	93	2, 382	135	713	0	3,934
Kenedy	0	0	0	160	0	0	0	0	0	0	0	160
Kleberg	0	0	0	0	0	0	0	428	0	168	0	596
Live Oak	240	240	0	0	0	0	14	1, 586	0	4	25	2,109
McMullen	0	0	0	0	0	0	0	0	0	0	0	0
Nueces	470	40	285	0	0	0	305	710	0	0	0	1,810
San Patricio	3,860	735	2,378	0	0	0	0	120	0	0	438	7,531
Total	**5,713**	**2,647**	**4,000**	**1,620**	**250**	**20**	**412**	**5, 988**	**790**	**3, 645**	**725**	**25,810**
Percent	**22.1**	**10.3**	**15.5**	**6.3**	**1.0**	**0.1**	**1.6**	**23.2**	**3.1**	**14.1**	**2.8**	**100**

Source: TWDB database, 2002. Provided to TWDB by NRCS.

County uses both surface water and groundwater supplies to meet water demands. The shortagedeclines over time from 627 acft in 2010 to 373 acft in 2060. Live Oak County irrigation water supply was based on TWDB water use data for 2000;[6] consisting of 75 percent groundwater and 25 percent surface water. This ratio was maintained through 2060, according to the groundwater supply procedure presented in Section 3. The City of Corpus Christi has irrigation permits in Live Oak County with firm yield of 200 acft.[7] The predominant crop in Live Oak County is hay-pasture; constituting 75 percent of the irrigated acres (Table 4C.2-1).

Table 4C.2-2.
Projected Water Demands, Supplies, and Water Needs (Shortages) for Irrigation Users Live Oak County

	Water Projections						
	2000 (acft)	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
Irrigation Demand	3,539	3,289	3,056	2,840	2,639	2,451	2,277
Irrigation Existing Supply							
Groundwater	2,649	2,462	2,287	2,126	1,975	1,835	1,704
Surface water	200	200	200	200	200	200	200
Total Irrigation Supply	2,849	2,662	2,487	2,326	2,175	2,035	1,904
Shortage	(690)	(627)	(569)	(514)	(464)	(416)	(373)

TWDB Rules for regional water planning require Regional Water Planning Groups to consider water conservation and drought management measures for each water user group with a need (projected water shortage). In addition, the Rules direct water conservation BMPs, as identified by the Water Conservation Implementation Task Force (Task Force), be considered in the development of the water conservation water management strategy.

4C.2.2 Available Yield

In March 2005, the CBRWPG recommended that counties with projected irrigation needs (shortages) reduce their irrigation water demands by 15 percent by 2060 using BMPs identified

[6] TWDB, Op. Cit., August 2001.
[7] Part of TCEQ Water Right #3214.

by the Task Force. A 15 percent reduction in irrigation water demand by 2060, results in a new demand of 1,935 acft for 2060 and maximum savings of 342 acft as shown in Table 4C.2-3.

Table 4C.2-3.
Projected Water Demands and Needs (Shortages) for Irrigation Users after Recommended Irrigation Water Conservation Live Oak County

	Water Projections					
	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
New Demand	3,272	3,004	2,737	2,470	2,203	1,935
Expected Savings	17	52	103	169	248	342
New Shortage	(610)	(517)	(411)	(295)	(168)	(31)
Shortage Reduction	3%	9%	20%	36%	60%	92%

The Task Force report lists the following irrigation BMPs that may be used to achieve the recommended water savings:[8]

1. Irrigation Scheduling;
2. Volumetric Measurement of Irrigation Water Use;
3. Crop Residue Management and Conservation Tillage;
4. On-farm Irrigation audit;
5. Furrow Dikes;
6. Land Leveling;
7. Contour Farming;
8. Conservation of Supplemental Irrigated Farmland to Dry-Land Farmland;
9. Brush Control/Management;
10. Lining of On-Farm Irrigation ditches;
11. Replacement of On-/farm Irrigation Ditches with Pipelines;
12. Low Pressure Center Pivot Sprinkler Irrigation Systems;
13. Drip/Micro-Irrigation System;
14. Gated and Flexible Pipe for Field Water Distribution Systems;
15. Surge Flow Irrigation for Field Water Distribution Systems;
16. Linear Move Sprinkler Irrigation Systems;
17. Lining of District Irrigation Canals;

[8] Water Conservation Implementation Task Force, Report to the 79th Legislature, Texas Water Development Board, Special Report, Austin, Texas, November 2004.

18. Replacement of District Irrigation canals and Lateral canals with Pipelines;
19. Tailwater Recovery and Use System; and
20. Nursery Production Systems.

The Task Force report describes the above BMP methods and how they reduce irrigation water use, however information regarding specific water savings and costs to install irrigation water saving systems is generally unavailable. The Task Force report does include water savings and costs for three irrigation water conservation BMPs: (1) furrow dikes; (2) low-pressure sprinklers (LESA); and (3) low-energy precision application systems (LEPA). These major irrigation water conservation techniques applicable in the Coastal Bend Region are described briefly below.

Furrow dikes are small mounds of soil mechanically installed a few feet apart in the furrow. These mounds of soil create small reservoirs that capture precipitation and hold it until it soaks into the soil instead of running down the furrow and out the end of the field. This practice can conserve (capture) as much as 100 percent of rainfall runoff, and furrow dikes are used to prevent irrigation runoff under sprinkler systems. This maintains high irrigation uniformity and increases irrigation application efficiencies. Capturing and holding precipitation that would have drained from the fields replaces required irrigation water on irrigated fields; and furrow dikes have been demonstrated to be useful management tools on both irrigated and non-irrigated cropland. Use of furrow dikes can have water savings up to 12 percent gross quantity of water applied using sprinkler irrigation. According to TWDB estimates of acreage equipped with sprinkler irrigation systems, if Live Oak County irrigators install furrow dikes, the expected water savings could be up to 422 acft/yr, assuming 100 percent participation of irrigated lands with sprinkler systems. Furrow dikes require special tillage equipment and costs $5 to $30 per acre to install.

Low-pressure sprinklers (LESA) with 75 percent application efficiency improve irrigation application efficiency in comparison to conventional furrow irrigation by reducing water requirements per acre by 15 percent. Currently, the application efficiency of sprinkler systems in Live Oak County is estimated at 60 percent.[9] Low-pressure sprinklers spray water into the atmosphere above the crops as the sprinkler systems are moved across the fields. In Live Oak County, conversion to LESA systems would save about 0.34 acft/acre converted and result in a total savings of 704 acft/yr.

[9] TWDB, Op. Cit., August 2001.

LEPA systems involve a sprinkler system that has been modified to discharge water directly into furrows at low pressure, thus reducing evaporation losses. When used in conjunction with furrow dikes, which hold both precipitation and sprinkler applied water behind small mounds of earth within the furrows, LEPA systems can accomplish the irrigation objective with less water than is required for the furrow irrigation and pressurized sprinkler methods. If LEPA is used with furrow dike systems the expected water savings would be approximately 0.62 acft/acre (a total reduction in water use of approximately 37 percent). Use of LEPA and furrow dikes allows irrigation farmers to produce equivalent yields per acre at lower energy and labor costs of irrigation. It has been demonstrated that LEPA systems improve production and profitability of irrigation farming. The barriers to installation are high capital costs; with no assurance (at the present time) that the water saved would be available to the irrigation farmer who incurred the costs.

A comparison of irrigation rates for furrow dikes, LESA, and LEPA systems to irrigation rates before irrigation water conservation are shown in Table 4C.2-4.

Table 4C.2-4.
Region G Irrigated Acreages and Effects of Water Conservation on Irrigation Water Use and Application Rates
Live Oak County

	Acreage Irrigated with Sprinklers (2000)	Irrigation Water Use (acft)	Irrigation Rate (acft/acre)	Estimated water savings (acft)
Before Conservation				
	2,091	3,518	1.68	—
With Conservation				
Furrow Dikes[1]	2,091	3,096	1.48	422
LESA[2]	2,091	2,814	1.35	704
LEPA[3]	2,091	2,638	1.26	879

[1] 12% savings of water applied using sprinkler irrigation.
[2] Assumes application efficiency of 75 percent.
[3] Assumes application efficiency of 80 percent.

4C.2.3 Environmental Issues

The irrigation water conservation methods described above have been developed and tested through public and private sector research, and have been adopted and applied within the Region. Hundreds of LEPA systems have been installed, and are in operation today, and experience has shown that there are not any significant environmental issues associated with this water management strategy. For example, this method improves water use efficiency without making changes to wildlife habitat. This method of application, when coupled with furrow dikes reduces runoff of both applied irrigation water and rainfall. The results are reduced transport of sediment and any fertilizers or other chemicals that have been applied to the crops. Thus, the proposed conservation practices do not have potential adverse effects, and in fact have potentially beneficial environmental effects.

4C.2.4 Engineering and Costing

The CBRPG recommended irrigation water conservation strategy for irrigation users results in a potential water savings of 342 acft. This savings can be accomplished by using any one or a combination of three strategies: furrow diking, LESA or LEPA. Furrow dikes can save up to 422 acft at an average unit cost of $173 per acft (Table 4C.2-5). Installing LESA or LEPA systems would incur a greater capital cost, and therefore higher annual costs, however both achieve a substantially higher water savings potential and therefore have more economical unit cost ($/acft) when compared to furrow dikes. The maximum water conservation potential can be realized by using the LEPA system, as shown in Table 4C.2-4. The capital cost to install LEPA irrigation is approximately $400 per acre.[8] It is estimated that it would take a total investment of $836,400 to equip the estimated 2,091 irrigated acres currently served by sprinkler systems in Live Oak County. This investment, at an annual cost of $60,764 (30 years at 6 percent), would save an estimated 879 acft/yr at an average unit cost of $69 per acft of water saved.

Each of the three irrigation water conservation strategies described (furrow dikes, LESA, and LEPA) have the potential to increase water savings beyond the recommendations of the CBRWPG. For example, installing LEPA or LESA for acreage currently equipped with sprinkler systems could potentially eliminate all shortages. The largest shortage for Live Oak County is 627 acft in 2010. If LEPA was installed on approximately 1,490 acres of 2,091 acres currently irrigated with sprinkler systems, the shortage would be eliminated. In 2060, only 890 acres would need to be equipped with LEPA to eliminate the shortage.

Table 4C.2-5.
Potential Water Savings and Costs
(Total Project, Annual Average, and Unit Costs)
to Implement Irrigation Water Conservation BMPs
Live Oak County

	Maximum Desired Water Savings (acft)	Maximum Amount Saved (acft)	Total Project Cost (average)	Average Annual Cost	Average Cost per acft
Furrow Dikes	342	422	—	$36,593	$173
LESA (90% efficiency)	342	704	$836,400	$60,764	$86
LEPA (95% efficiency)	342	879	$836,400	$60,764	$69

It may not be economically feasible for some agricultural producers to pay for additional water supplies to meet projected irrigation water needs (shortages), even if such supplies were available. For example, in 2004, for irrigated cotton, the estimated income remaining after other production expenses had been paid was about $158 per acre. For cotton farming, although limited in the Coastal Bend Region, it may be practical to install furrow, LESA, or LEPA systems. For other crops, if the cost of water exceeds the estimated income, then it would not be practical to pay for additional water.

4C.2.5 Implementation Issues

The rate of adoption of efficient water-using practices is dependent upon public knowledge of the benefits, information about how to implement water conservation measures, and financing. There is widespread public support for irrigation water conservation and it is being implemented at a steady pace, and as water markets for conserved water expand, this practice will likely reach its maximum potential. A major barrier to implementation of water conservation is financing. The TWDB has irrigation conservation programs that may provide funding to irrigators to implement irrigation BMPs that increase water use efficiency. Future planning efforts should consider the use of detailed studies to fully determine the maximum potential benefits of additional irrigation conservation.

4C.2.6 Evaluation Summary

An evaluation summary of this water management option is provided in Table 4C.2-6.

Table 4C.2-6.
Evaluation Summary of Irrigation Water Conservation

Impact Category	Comment(s)
a. Water Supply	
1. Quantity	1. Firm yield: Variable according to BMP selected. Ranges up to 879 acft, depending on BMP and extent of participation.
2. Reliability	2. Highly reliable quantity.
3. Cost of Treated Water	3. Cost: Ranges from $69 to $173 per acft water saved based on BMP selected.
b. Environmental factors	
1. Instream flows	1. None or low impact.
2. Bay and Estuary Inflows	2. None or low impact..
3. Wildlife Habitat	3. No apparent negative impact.
4. Wetlands	4. None.
5. Threatened and Endangered Species	5. None.
6. Cultural Resources	6. No cultural resources affected.
7. Water Quality	7. None or low impact.
a. dissolved solids	
b. salinity	
c. bacteria	
d. chlorides	
e. bromide	
f. sulfate	
g. uranium	
h. arsenic	
i. other water quality constituents	
c. Impacts to State water resources	• No apparent negative impacts on water resources.
d. Threats to agriculture and natural resources in region	• None.
e. Recreational impacts	• None.
f. Equitable Comparison of Strategies	• Standard analyses and methods used.
g. Interbasin transfers	• None.
h. Third party social and economic impacts from voluntary redistribution of water	• None.
i. Efficient use of existing water supplies and regional opportunities	• Improvement over current conditions by reducing rate of decline of local groundwater levels.
j. Effect on navigation	• None.

4C.3 Manufacturing Water Conservation and Nueces River Water Quality Issues (N-3)

4C.3.1 Description of Strategy

Manufacturing is an integral part of the Texas economy, and for many industries, water plays a key role in the manufacturing process. Some of these processes require direct consumption of water as part of the products; others consume very little water but use a large quantity for cleaning and cooling. In 2000, Nueces and San Patricio Counties accounted for 96.3 percent of the total manufacturing water use in Coastal Bend Region of 54,481 acft. Manufacturing use for the entire planning region is projected to increase to 73,861 acft in 2030 and 88,122 acft by 2060. In 2060, Nueces and San Patricio Counties will account for 97.1 percent of the total manufacturing water use in the region.

In the manufacturing sector, water quality impacts the quantity of water needed for cooling purposes. Cooling water accounts for 60 to 75 percent of the industrial demand in the region.[1] Assuming 60 percent demand, the industrial demand for cooling water in Nueces and San Patricio Counties is expected to grow from about 31,490 acft/yr in 2000 to 51,360 acft/yr in 2060. The quantity of water needed by industry for cooling is substantial and could potentially be reduced by providing water with lower mineral content. High levels of dissolved minerals result in an increase in manufacturing water demands, due to accelerated build-up of mineral deposits in industrial cooling facilities. Additional water savings can also be achieved by stabilizing the water quality and thereby minimizing the variation in water quality. Manufacturing water conservation would benefit the entire Coastal Bend Region by preventing the need to obtain, treat, and distribute the amount of water that is conserved. Alternatively, the amount of water that is conserved could be used for other beneficial purposes.

Previous studies by the U.S. Geological Survey (USGS) and others have indicated a significant increase in the concentration of dissolved minerals in the Lower Nueces River between Mathis and the Calallen Saltwater Barrier Dam. Figure 4C.3-1 shows that chloride concentrations at the Calallen Pool on the average are 2.5 times the level of chlorides in water released from Lake Corpus Christi. Figure 4C.3-1 also shows the change in chloride concentrations occurring between Lake Corpus Christi (Hwy 359 site) and the Calallen Dam for five previous studies. The results of these studies indicate that on the average about 60 percent of

[1] City of Corpus Christi, "Effluent Reuse Study," February 2002.

the increase in chlorides occurs upstream of the Calallen Pool and about 40 percent of the increase within the pool. Despite similar conclusions from the various previous studies, the source(s) of this increase in mineral concentrations has not previously been conclusively established. Potential sources of minerals to the Calallen Pool include saltwater intrusion, groundwater seepage, and upstream sources of contamination from abandoned wells in adjacent oil fields and gravel washing operations. During the course of this study, a Nueces River sampling program was initiated to confirm the increase in mineral concentrations and to determine the source of dissolved minerals within the Calallen Pool.

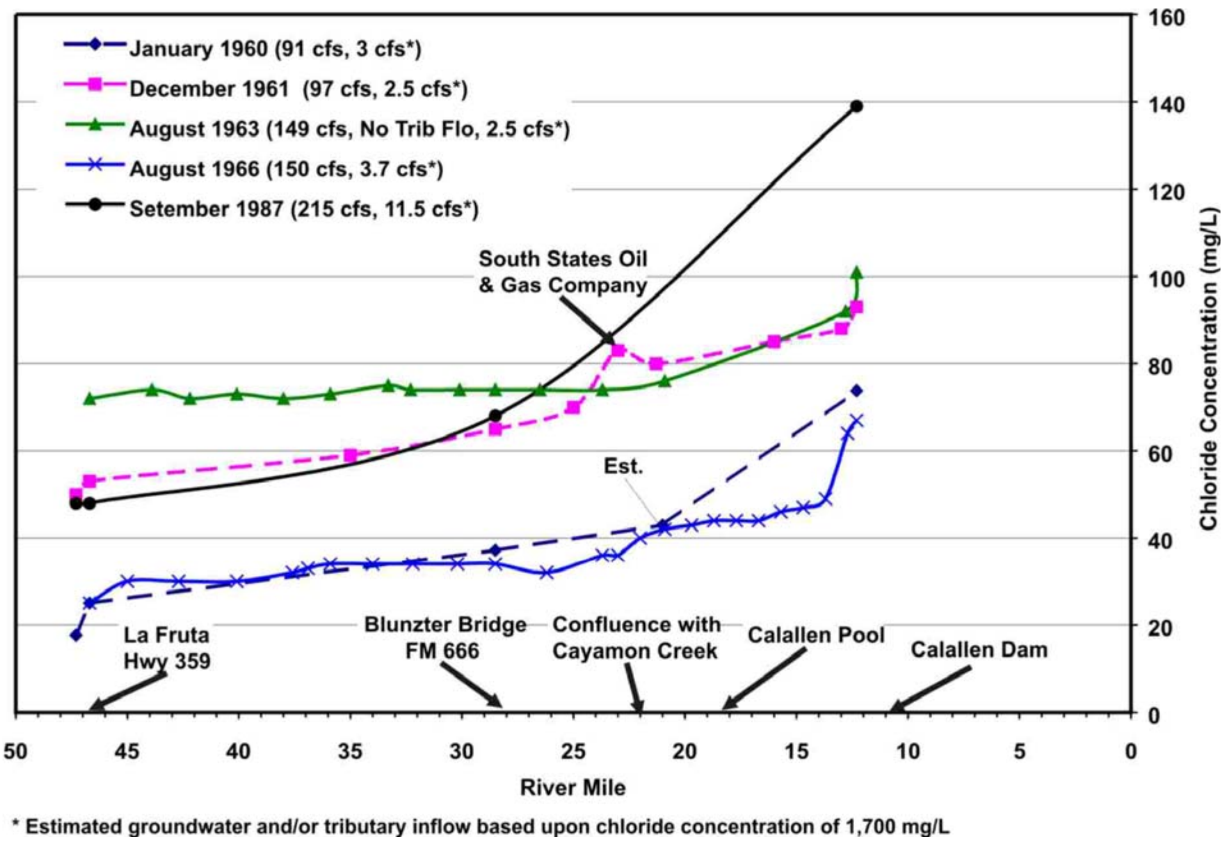


Figure 4C.3-1. Summary of Historical Data — Chloride Content of the Lower Nueces River, Segment 2102

During drought conditions, Choke Canyon Reservoir water levels are lower, which results in higher concentrations of total dissolved solids (Figure 4C.3-2). By operating the CCR/LCC System with safe yield supply conditions and keeping a reserve quantity of water in storage in Lake Corpus Christi for blending purposes, total dissolved solids concentrations can be better managed.

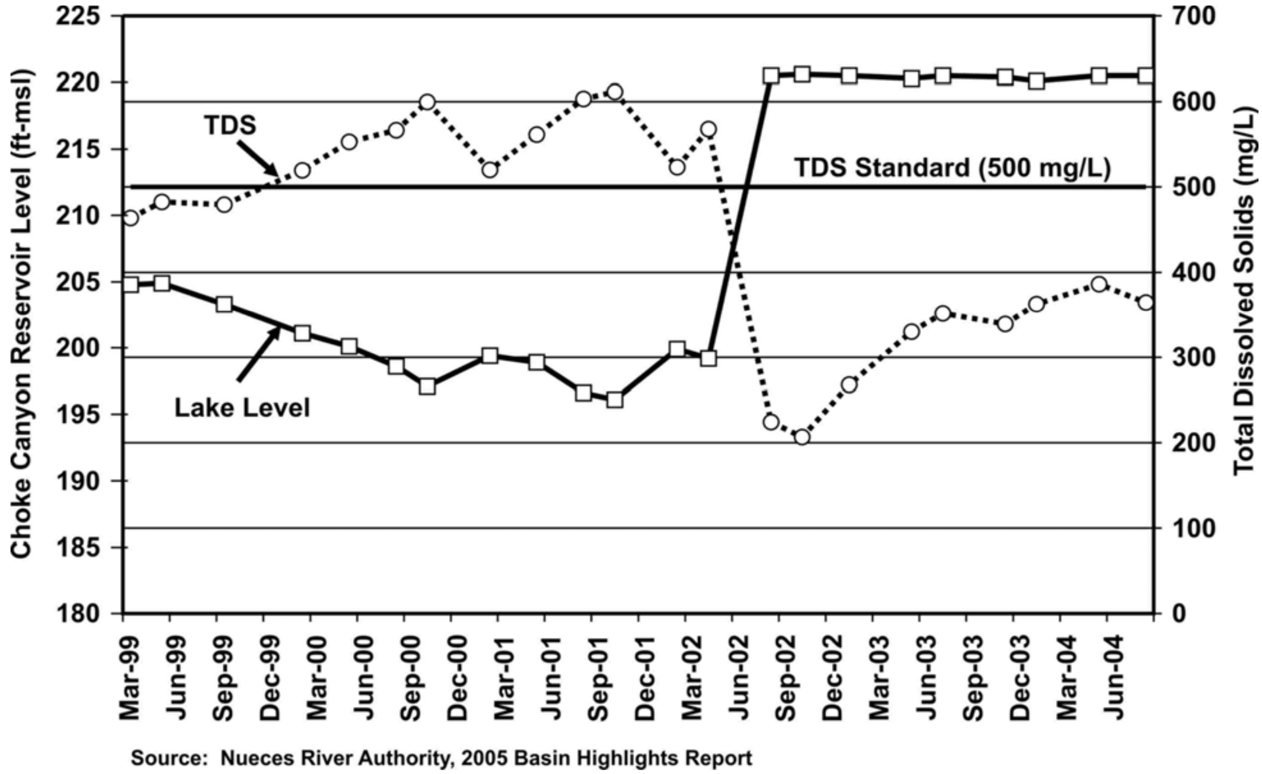


Figure 4C.3-2. Comparison of Total Dissolved Solids and Choke Canyon Reservoir Levels

4C.3.1.1 Surface Water – Groundwater Sampling

Sampling trips were conducted once a month through the calendar year beginning in August 1999 and are continuing through 2000 to monitor surface water pH, temperature, dissolved oxygen, and specific conductance. Surface water and groundwater samples were analyzed for dissolved constituents including calcium, magnesium, sodium, potassium, sulfate, chloride, bromide, total dissolved solids (TDS) and alkalinity (as calcium carbonate). Sampling locations are described in Table 4C.3-1 and shown in Figures 4C.3-3 and 4C.3-4.

The most compelling observations to date of the stream monitoring and lab analysis are summarized in Figures 4C.3-5, 4C.3-6, and 4C.3-7. Three sites are represented to demonstrate the range in constituent concentration along the course of the river and at various depths within the channel at each site. The maximum, median and minimum surface water and composite groundwater concentration ranges are plotted for chloride, hardness, TDS, sulfate, bromide and dissolved oxygen at each site. Median values are plotted instead of mean values to prevent the maximum values from skewing the data.

Table 4C.3-1.
Sample Sites for Nueces River Study

Sample Site	*Location Description*	*River Mile*	*Hydrolab Monitoring*	*Water Samples*
Surface Water				
1	Nueces River just Downstream from Calallen Dam	10.9	S	G
2	Nueces River just above Calallen Dam	11	D_H	D_P
3	Nueces River at San Patricio MWD Intake	11.1	D_H	—
4	Nueces River 200 yd. upstream from San Patricio Intake	11.2	D_H	D_P
5	Nueces River 100 yd. Downstream from Stevens Intake	12.4	D_H	D_P
6	Nueces River 100 yd. Upstream from Stevens Intake	12.6	D_H	D_P
7	Nueces River River View	14.5	S	G
Groundwater				
SP1	Adjacent to San Patricio Intake, 410 ft. from Bank	—	—	G
SP2	Adjacent to San Patricio Intake, 130 ft. from Bank	—	—	G
SP3	Adjacent to San Patricio Intake, 5 ft. from Bank	—	—	G
HB1	Hazel Bazemore Park, 1000 ft from Bank, Adjacent to Western Fence line	—	—	G
HB2	Hazel Bazemore Park Wetland area, Near Park Road	—	—	G

Key: S-single reading of parameters (temperature, specific conductance, pH, dissolved oxygen, salinity, chloride); D_H-parameter readings taken at top, middle and bottom depths within center of channel; G- single grab sample; D_P-water samples taken at middle and bottom depths within channel (Figure 4C.3-3 and Figure 4C.3-4).

Figure 4C.3-5 shows the range of chloride and bromide concentrations at the River View sampling site, just downstream of the O.N. Stevens Intake (Site 5) and just upstream of the Calallen Dam. The median chloride concentration range is from 95 to 117 mg/L along the river channel. The most significant concentration increase in chlorides (and dissolved minerals in general) occurs, however, with increasing depth within the channel. This is most apparent at Site 5, just downstream of the O.N. Stevens Intake where the maximum chloride concentration ranges from 311.6 to 3,230 mg/L.

Bromide is a precursor to disinfection byproducts and is present in elevated concentrations in the Calallen Pool during low flow conditions. Figure 4C.3-5 presents the range of bromide within the pool. The median bromide concentration at the bottom of the river is

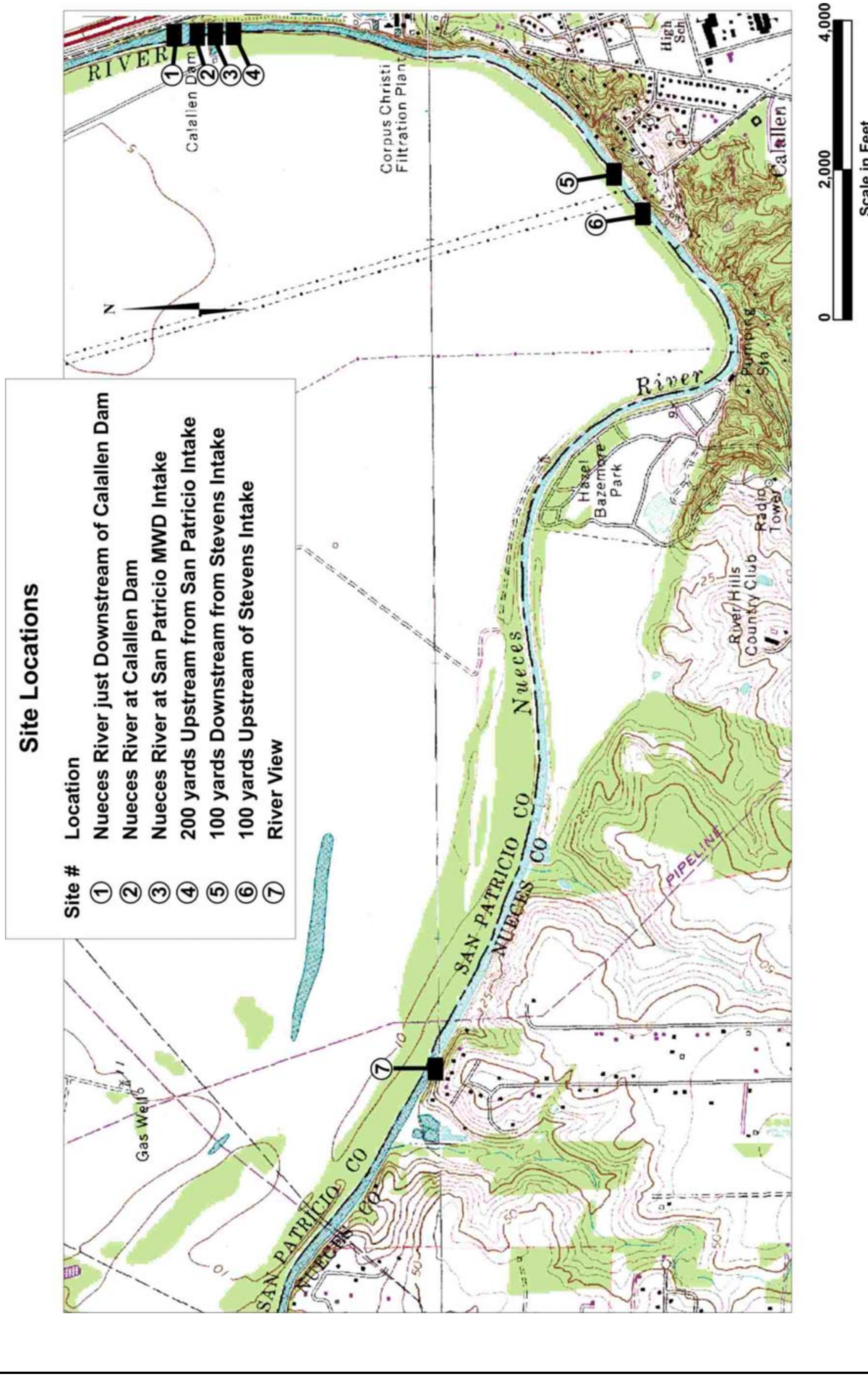


Figure 4C.3-3. Nueces River Sampling Site Locations

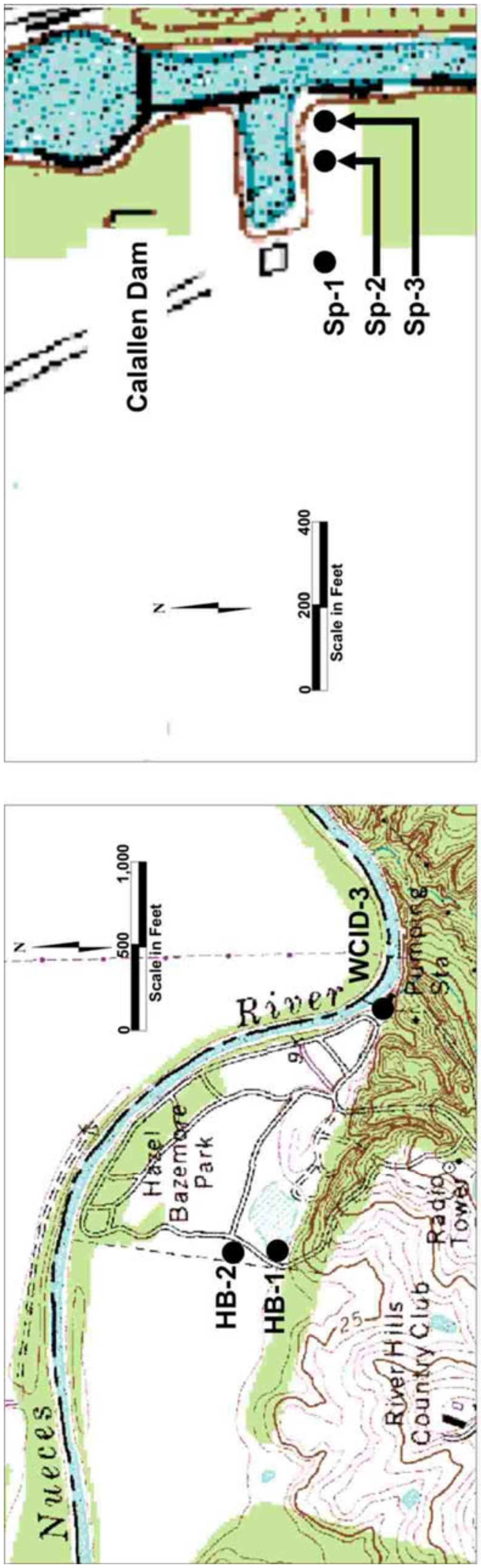
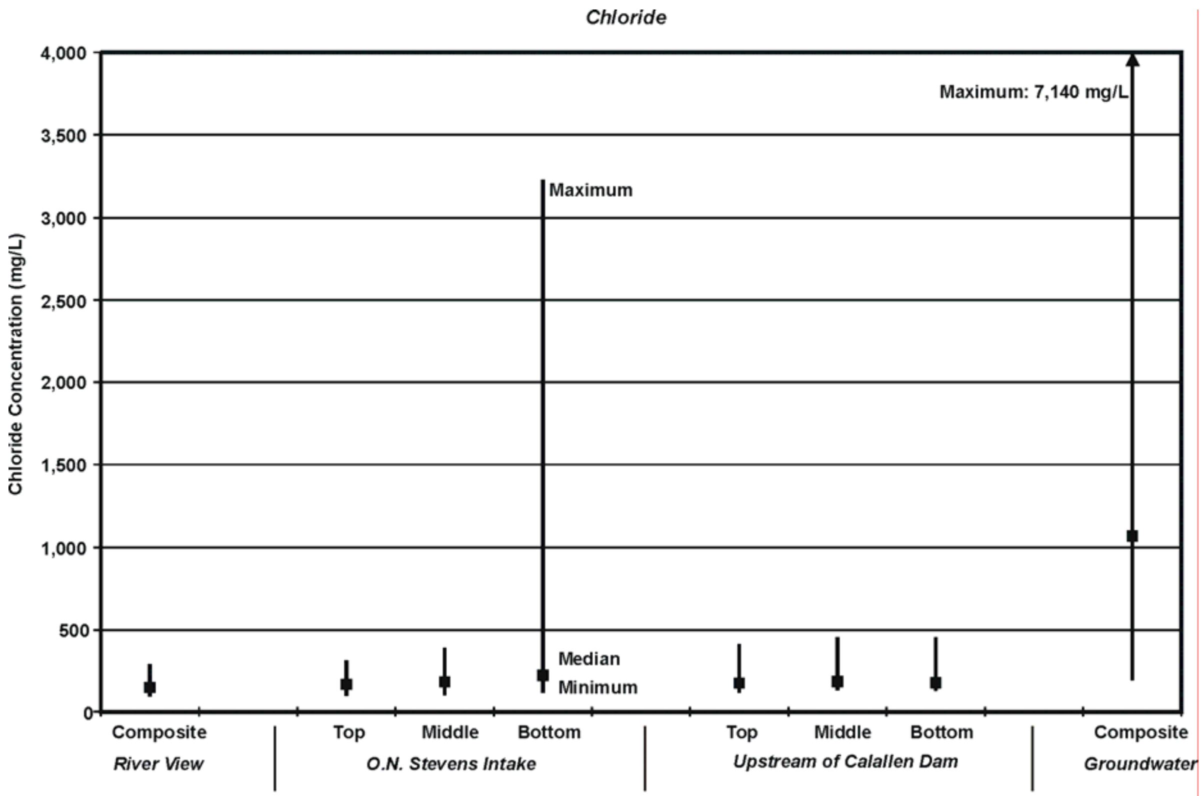


Figure 4C.3-4. Groundwater Sampling Sites for the Nueces River Dissolved Minerals Study



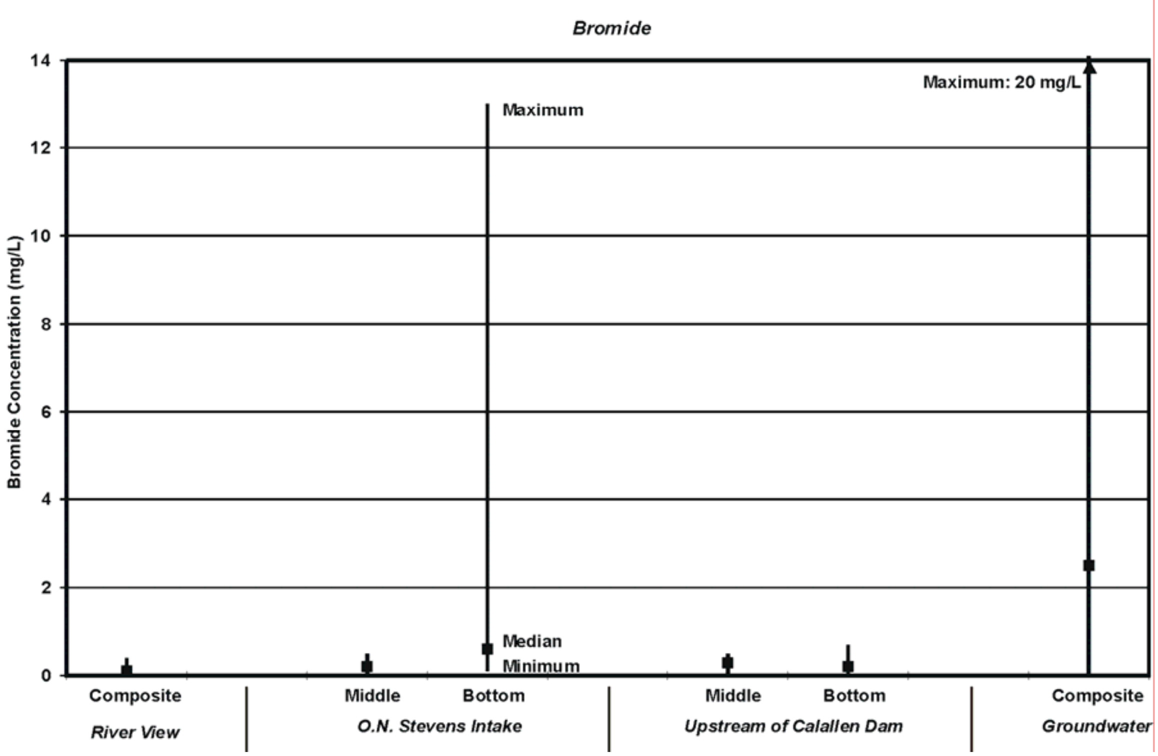
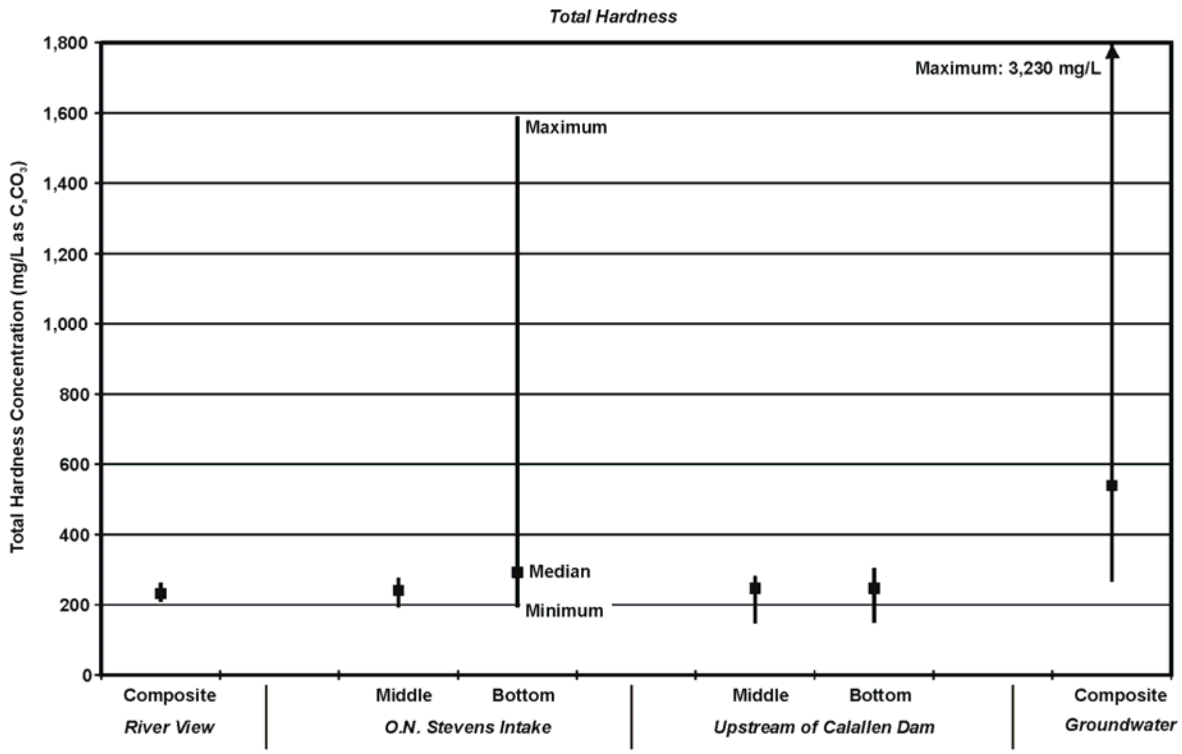


Figure 4C.3-5. Chloride and Bromide Concentrations from the Nueces River Dissolved Minerals Study



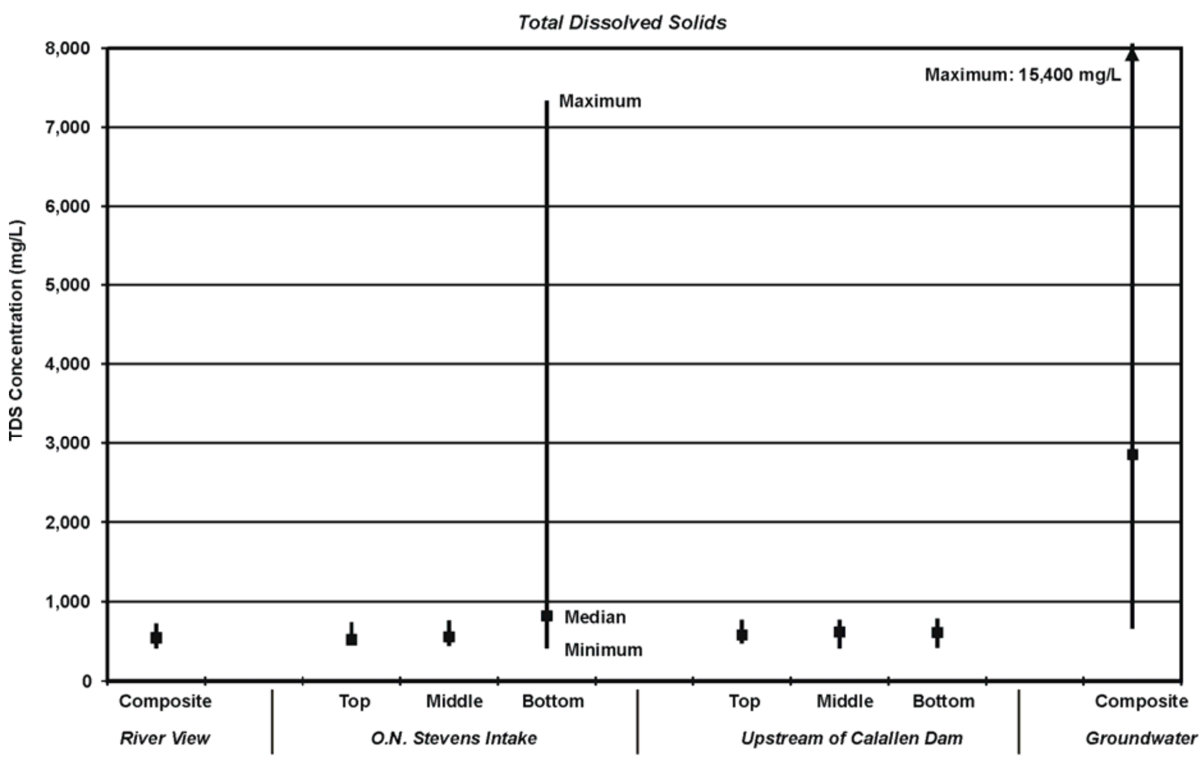
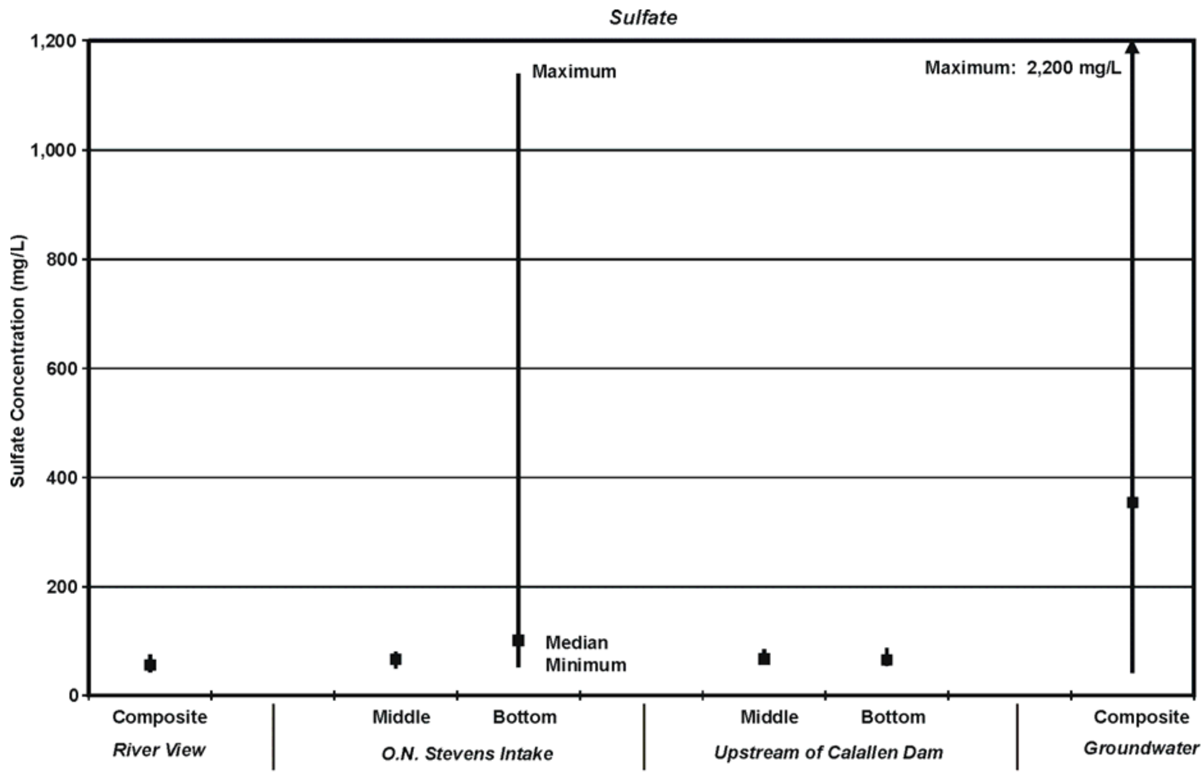


Figure 4C.3-6. Total Hardness and Total Dissolved Solids from the Nueces River Dissolved Minerals Study



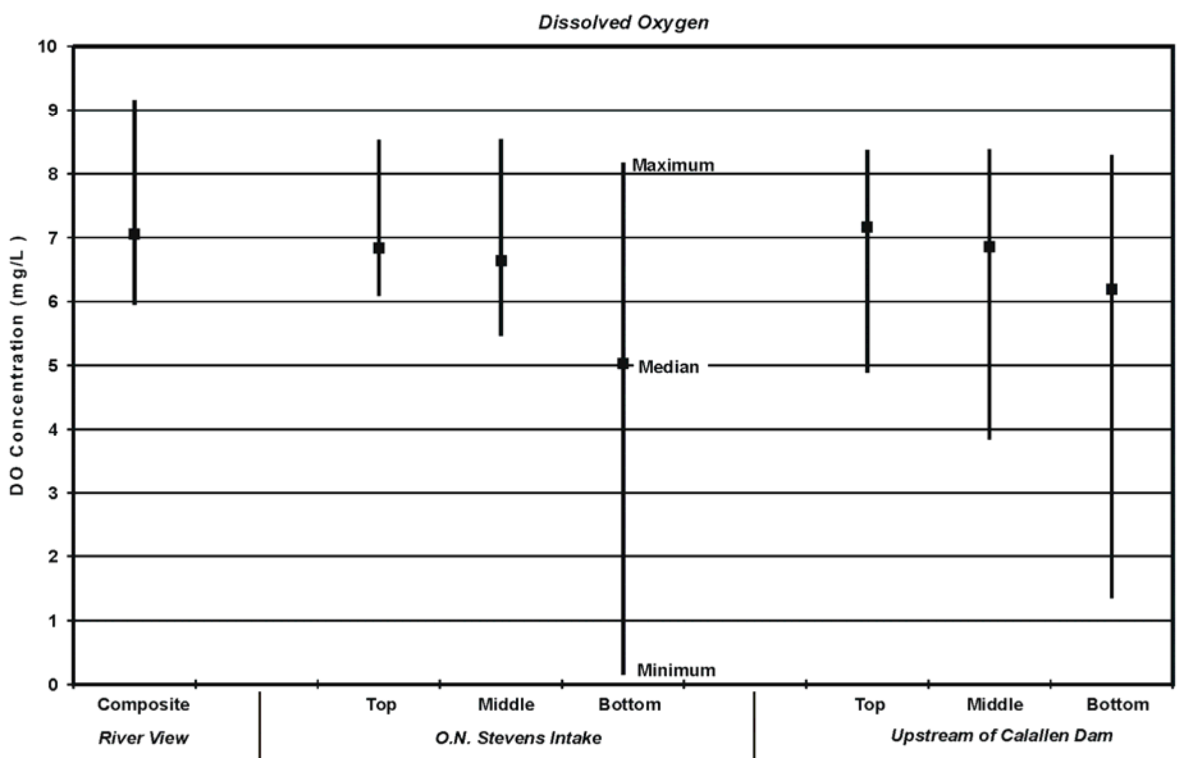


Figure 4C.3.7. Sulfate and Dissolved Oxygen Concentrations from the Nueces River Dissolved Minerals Study

0.6 mg/L and was measured as high as 13 mg/L. These values are in contrast to the median bromide concentration at River View of 0.1 mg/L.

Figure 4C.3-6 shows the concentration range of total hardness and total dissolved solids. The concentration of total hardness at River View was measured within a very narrow range compared to values downstream at the O.N. Stevens Intake and at the Calallen Dam. The median total dissolved solids concentration at Calallen is 34 percent higher than at River View.

Figure 4C.3-7 represents the concentration ranges of sulfate and dissolved oxygen. The variation in sulfate is very small for all samples except for the samples taken at the bottom of the Stevens intake site. At this site the concentration ranges from 52 to 1,140 mg/L. Dissolved oxygen concentration decreases with depth within the channel. The lowest values of dissolved oxygen were detected at the bottom of the channel at the Stevens intake

The results of the sampling program are included in Appendix I-1. Sampling results to date show stratification within the Calallen Pool, with large mineral concentration increases occurring within the bottom 2 feet near the water intake locations. The stratification of the channel was found to be the most significant when no water was spilling over Calallen Dam and the least detectable during periods of high flow. The largest increase in dissolved mineral concentrations was found 100 yards downstream of the O.N. Stevens intake.

To determine the source of the dissolved minerals, the river segment was evaluated using a geochemical approach to discern different hydrochemical water types for the inflows and outflows of the river segment. A Schoeller diagram (Figure 4C.3-8) plots the major ion concentrations for a composite set of surface water sample values, a groundwater sample taken at Hazel Bazemore Park (Site HB1) and a surface water sample taken from the bottom of the pool at the O.N. Stevens Intake (Site 5). The relative ion concentrations of calcium, magnesium, sodium, chloride, sulfate and bicarbonate (calculated from hardness and alkalinity values) are plotted on a logarithmic scale. The diagram shows that the surface water sample taken at the Stevens intake is geochemically more similar to the groundwater sample taken at Hazel Bazemore Park, than to any of the other surface water samples (including samples taken at the same location, just three feet higher in the water column). This suggests that groundwater intrusion is taking place in the Calallen Pool.

In August 2003, the NRA conducted a surface water and bathymetric study for the Nueces Tidal Segment of the Nueces River (Segment 2101). Surface water samples were

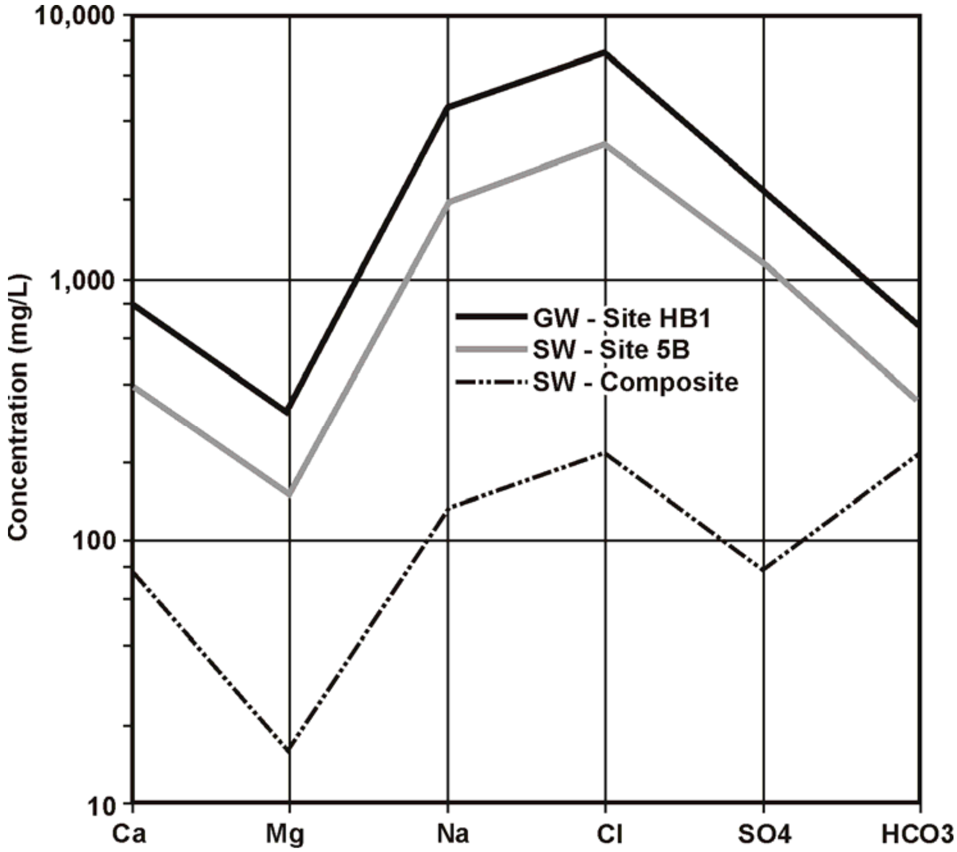


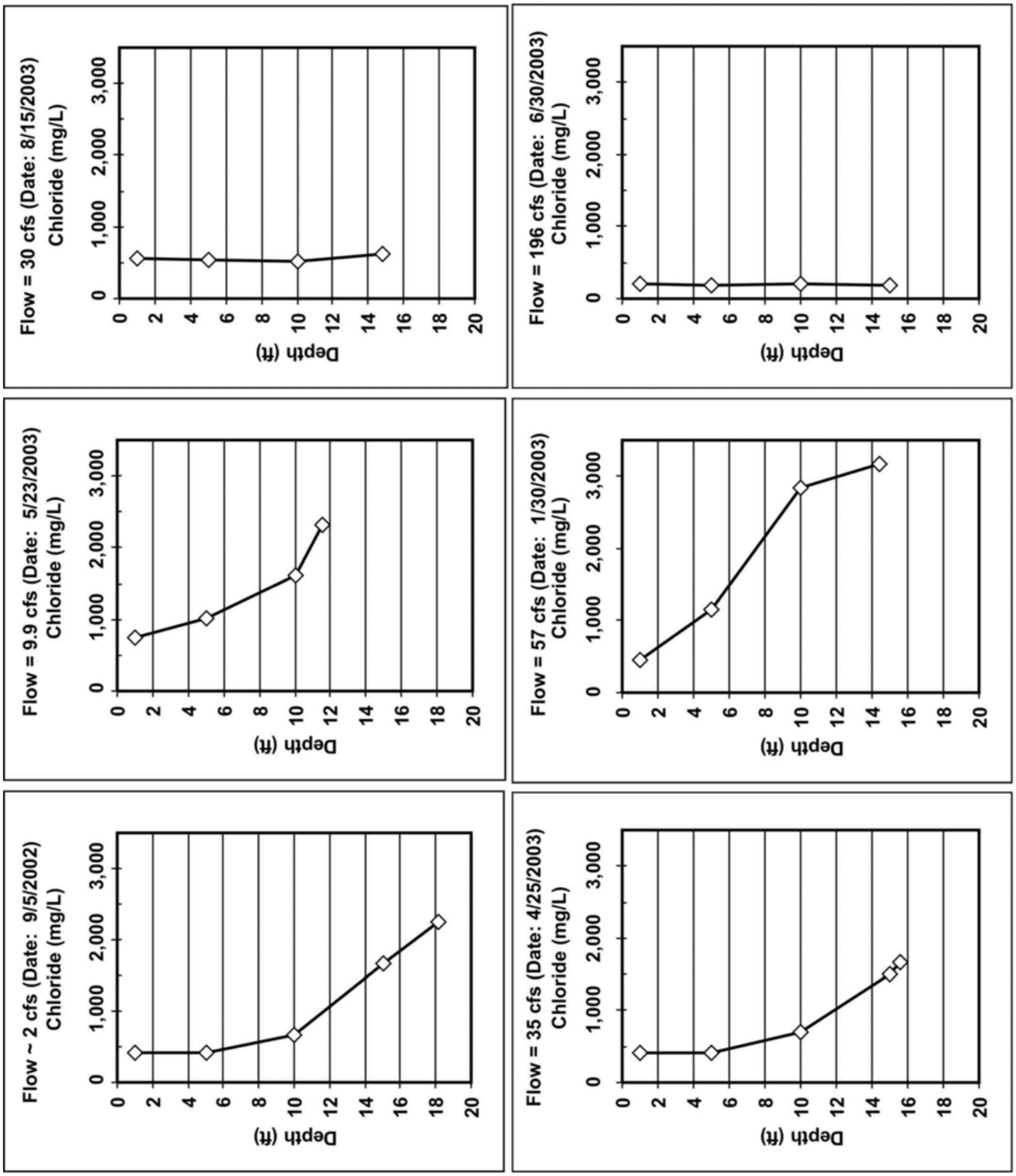
Figure 4C.3-8. Schoeller Diagram of Surface Water and Groundwater Geochemical Analysis

collected periodically from August 2002 to August 2003 at several locations along the segment and monitored at various water depths during various flow conditions to determine stratification of water quality parameters.

The following parameters were measured:

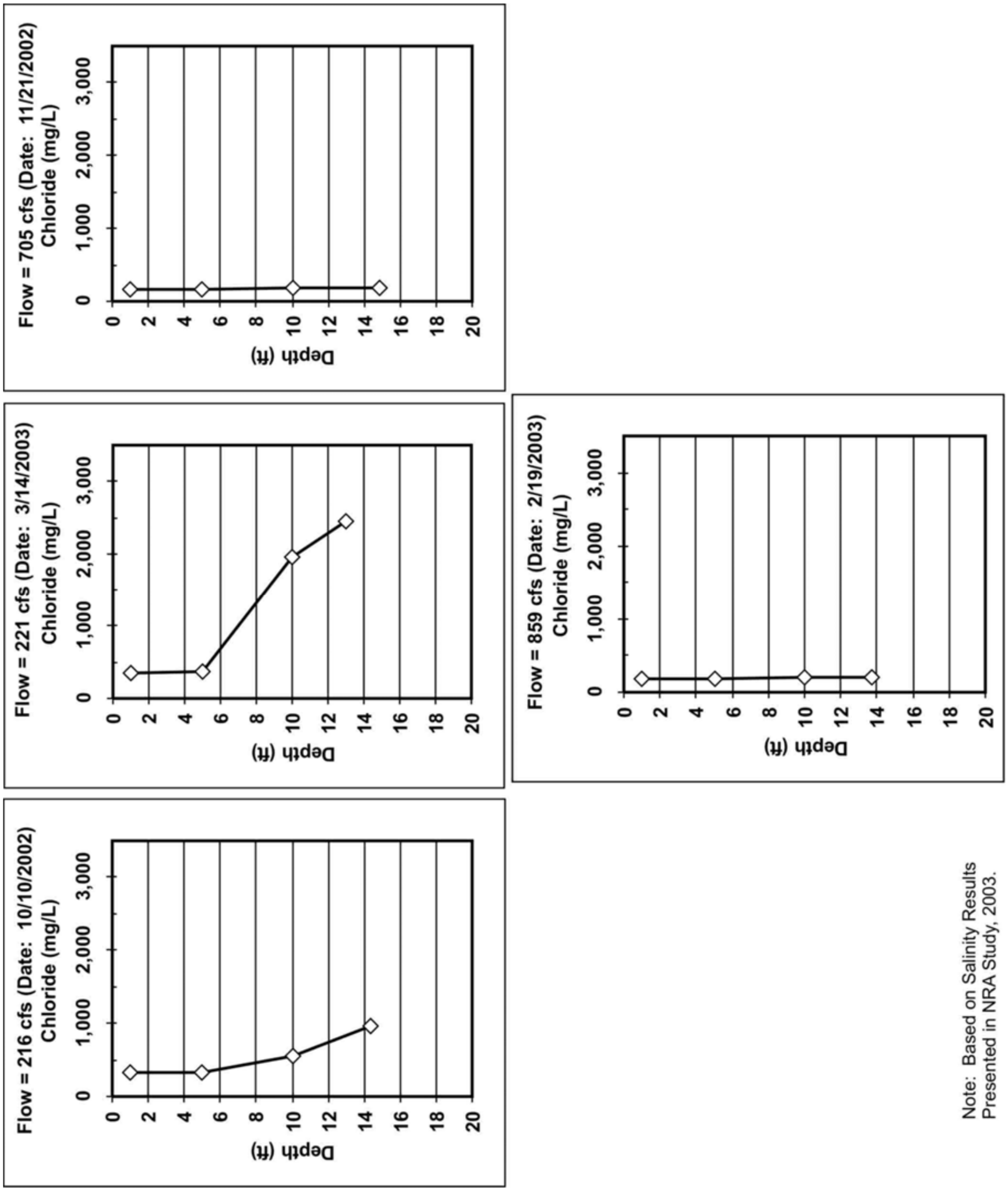
1. Depth;
2. Temperature;
3. Dissolved oxygen;
4. pH;
5. Specific conductance; and
6. Salinity.

Salinity results were used to calculate chloride levels (i.e., salinity (ppt) = chloride (ppt) * 1.80655). The chloride results for various depths and flow conditions for the sample location near Calallen Pool at IH37 is presented in Figure 4C.3-9.



Note: Based on Salinity Results Presented in NRA Study, 2003.

Figure 4C.3-9. Chloride Concentrations near Calallen Pool at IH-37 (Page 1 of 2)



Note: Based on Salinity Results Presented in NRA Study, 2003.

Figure 4C.3-9. Chloride Concentrations near Calallen Pool at IH-37 (Page 2 of 2)

As streamflow rates decreased and during periods of low flow, vertical profiles were high stratified, especially with respect to salinity and dissolved oxygen.[2] Similar trends were apparent for all other parameters to a lesser extent.

4C.3.1.2 Surface Water – Groundwater Interactions

A second phase of this investigation was initiated in an effort to identify the possible sources of elevated levels of dissolved solids in the Nueces River water in addition to the surface water sampling effort just described. This effort included monitor well installation, groundwater and surface water sampling, obtaining and interpreting aerial/satellite imagery of the area between Wesley Seale Dam and Calallen Pool, to identify possible point source contributions (specifically, abandoned oil and gas wells and sand/gravel washing operations), and groundwater intrusion. The results of this study are included in Appendix I-2 of this report.

One of the primary objectives of this second phase was to investigate the potential interaction of groundwater in sediments along the Nueces River with surface water in the Calallen Pool. In order to measure groundwater levels and obtain samples of the groundwater, the study included the installation of several permanent monitoring wells. Seven borings, completed as monitor wells, were drilled at four locations adjacent to the Nueces River. The locations, well designations, and location considerations were as follows: (Note: the locations of these monitoring well sites are shown in Appendix I-2.)

The first Hazel Bazemore Park site (HB-1, HB-2) is located where previous hand augered groundwater samples were collected. (Previous analyses indicated that the ionic ratios in those samples closely matched the ionic ratios found in samples of the more saline, stratified water of concern in the Calallen Pool.) The second site, in Hazel Bazemore Park (HB-3, HB-4), is located near the Nueces County WCID #3 intake and adjacent to a deeper pool of the Nueces River where stratification of water has been observed in previous investigations. The third site, on the SPMWD pump station property (SP-1, SP-2), is located near the Calallen Dam and a raw water intake where there has been noticeably elevated total dissolved solids and chlorides concentrations. The last site, at the City of Corpus Christi Cunningham Plant (CP-1), is adjacent to a deeper pool of the Nueces River close to both the Celanese—Bishop and the Koch Refinery raw water pump stations. (This site is on the opposite side of the Nueces River from the SP-1 and

[2] Nueces River Authority, "A Final Report on the Surface Water Monitoring and Bathymetric Data Collection Study for the Nueces Tidal Special Study," August 2003.

SP-2 sites and will be important for future use in making water level comparisons from each bank and the river surface to establish gaining and losing stream conditions as water releases and other system changes occur.)

On October 27, 2000 the new groundwater wells were sampled. On October 30, 2000, additional samples were collected from the Nueces River. Surface water and groundwater samples were analyzed for dissolved constituents including cations (calcium, magnesium, sodium, and potassium) anions (carbonate, bicarbonate, sulfate, chloride), TDS, alkalinity (as calcium carbonate) and hardness (as calcium carbonate).

The results of the surface and groundwater sampling support the findings of the previous sampling effort. The groundwater sampled in the wells has chloride concentrations in excess of 1,000 ppm and more in the range of 2,000 to 3,000 ppm, except for CP-1 and SP-2. CP-1 is screened in a gravel/sand which appears to be in direct communication with the river. SP-2 is completed almost entirely in clay and goes dry during purging. Analytical results from SP-2 probably more closely represent pore water in the clays than formation water from a productive aquifer system. The chloride concentrations are shown in Figure 4C.3-10.

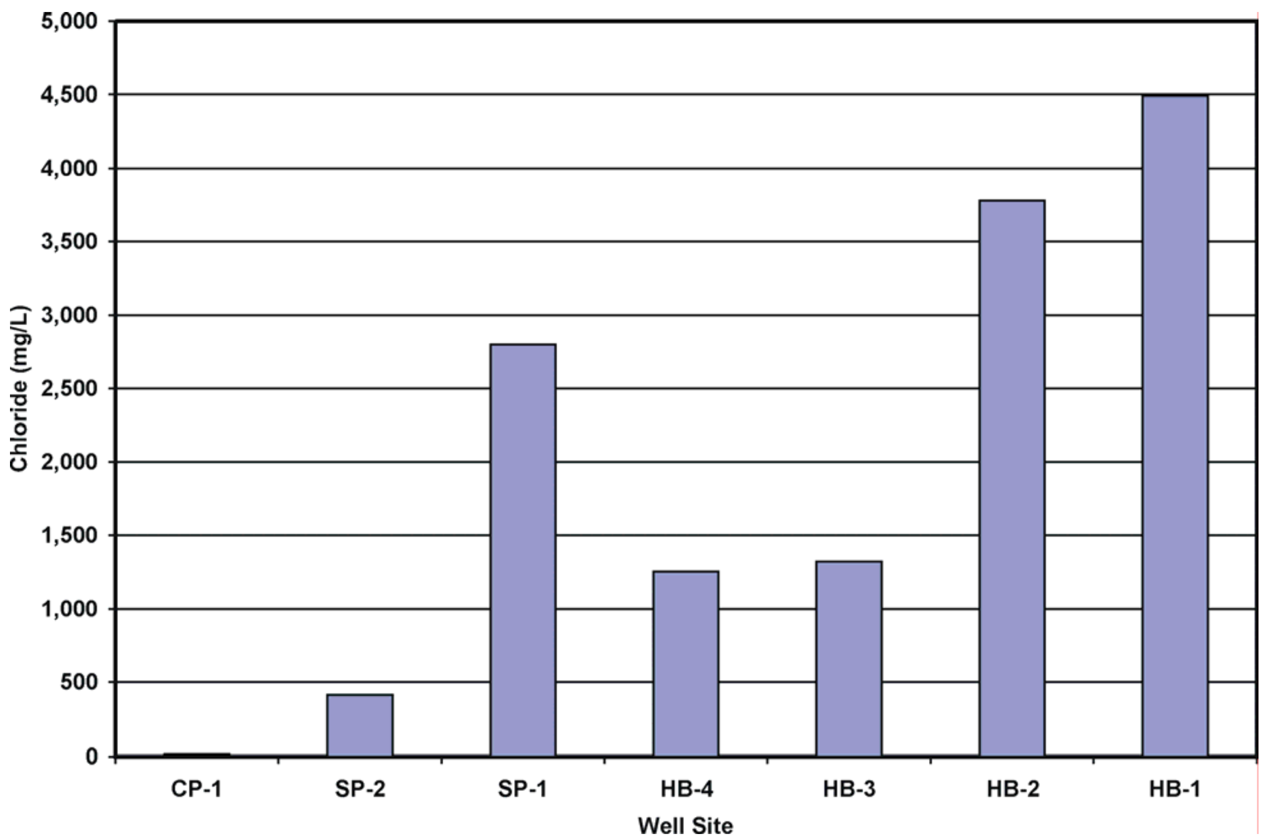


Figure 4C.3-10. Chloride Concentrations of Well Samples along the Lower Nueces River

The opportunity exists with permanent monitor wells in place around the Calallen Pool to conduct a comprehensive sampling program to evaluate the gaining and losing nature of the surface/groundwater system and then relate this information to surface water and groundwater sample results acquired within a time period during which the Calallen Pool experiences low and high flow conditions. Based upon the results of the sampling program, best management practices and mitigation can then be suggested.

4C.3.1.3 Projected Water Needs (Shortages) for Manufacturing Users during 2000 to 2060 Planning Period

There are four counties in the Coastal Bend Region with projected manufacturing water needs: Aransas, Live Oak, Nueces, and San Patricio Counties. Aransas County manufacturers receive groundwater supplies that are limited by well capacity, resulting in a maximum shortage of 136 acft in 2060. Live Oak County receives both surface water[3] and groundwater supplies, with groundwater limited by CBRWPG drawdown criteria. Their maximum projected shortage is 764 acft in 2060. Nueces and San Patricio County manufacturers receive a small supply of groundwater, both the majority is surface water provided from the CCR/LCC System. Since CCR/LCC System demands exceed supply, non-municipal water users have projected shortages. Nueces County manufacturers see projected shortages beginning in 2040 (11,627 acft) and continuing to 2060 (37,893 acft). San Patricio County has a maximum manufacturing shortage of 4,299 acft in 2060. A maximum shortage of 43,092 acft for manufacturing water users is projected for the entire Coastal Bend Region in 2060.

TWDB Rules for regional water planning require RWPGs to consider water conservation and drought management measures for each water user group with a need (projected water shortage). The Task Force report lists the following industrial BMPs that may be used to achieve water savings:[4]

1. Industrial Water Audit
2. Industrial Water Waste Reduction
3. Industrial Submetering
4. Cooling Towers
5. Cooling Systems (other than Cooling Towers)
6. Industrial Alternative Sources and Reuse and Recirculation of Process Water

[3] Surface water firm yield supply of 800 acft/yr from City of Three Rivers run-of-river water right in Nueces River Basin (TCEQ Water Right 3215).
[4] Water Conservation Implementation Task Force, Report to the 79th Legislature, Texas Water Development Board,

7. Rinsing/Cleaning
8. Water Treatment
9. Boiler and Steam Systems
10. Refrigeration (including Chilled Water)
11. Once-Through Cooling
12. Management and Employee Programs
13. Industrial Landscape
14. Industrial Site Specific Conservation

The Task Force report describes the above BMP methods and how they reduce water use, however information regarding specific water savings and costs to implement conservation programs is generally unavailable. Conservation savings and costs are by nature facility specific. Since manufacturing entities are presented on a county basis and are not individually identified, identification of specific water management strategies are not a reasonable expectation.

The CBRWPG recommends enhancing water quality to reduce manufacturing water use.

4C.3.1.4 Summary of Manufacturing Water Use Savings Alternatives

Water supply intakes in the Calallen Pool receive Lake Corpus Christi water via the 'bed and banks' of the Nueces River. The purpose of this section is to evaluate options to improve the quality of the water entering the water supply intakes. The following control strategies are considered:

- Blending of Lake Texana Water with Nueces River Water
- Outlet Works to Remove High TDS Water from the Calallen Pool
- Modification of Existing Intakes
- Pipeline from Lake Corpus Christi to the O.N. Stevens WTP
- Plugging Leaky and Abandoned Oil Wells

The potential for manufacturing water use savings is based on the reduction in chloride concentration of the water supply achieved by each option. Figure 4C.3-11 shows the estimated industrial cooling water usage savings for various levels of water quality improvement. These estimates are based on correspondence with local industries and other sources.

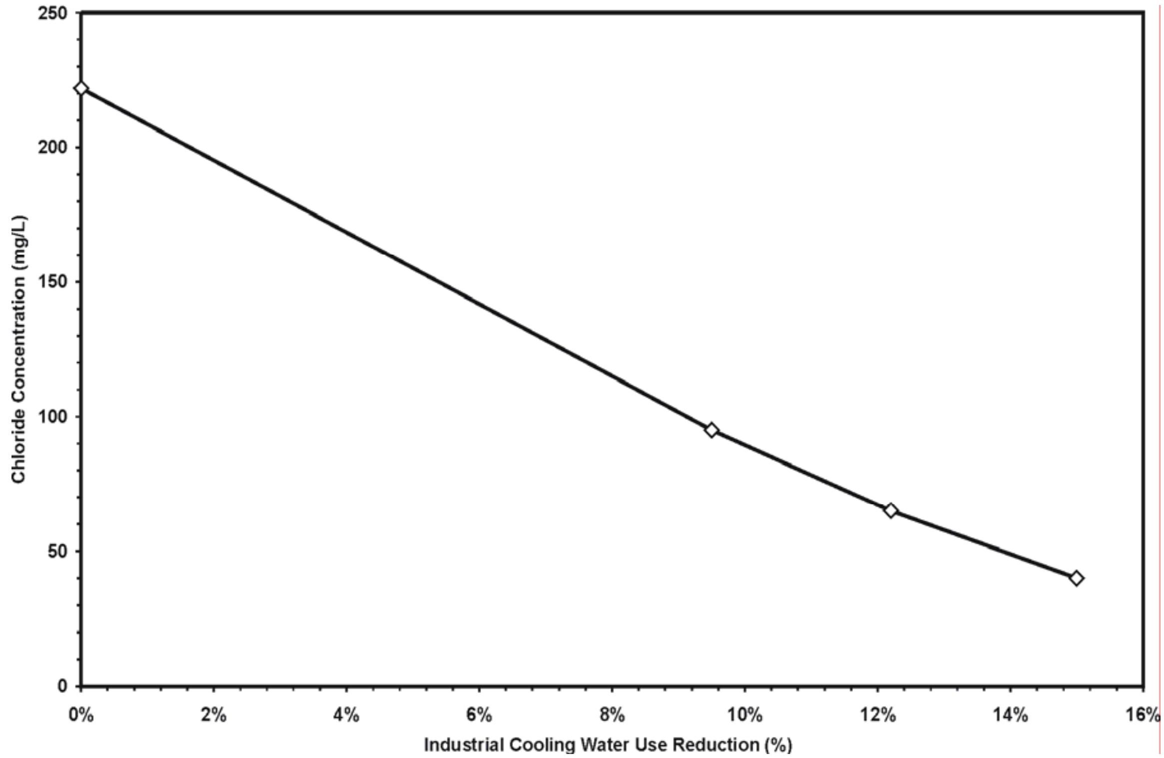


Figure 4C.3-11. Potential for Manufacturing Water Use Savings Based on Reduction in Chlorides

4C.3.2 Available Yield and Water Quality

Cooling towers permit the reuse of cooling water by industry. However, the extent of reuse is limited by water chemistry. Changes in chemistry during cycling of cooling water impact corrosion, scale deposition, and biological fouling of industrial facilities. To control the chemical character of recycled cooling water and prevent these adverse effects, industries discharge (blow down) water from the system. The quantity of makeup water needed is the amount evaporated plus the amount of blow down. Improving makeup water quality would allow industry to reduce their blow down quantity. Other savings include reduced cooling tower chemical costs, and reduced treated water chemical usage and costs. The amount of industrial conservation achieved by improving water quality depends on the current water quality, industrial operations, and amount of water quality improvement effected.

Chloride is an effective indicator of total dissolved solids and is used here as an illustrative example of the savings potential as a result of improving the quality of water entering the manufacturing industry's systems. Another important constituent to cooling water quality is hardness. The concentration of hardness is a critical limitation in the quality of the cooling tower water supply.

The presence of bromide in drinking water supplies affects the formation of disinfection byproducts (DBPs) such as brominated trihalomethane (THM) and haloacetic acid (HAA) species during treatment. THMs and HAAs have been linked to a number of serious health risks and are regulated by the U.S. Environmental Protection Agency. Reducing the level of bromide in drinking water sources, such as the Nueces River, will reduce the amount of DBPs in the finished drinking water and decrease the cost associated with treatment. The following options were evaluated with respect to the concentration ranges of chloride, hardness and bromide. The potential water savings as a result of each option were based on both the maximum and minimum reductions in chloride levels as indicated in Figure 4C.3-11.

4C.3.2.1 Blending of Texana Water

Corpus Christi currently contracts for a firm amount of 41,840 acft/yr and an interruptible amount of 12,000 acft/yr of water from Lake Texana. Lake Texana supplies constitute about 25 percent of the safe yield supply of 205,000 acft in 2010. The addition of Lake Texana water to the region's water supply has lowered total dissolved solids and improved water quality for most industrial users. The mean chloride concentration of Nueces River water at Calallen Pool is 163 mg/L and the maximum is about 222 mg/L. Blending 75 percent Nueces River water with 25 percent Lake Texana water would reduce the mean chloride concentration to 127.5 mg/L and the maximum to about 175 mg/L. Figure 4C.3-12 presents the maximum, median, and minimum chloride, hardness and bromide concentrations for the Nueces River at O.N. Stevens WTP, Lake Texana, and the blended supplies. The average hardness concentration is reduced by 18 percent to 197 mg/L from 242 mg/L. The median bromide concentration is reduced by 20 percent as a result of blending.

In order to obtain the maximum potential savings in manufacturing water use this blended water would need to be made available to as many industries as possible. Two significant industries that withdraw raw water from the Calallen Pool that currently do not have access to the Texana water include Koch and Celanese. These industries have seen a decline in

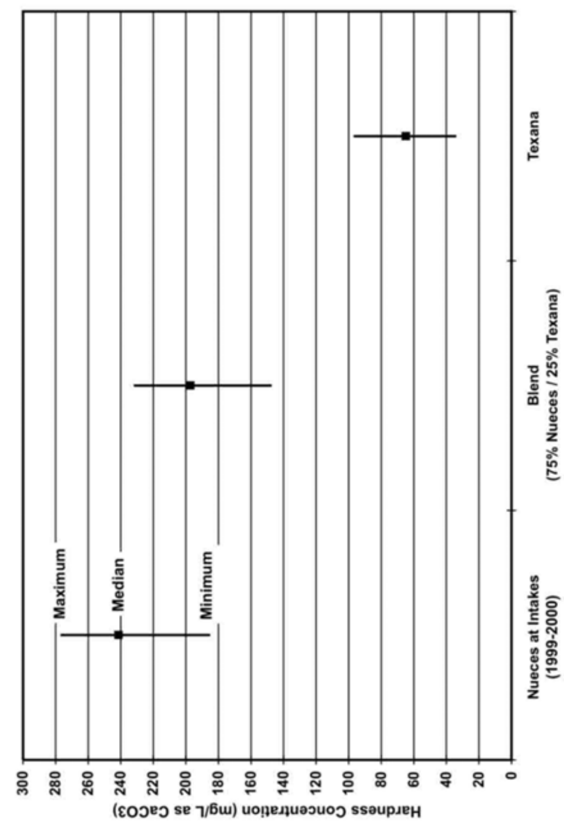
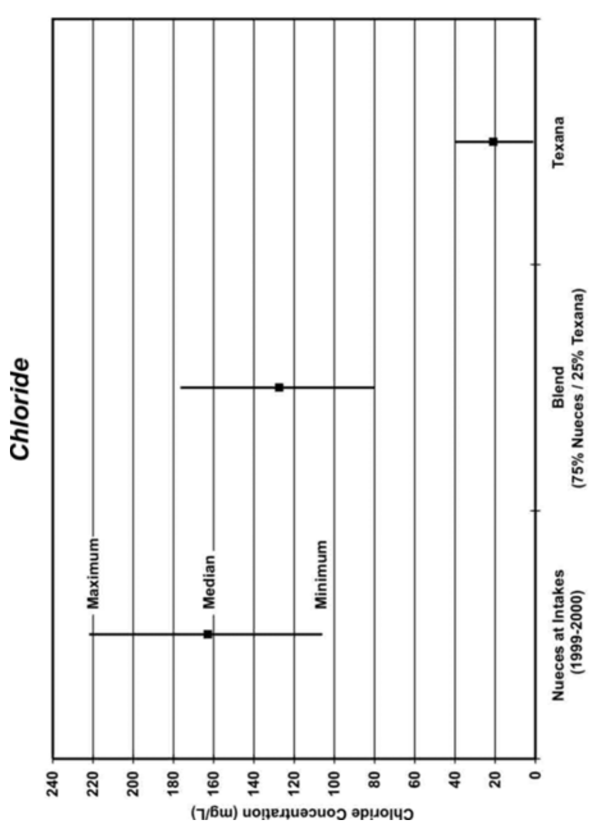
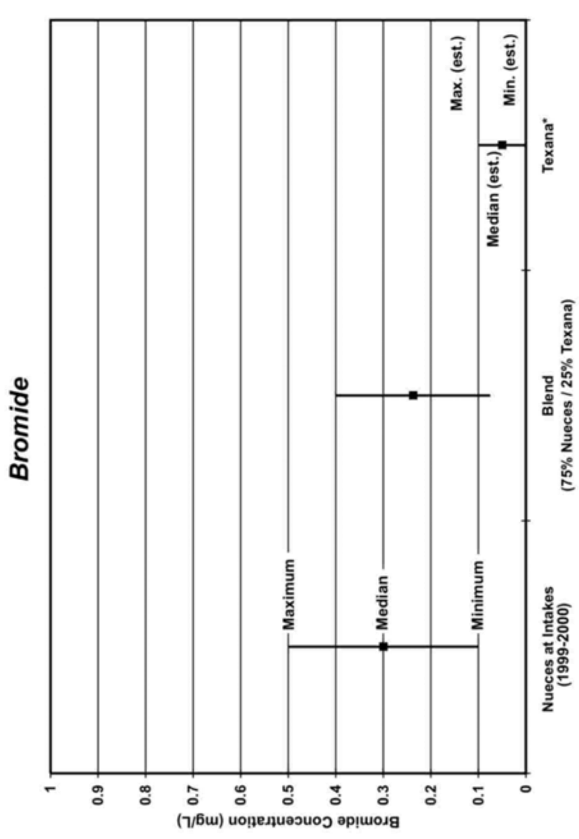


Figure 4C.3-12. Blending Nueces River and Lake Texana Water Decreases Selected Dissolved Mineral Concentration and Variability





Note: The detection limit for bromide is 0.1 mg/L. This is the maximum value assigned to Lake Texana water even though it is likely to be lower.

water quality due to reduced water supply releases from Lake Corpus Christi resulting in higher dissolved solids and mineral concentrations in the Calallen Pool.[5] Although identification of specific modifications necessary to their water pumping facilities to allow for blending is beyond the scope of this study, such an evaluation is recommended in order for these industries to participate in contributing to conservation efforts.

Reductions in chloride levels are expected to result in a 3 to 4 percent savings in cooling water use in the region. Industrial water conservation savings associated with reducing the mean chloride concentration by about 21 percent are as follows:

- Year 2000 – 940 to 1,260 acft/yr
- Year 2060 – 1,540 to 2,050 acft/yr

4C.3.2.2 Outlet Works to Remove High TDS from Calallen Pool

The sampling data has shown that within the Calallen Pool there are sites where saline groundwater entering the system remains at the bottom of the deepest parts of the pool. Removal of the groundwater before the dissolved minerals diffuse into the entire channel could significantly improve the overall quality of the water remaining. This option includes a gravity line to siphon a maximum of 6 MGD from the bottom of the channel at up to eight locations. The alignment of the pipe system is shown in Figure 4C.3-13. The pipe system discharges into an inlet/outlet structure that bypasses the Calallen Dam that will allow for accurate measurement. The line is designed to be flushed by either connecting to San Patricio Municipal Water District's raw water discharge line to backwash the pipeline to remove any buildup of debris or use compressed air to flush the system. Removing the saline groundwater from the channel is estimated to reduce chloride concentrations of the Nueces River water by 15 percent to 138 mg/L based on the median levels, and to 189 mg/L based on the maximum levels as shown in Figure 4C.3-14. The outlet works are estimated to reduce hardness levels by 3.8 percent to an average concentration of 232 mg/L. Figure 4C.3-14 also shows a 39.7 percent reduction in bromide from an average concentration of 0.3 mg/L to 0.18 mg/L.

[5] HDR Engineering Inc., "Effluent Reuse Study," February 2002.

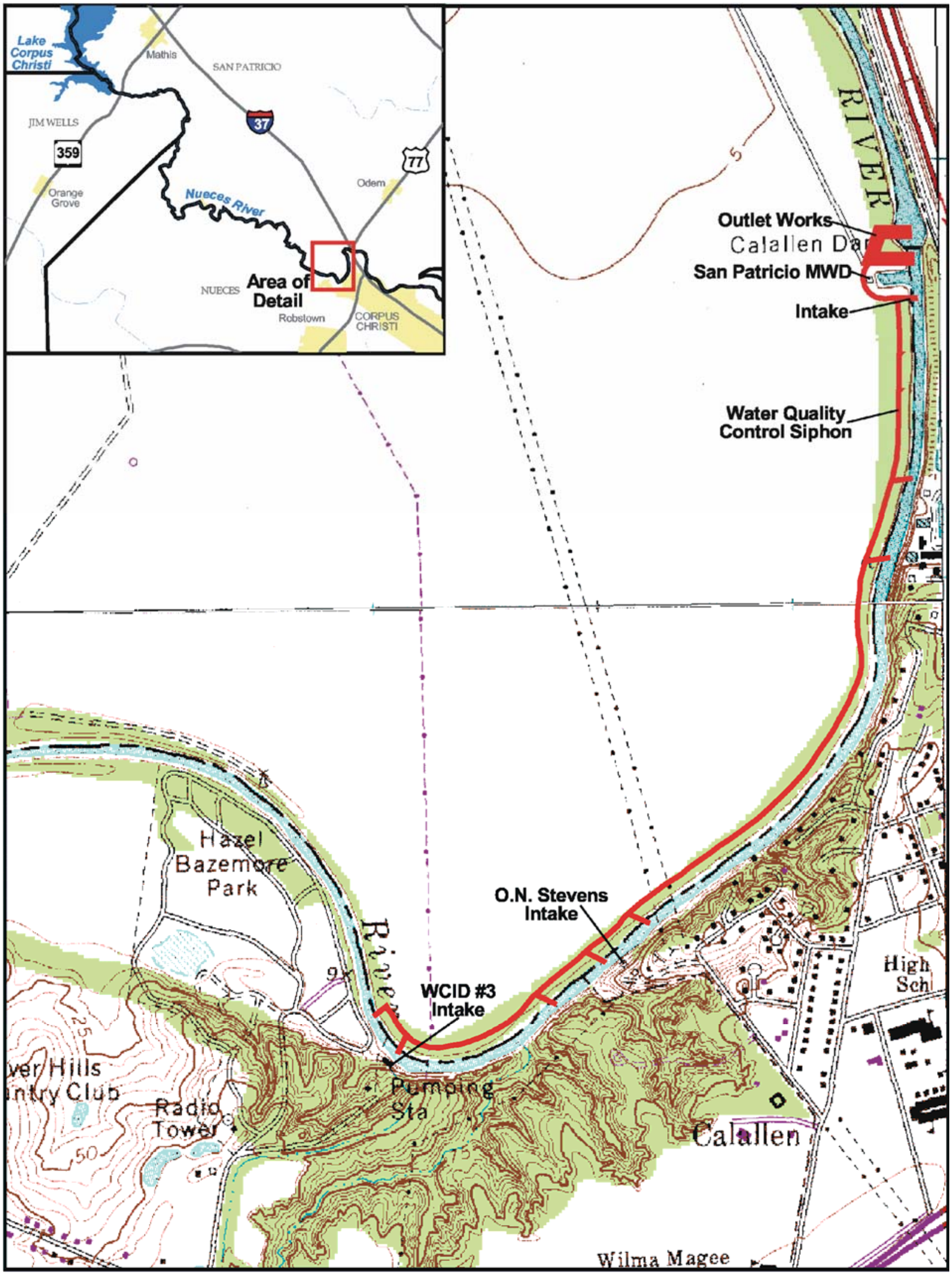
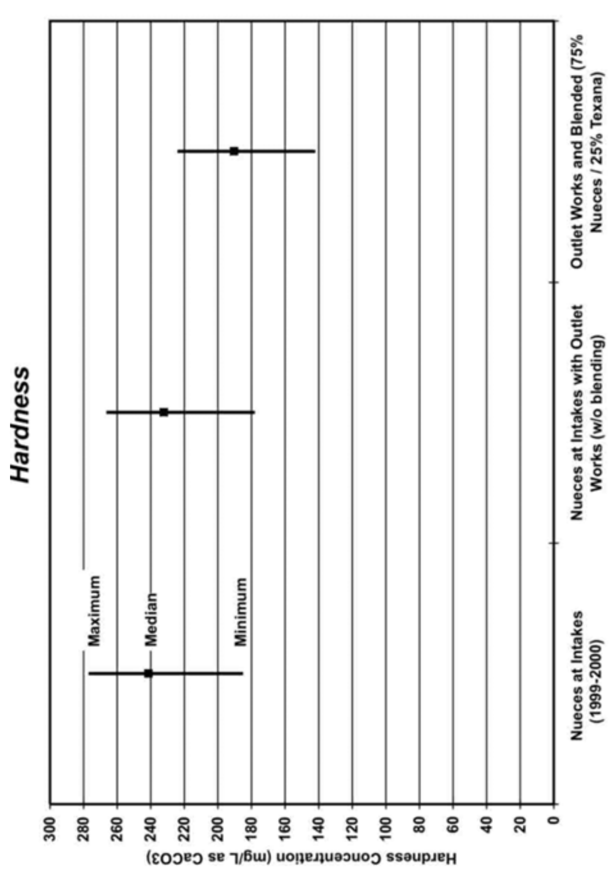
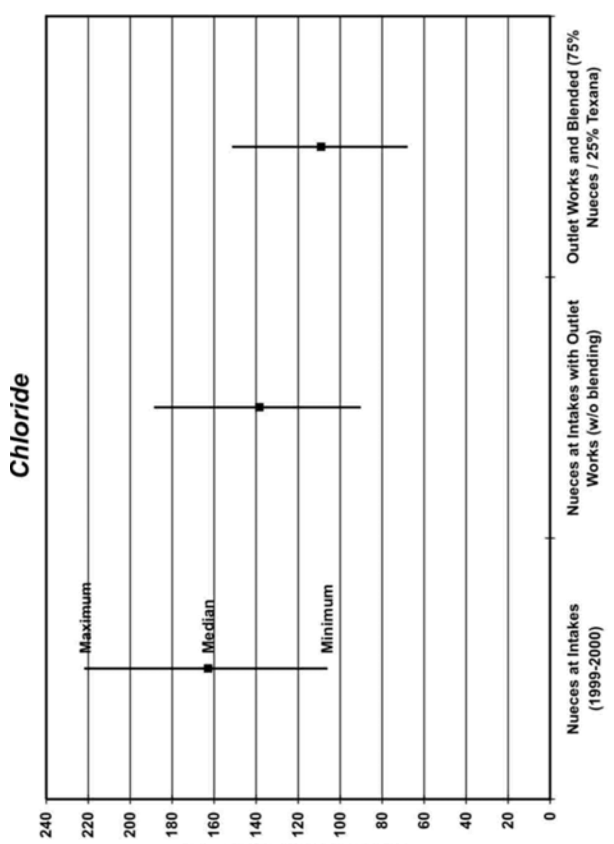


Figure 4C.3-13. Location of Water Quality Control Siphon and Outlet Works





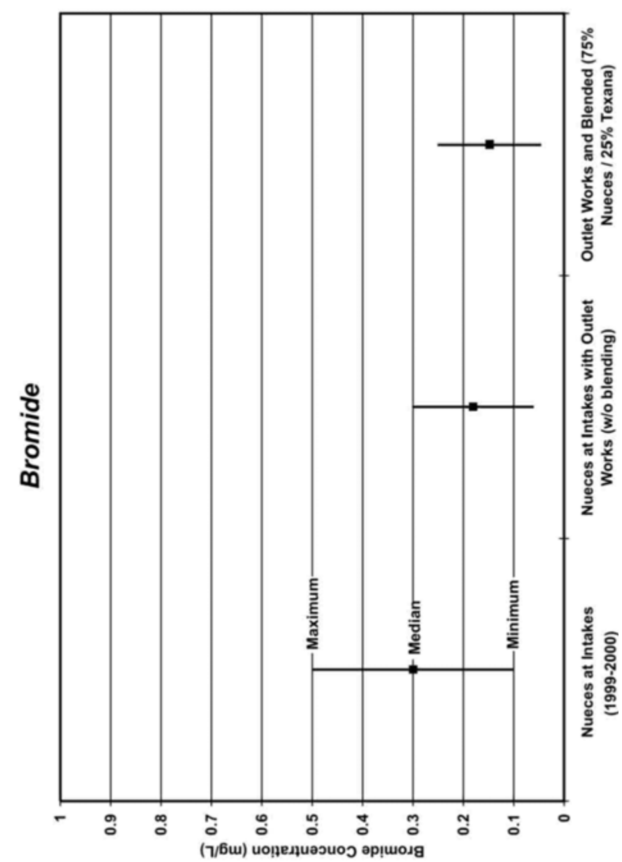


Figure 4C.3-14. Decrease in Selected Dissolved Minerals with Outlet Works and Blending with Lake Texana Water

For determining the estimated benefit of this option, it is assumed that the outlet works are implemented in conjunction with blending Texana water with Nueces River water. After blending with the Texana water, the final median chloride concentration is reduced by an additional 20 percent to 109 mg/L and the maximum to about 152 mg/L. The additional reductions in hardness and bromide concentrations are 18 percent and 17 percent respectively. This option results in an additional savings of manufacturing water consumption by the following amounts:

- Year 2000 – 150 to 470 acft/yr; and
- Year 2060 – 300 to 730 acft/yr.

4C.3.2.3 Intake Modifications

The results of the sampling program show stratification within the Calallen Pool, with large mineral concentration increases occurring within the bottom 2 feet near the water intake locations. A potential option for increasing manufacturing water conservation is modification of the industrial intake structures to prevent withdrawal of water from the deepest part of the channel. Modifications to existing surface water intakes to allow only water from the uppermost portion of the water column to enter the system will differ depending upon the design of the intake. There are two major types of intakes within the channel. The first is a screened pipeline intake and the second is a side stream intake.

The first intake system would require the installation of a pipe with variable level intake screens, which can be opened and closed to allow the optimum quality of water to be withdrawn from the channel. There are multiple modifications possible for the side stream intake. These include the addition of framing, which will allow stop logs to be placed in front of the intake and allow water from selected depths to enter the system. The second is the installation of an exterior sill wall outside of the intake structure. The third option is the construction of an interior baffle wall within the intake structure. The four intakes that would result in the most benefit from modifications include the two side stream intakes operated by the City of Corpus Christi, a single side stream intake operated by the Celanese Corporation Bishop Facility, and a screened pipeline intake operated by Nueces County WCID #3.

The benefit of intake modifications is considered only in conjunction with the outlet works and siphon pipeline, as the siphon would be necessary to prevent the build-up of poor quality groundwater in the bottom of the Calallen Pool. Allowing only water from the uppermost portion of the Nueces River water column to enter the intakes after the most of the saline groundwater has been removed from the channel by the outlet works results in an additional reduction in median and maximum chloride of about 5 percent over the reductions achieved by the outlet works alone. An additional 12 percent reduction in bromide is achieved and hardness is further reduced by 1 percent, as shown in Figure 4C.3-15. It is estimated that the additional water savings due to this option are 150 acft/yr for year 2000 and 300 acft/yr for 2060.

4C.3.2.4 Pipeline from Lake Corpus Christi to the O.N. Stevens Water Treatment Plant

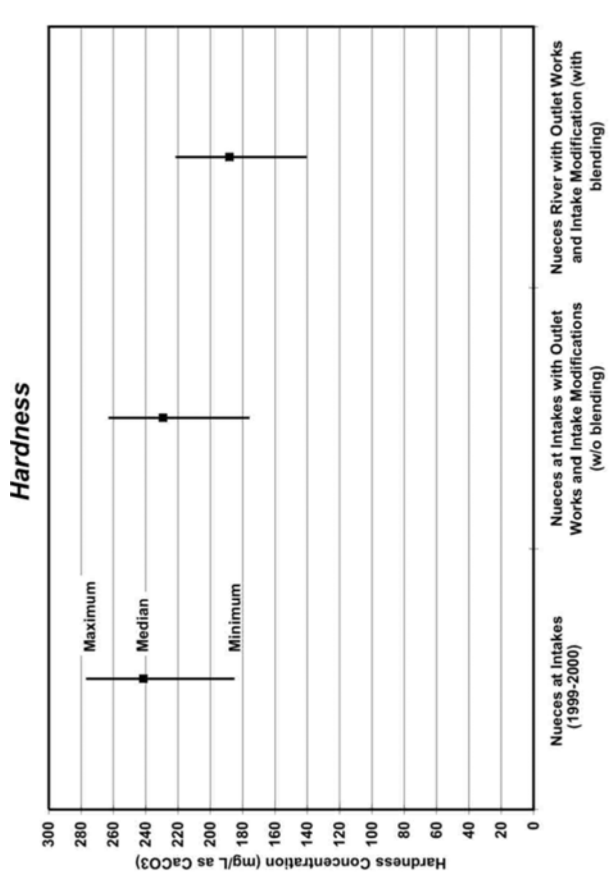
A pipeline to deliver the total system safe yield of 150,000 acft/yr[6] from Lake Corpus Christi to the O.N. Stevens WTP would significantly reduce the chloride concentration of the raw water. Delivering just a portion of the total system yield from the Nueces River system to some users would increase the concentration of dissolved solids of the water remaining within the channel that would be diverted by other industrial and municipal users. Delivering the entire system yield eliminates this problem by supplying water with improved quality to all industrial and municipal users.

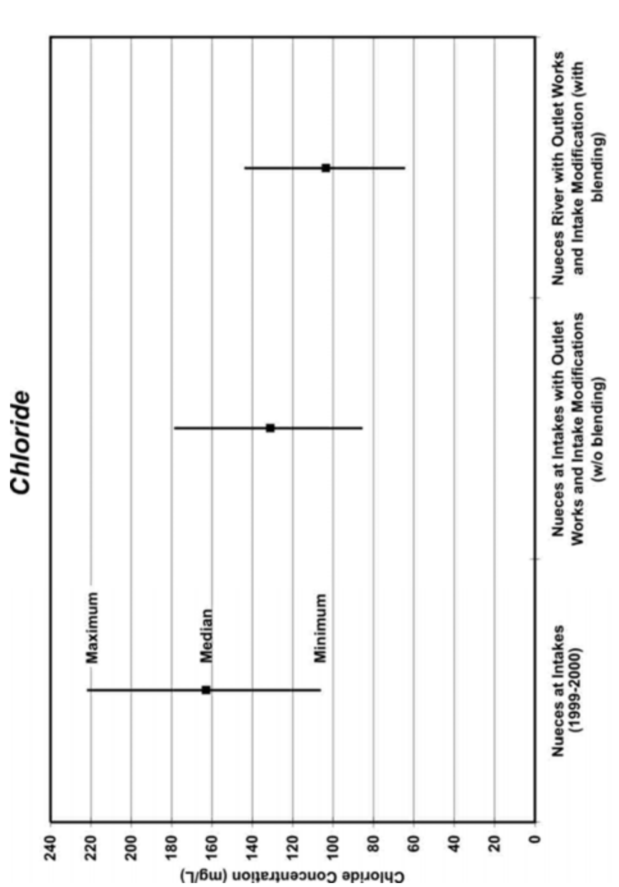
The quality of the water would improve from an average chloride concentration of 163 mg/L to an average chloride concentration of 39 mg/L as shown in Figure 4C.3-16. The hardness levels of Lake Corpus Christi are 27 percent lower than the Nueces River. The average improvement in hardness is from 185 mg/L to 136 mg/L. It is estimated that the manufacturing industry would save about 10 percent to 13 percent of water consumption as a result of the decrease in chloride concentration. This results in a 3,100 acft/yr to 4,000 acft/yr savings in 2000 and 5,100 acft/yr to 6,600 acft/yr savings in 2060. Other benefits to industry include:

- Reduced cooling tower chemical costs
- Reduced demineralized water chemical usage and costs
- Reduced salt loading in the final plant effluent (environmental benefit).

The major facilities needed to deliver raw water from Lake Corpus Christi to the O.N. Stevens WTP include an intake pump station at the lake and a 21-mile transmission pipeline to Calallen. The river habitat downstream of Lake Corpus Christi would be supplied with water from natural inflows and pass-throughs to the Nueces Estuary from Lake Corpus

[6] Safe yield for CCR/LCC System in 2010 is 150,000 acft/yr without Lake Texana supplies.





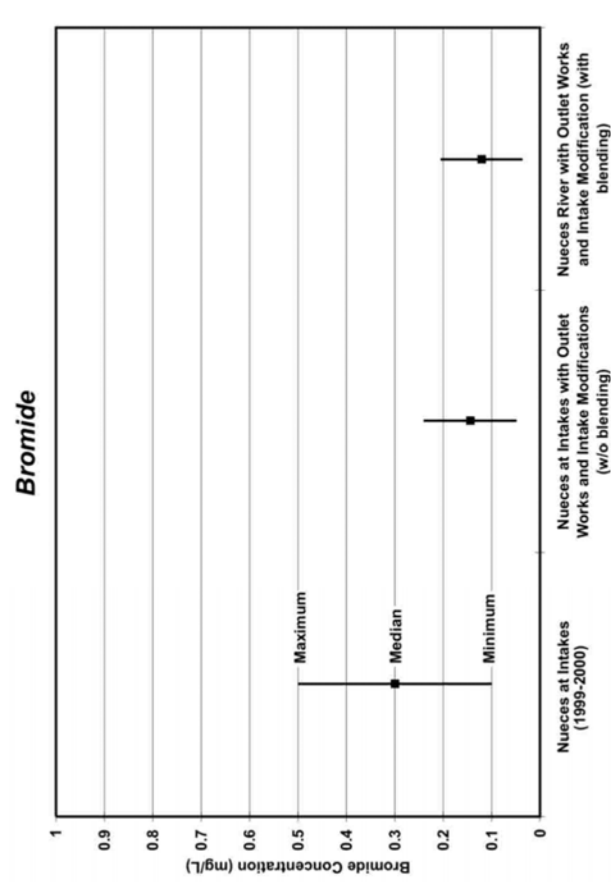
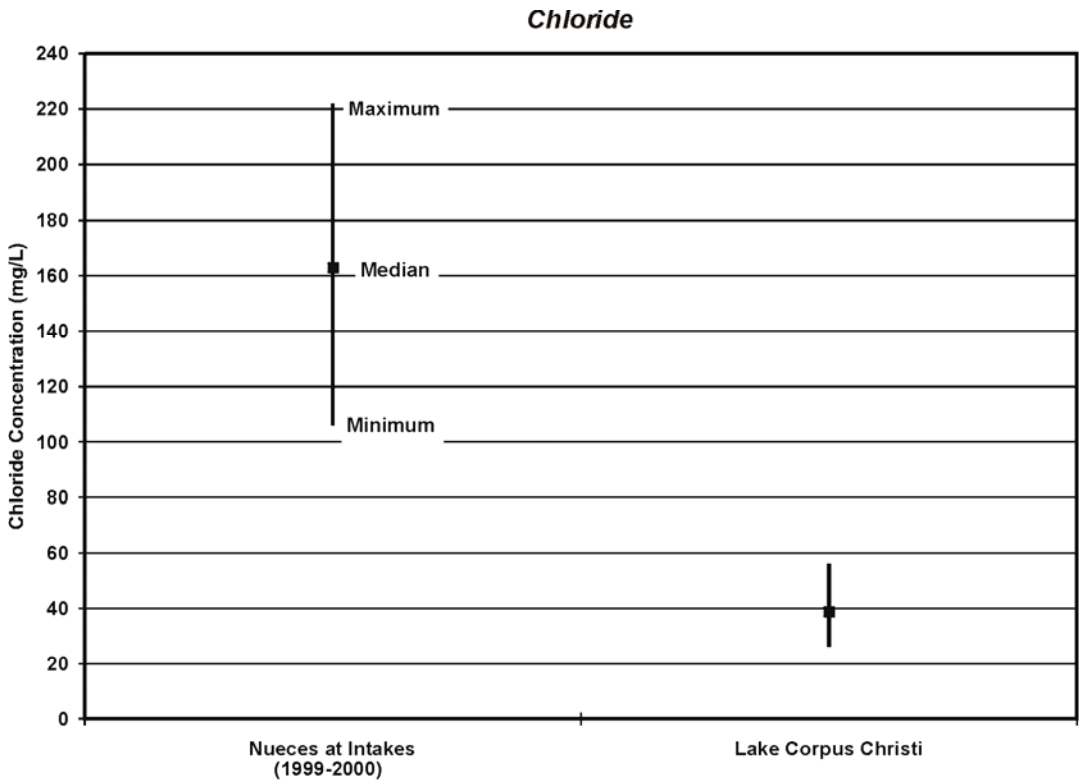


Figure 4C.3-15. Decrease in Selected Dissolved Mineral Concentrations with Intake Modifications, Outlet Works, and Blending with Lake Texana Water



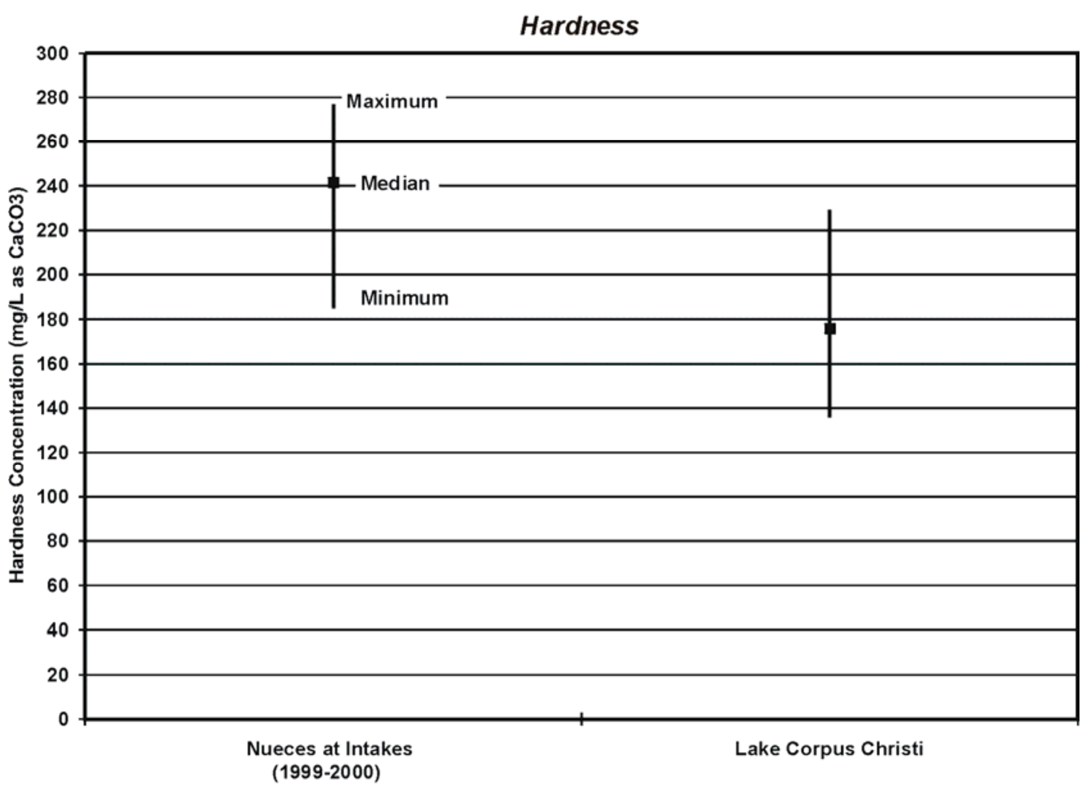


Figure 4C.3-16. Comparison of Chloride and Hardness Concentrations

Christi. The total yield for this option includes reduced channel losses and increased manufacturing water conservation. Recent studies indicate channel losses average 11 percent between Lake Corpus Christi and the Calallen Pool (or about 16,500 acft/yr on water supply releases of 150,000 acft), depending on flow and seasonal conditions.[7] This project would result in total savings of between 19,600 to 23,100 acft/yr.

4C.3.2.5 Plugging Leaky and Abandoned Oil Wells

Unplugged and leaking plugged wellbores pose a threat of pollution to the surface and subsurface waters by providing a pathway for the migration of fluids (in particular oil and saltwater) from hydrocarbon bearing zones into formations containing usable quality water and into surface waters. As long as a well remains unplugged, the potential threat remains until it is eliminated by properly plugging the wellbore.

The State of Texas has maintained a well plugging fund since 1965 to plug abandoned wells that pose a pollution hazard when: the responsible owner/operator cannot be located; is insolvent; or the responsible owner/operator is unwilling to plug the well. Wells are considered in the Nueces River and Lake Corpus Christi for plugging when they become non-compliant or inactive for at least 12 months and have not received an approved permit extension. A priority system is used to rate the need for plugging non-compliant wells based upon 20 human health, safety, environmental, and wildlife factors. Leaking wells receive the highest priority (Level 1) and all other wells receive a priority between 2 and 4 depending on the level of threat to the environment. Wells with a priority of 1, 2, or 3 are recommended for plugging with Oil Field Cleanup Funds. The Texas Railroad Commission has utilized the Oil Field Cleanup (OFCU) Fund to plug more that 15,000 wells within the state of Texas. Of those, 139 wells have been in San Patricio County and 96 were in Nueces County. However, thousands of additional abandoned wells remain in Texas. There are currently 193 and 184 non-compliant wells in San Patricio and Nueces Counties, respectively. Of these non-compliant wells, only 31 have a Level 4 priority. It is unknown how many improperly plugged wells are leaking and are in need of repair. Within San Patricio and Nueces Counties, there were 16 total wells scheduled to be plugged in 2000 at an average estimated cost of $21,000 per well. Additional study is needed to determine the impact of the leaking wells on the lower Nueces River.

[7] CRR/LCC updates, 2005.

4C.3.3 Environmental Issues

Any major construction undertaken within the Nueces River channel or along the riparian corridor such as intake modifications, building a siphon system to remove high TDS or a pipeline, will have some, though minor, environmental impacts.

Construction of the siphon system will include up to eight intake structures placed in the Nueces River. As the water volumes to be moved by this system will be relatively small (6 MGD, an intake stream of about 1.2 cfs at each of the eight intakes), the intake structures will be small. Disturbance of riparian and riverine habitats due to construction of eight intake structures is expected to total substantially less than one acre. Construction of the approximately 1.7 mile long pipeline to the upper end of Segment 2101 (Nueces River Tidal) will disturb about 6.7 acres of ground cover within a 30 foot wide construction easement. Impacts to riparian areas can be minimized by locating the pipeline outside of the very narrow wooded corridor that lines the left bank of the Nueces River in this reach.

Operation of the siphon system will result in changes in the ambient Nueces River TDS concentrations that are within the tolerance limits of the freshwater fish and invertebrate species of the lower Nueces River. Likewise, the relatively small discharge of Nueces River bottom water into the tidal segment will still be well within the generally accepted freshwater range (i.e., <2,500 mg/l), and will mix with brackish bay waters through tidal action, as is the case with existing Nueces River flows over Calallen Dam.

The operation of the siphon is expected to have a negligible effect on the estuary, as water quality of the releases will be fresh relative to the estuary salinity.

Additional studies should be conducted prior to implementing a siphon system at Calallen Pool to evaluate water quality constituents (other than salinity and TDS) and impacts associated with leaky and abandoned oil wells.

The proposed Lake Corpus Christi to Calallen pipeline corridor would be within Jim Wells and San Patricio Counties. The pipeline is intended to transfer water without using the bed and banks of the Nueces River. The major environmental issues related to pumping water via a pipeline from Lake Corpus Christi to Calallen include the effects of changes in Nueces River flows. The remaining flows in the river would include pass throughs to the estuary from Lake Corpus Christi and natural inflows. Further studies would be needed to assess the required flows within the channel to maintain stream habitat and the project's impact on these flows.

All of the options result in conservation of manufacturing water use by improving water quality and thereby increasing the amount of water available for other users. Also, reducing the dissolved solids content of the water entering the manufacturing industries' cooling systems reduces the mineral loading content of the final plant effluent. Plugging leaky and abandoned oil wells reduces hydrocarbon pollution and contamination by saline water to surface and subsurface water.

4C.3.4 Engineering and Costing

4C.3.4.1 Blending Lake Texana Water with Nueces River Water

The blend ratio considered for this option includes 75 percent Nueces River water and 25 percent Texana water, since Lake Texana supplies constitute approximately 25 percent of the safe yield supply of 205,000 acft in 2010.

4C.3.4.2 Outlet Works to Remove High TDS from Calallen Pool

The cost estimate for the pipe system facilities to remove water with high TDS from the bottom of the Calallen Pool is shown in Table 4C.3-2. The total capital cost is estimated at $1,572,000. The project cost is $2,240,000. The total annual cost is estimated to be $179,000. Assuming that the outlet works are implemented in conjunction with blending Texana water with Nueces River water to provide water to the industries, the additional system yield savings of 150 to 730 acft/yr results in a unit cost ranging from $245 to $1,193 per acft/yr.

4C.3.4.3 Intake Modifications

The benefit of intake modifications is considered in conjunction with the outlet works and siphon pipeline. The approximate capital cost of each intake modification is estimated to range from $200,000 to $1,000,000 per intake. Considering there are four intake structures that would benefit from modification, the capital cost is estimated to be about $2,595,000. The four intakes include one operated by the Celanese Bishop Plant Facility, two by the City of Corpus Christi and one operated by Nueces County WCID #3. Intake modification with the outlet works is estimated to save an additional 150 to 300 acft/yr for 2000 and 2060. The cost estimate for this control strategy is shown in Table 4C.3-3. The total capital cost is estimated at $4,167,000. The project cost is $5,884,000. The total annual cost is estimated to be $508,000. Therefore the unit cost of water saved is estimated to be about $1,693 to $3,387 per acft per year.

Table 4C.3-2.
Cost Estimate Summary for Outlet Works and Siphon to Remove High TDS from Calallen Pool (Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Siphons , Control Valves and Vaults (8 siphons)	$172,000
Intake at Dam, Valves and Vaults at Intake	719,000
Gravity Pipeline (12”, 14”, 18” and 24” telescopic line)	681,000
Total Capital Cost	**$1,572,000**
Engineering, Contingencies and Legal Costs	$472,000
Environmental & Archaeology Studies and Mitigation	46,000
Pipeline Land Acquisition and Surveying (6.2 acres)	64,000
Interest During Construction (1 year)	86,000
Total Project Cost	**$2,240,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$163,000
Operation and Maintenance	16,000
Total Annual Cost*	**$179,000**
Available Project Yield (acft/yr)	**150 to 730**
Total Annual Cost of Water ($ per acft)	**$245 to $1,193**
Annual Cost of Water ($ per 1,000 gallons)	**$0.75to $3.66**

4C.3.4.4 Pipeline from Lake Corpus Christi to O.N. Stevens Water Treatment Plant

The major facilities needed to deliver 150,000 acft/yr of raw water from Lake Corpus Christi to the Calallen Dam include an intake pump station and 21-mile transmission pipeline. The pipeline capacity was calculated based upon a peak day to average day ratio of 1.75 and is capable of transferring up to 234 MGD. The cost for the facilities is shown in Table 4C.3-4. The total capital cost is estimated at $85,379,000. The total project cost is $122,100,000. The total annual cost is estimated to be $11,177,000. Increases in yield include reduced channel losses (16,500 acft/yr) and increased manufacturing water conservation (3,100 to 6,600 acft/yr), resulting in total savings of between 19,600 and 23,100 acft/yr and a unit cost of $484 to $570 per acft/yr.

Table 4C.3-3.
Cost Estimate Summary for Intake Modifications and Outlet Works to Remove High TDS from Calallen Pool (Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Intake Modifications	$2,595,000
Siphons (8), Control Valves and Vaults	172,000
Intake (250 cfs) and Outlet Structure at Dam, Valves and Flow Meters	719,000
Gravity Pipeline (12-, 14-, 18- and 24-inch telescopic line)	681,000
Total Capital Cost	**$4,167,000**
Engineering, Contingencies and Legal Costs	$1,381,000
Environmental & Archaeology Studies, Mitigation, and Permitting	46,000
Pipeline Land Acquisition and Surveying (107 acres)	64,000
Interest During Construction (1 year)	226,000
Total Project Cost	**$5,884,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$428,000
Operation and Maintenance	80,000
Total Annual Cost	**$508,000**
Available Project Yield (acft/yr)	**150 to 300**
Total Annual Cost of Water ($ per acft)	**$1,693 to $3,387**
Annual Cost of Water ($ per 1,000 gallons)	**$5.20 to $10.39**

4C.3.4.5 Plugging Leaky and Abandoned Oil Wells

Within San Patricio and Nueces Counties, there were 16 wells scheduled to be plugged by the Texas Railroad Commission in 2000 at an average estimated cost of $21,000 per well. It is unknown how many old plugged wells continue to leak and are in need of repair. Additional study is needed to determine the impact of the leaking wells on the lower Nueces River.

Table 4C.3-4.
Cost Estimate Summary for
Pipeline from Lake Corpus Christi to Calallen Dam
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Intake and Pump Station (234 MGD)	$10,801,000
Transmission Pipeline (114-inch dia., 21 miles)	74,578,000
Total Capital Cost	**$85,379,000**
Engineering, Contingencies and Legal Costs	$26,154,000
Environmental & Archaeology Studies, Mitigation, and Permitting	533,000
Pipeline Land Acquisition and Surveying (105 acres)	989,000
Interest During Construction (2 years)	9,045,000
Total Project Cost	**$122,100,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$8,870,000
O&M: Intake, Pipeline, Pump Station	1,016,000
Pumping Energy Costs (21,513,004 kWh @ $0.06 per kWh)	1,291,000
Total Annual Cost	**$11,177,000**
Available Project Yield (acft/yr)	**19,600 to 23,100**
Total Annual Cost of Water ($ per acft)	**$484 to $570**
Annual Cost of Water ($ per 1,000 gallons)	**$1.48 to $1.75**

4C.3.5 Implementation Issues

4C.3.5.1 Blending of Texana Water

With current contracts, the water supply from Lake Texana is approximately 25% of the safe yield supply. Blending of Lake Texana water with Nueces River water is already occurring and local industries that currently do not benefit from these water quality improvements should consider water pumping facilities to allow for blending.

4C.3.5.2 Outlet Works to Remove High TDS from Calallen Pool

Releases of water from the Calallen Pool through the siphon line should contribute towards Lake Corpus Christi's Bay and Estuary release credits. Permits and potential mitigation requirements would be needed for construction of the pipeline and Calallen Dam bypass. The construction of the outlet works may require an USCOE Section 404 Permit and would require cultural resource studies along the pipeline route.

4C.3.5.3 Intake Modifications

Intake modifications within the Nueces River channel may require an USCOE Section 404 permit. Also, major modifications may require the intake pump station to be out of service for a portion of the construction period. However, it is possible to complete the construction in phases in order to minimize or eliminate down time.

4C.3.5.4 Pipeline from Lake Corpus Christi to the O.N. Stevens Water Treatment Plant

The primary implementation issue that would need to be addressed would be the impact of the reduced flows in the Nueces River downstream of Lake Corpus Christi. An evaluation of the impacts of reduced flows on the river and riparian water rights would have to be undertaken to fully investigate the consequences of implementing this alternative. In addition, the TECQ permits may need to be amended depending on changes in locations of diversions. Also, before a significant expenditure of funds would be considered for this alternative, a detailed long-term investigation of channel losses should be undertaken to fully understand the seasonality and variability of channel losses that occur within the river reach. Additional implementation issues for the development of a water supply from Lake Corpus Christi to Calallen include:

- USCOE Sections 10 and 404 dredge and fill permits for the pipelines.
- GLO Sand and Gravel Removal permit for pipeline stream crossings.
- GLO Easement for use of State-owned land (if any).
- TPWD Sand, Gravel, and Marl permit.
- Mitigation requirements would vary depending on impacts, but could include vegetation restoration, wetland creation or enhancement, or additional land acquisition.
- Cultural resource studies would need to be performed along the pipeline route.

4C.3.5.5 Plugging Leaky and Abandoned Oil Wells

Although the Texas Railroad Commission conducts an active well plugging program, the extent of contamination from these wells to surface waters prior to plugging is unknown. Also, it is possible that there are many undetected leaking wells that were plugged decades ago, but have since degraded. It is an important issue to investigate this possible contamination source.

4C.3.6 Evaluation Summary

Evaluation summaries of this regional water management strategy are provided in Tables 4C.3-5 and 4C.3-6.

Table 4C.3-5.
Evaluation Summary of Manufacturing Water Conservation Strategies

Impact Category	*Comment(s)*
a. Water Supply	
1. Quantity	1. Estimated savings are shown in Table 4C.3-6.
2. Reliability	2. Unknown – additional studies needed.
3. Cost of Treated Water	3. Unit costs are shown in Table 4C.3-6.
b. Environmental factors	
1. Instream flows	1. Some impact since pipeline to Lake Corpus Christi would reduce flows in Lower Nueces River.
2. Bay and Estuary Inflows	2. Return flows of about 10,000 to 12,000 acft/yr would increase flows to the Nueces Estuary.
3. Wildlife Habitat	3. Possible minor impacts to wildlife habitat from construction of facilities.
4. Wetlands	4. Possible benefit to wetlands due to enhanced water quality.
5. Threatened and Endangered Species	5. Pipeline to Lake Corpus Christi would require detailed studies of Lower Nueces River to determine impacts to threatened and endangered species.
6. Cultural Resources	6. Cultural resource investigations should be conducted along pipeline route to evaluate impacts. Cultural resources will need to be avoided when facilities are constructed.
7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	7. During drought conditions sampling indicates worsening of water quality. Water quality improvements benefit manufacturing and municipal entities, and Nueces Bay and Estuary. The CBRWPG identified six water quality concerns associated with manufacturing water conservation strategy, as described below. a. Water quality improvement projects will reduce total dissolved solids. b. None or low impact. c. None or low impact. d. Water quality improvement projects will reduce chloride levels in Lower Nueces River.

Concluded on next page

Table 4C.3-5 Concluded

Impact Category	*Comment(s)*
7. Water Quality (continued)	e. Water quality improvement projects will reduce bromide levels in Lower Nueces River. f. Further studies should be conducted to determine impacts of water quality improvement projects on sulfate levels in Lower Nueces River. g. None or low impact. h. None or low impact. i. CBRWPG also identified dissolved oxygen and hardness as water quality concerns related to this water management strategy. Dissolved oxygen decreases with depth within the channel. The Nueces River Dissolved Minerals Study addresses this concern. Hardness can be reduced by implementation of water quality improvement projects.
c. Impacts to State water resources	• No significant impacts.
d. Threats to agriculture and natural resources in region	• None
e. Recreational impacts	• None, except pipeline to Lake Corpus Christi would reduce flows in Lower Nueces River.
f. Equitable Comparison of Strategies	• Water quality improvements benefit both manufacturing and municipal entities.
g. Interbasin transfers	• None.
h. Third party social and economic impacts from voluntary redistribution of water	• None.
i. Efficient use of existing water supplies and regional opportunities	• Increases existing system efficiency.
j. Effect on navigation	• None

Table 4C.3-6.
Summary of Water Quality Control Strategies

Water Options	*Amount of Water Conserved (acft/yr)*	*Total Annual Cost of Water ($ per acft)*
1. Blending of Lake Texana Water with Nueces River Water	940 to 2,050	None*
2. Outlet Works to Remove High TDS from the Calallen Pool	150 to 730	$245 to $1,193
3. Modification to Existing Intakes	150 to 300	$1,693 to $3,387
4. Pipeline from Lake Corpus Christi to Calallen	19,600 to 23,100	$484 to $570
* No additional costs to be incurred unless additional water is purchased from LNRA from Lake Texana.		

4C.4 Mining Water Conservation (N-4)

4C.4.1 Description of Strategy

Water for mining uses is primarily associated with oil and gas extraction, coal mining, metal mining, and nonmetallic mineral operations. Gross state product data released from the U.S. Department of Commerce showed mining economic outputs of $37.6 billion for 1999 and $29.9 billion for 2000.[1] The TWDB water demand projections for mining users is generally based on projected economic output, assuming that past and current water use trends remain constant over time.

In the Coastal Bend Region, the trends for mining water demands are projected to increase each decade with a maximum demand of 19,114 acft by 2060, as shown in Figure 4C.4-1. The increase in water demand is due to anticipated economic growth in mining activities in the Coastal Bend Region. Duval, Live Oak, and Kleberg Counties have the largest projected mining water demands, constituting 85 percent of the regional mining water demand (Figure 4C.4-2).

In the Coastal Bend Region, 10 of the 11 counties (except Nueces County) receive their full mining water supply from groundwater sources. Nueces County mining users receive groundwater and surface water supplies from the City of Corpus Christi and a small run-of-river water right from the Nueces River (12 acft).[2]

In the Coastal Bend Region, three counties (Duval, Live Oak, and Nueces) are projected to have mining needs (shortages) during the 2000 to 2060 planning period, as shown in Table 4C.4-1. Groundwater supply for Duval County-Mining is limited by Coastal Bend Region drawdown criteria, described in Section 3.4. Duval County-Mining can receive 51 percent of their projected water demand in 2060 and still meet drawdown criteria, resulting in a shortage of 4,205 acft in 2060. Similarly, Live Oak County-Mining has a shortage of groundwater supplies limited by Coastal Bend Region drawdown criteria. Live Oak-Mining can receive 67 percent of their projected groundwater use in 2060 and still meet drawdown criteria. For Nueces County, the City of Corpus Christi's wholesale water supply is insufficient to meet the demands of its customers beginning in 2030 and, consequently, a shortage is expected for their mining customers.

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[1] TWDB, "Water Demand Methodology and Projections for Mining and Manufacturing," March 2003.
[2] Part of TCEQ Water Right #2464.

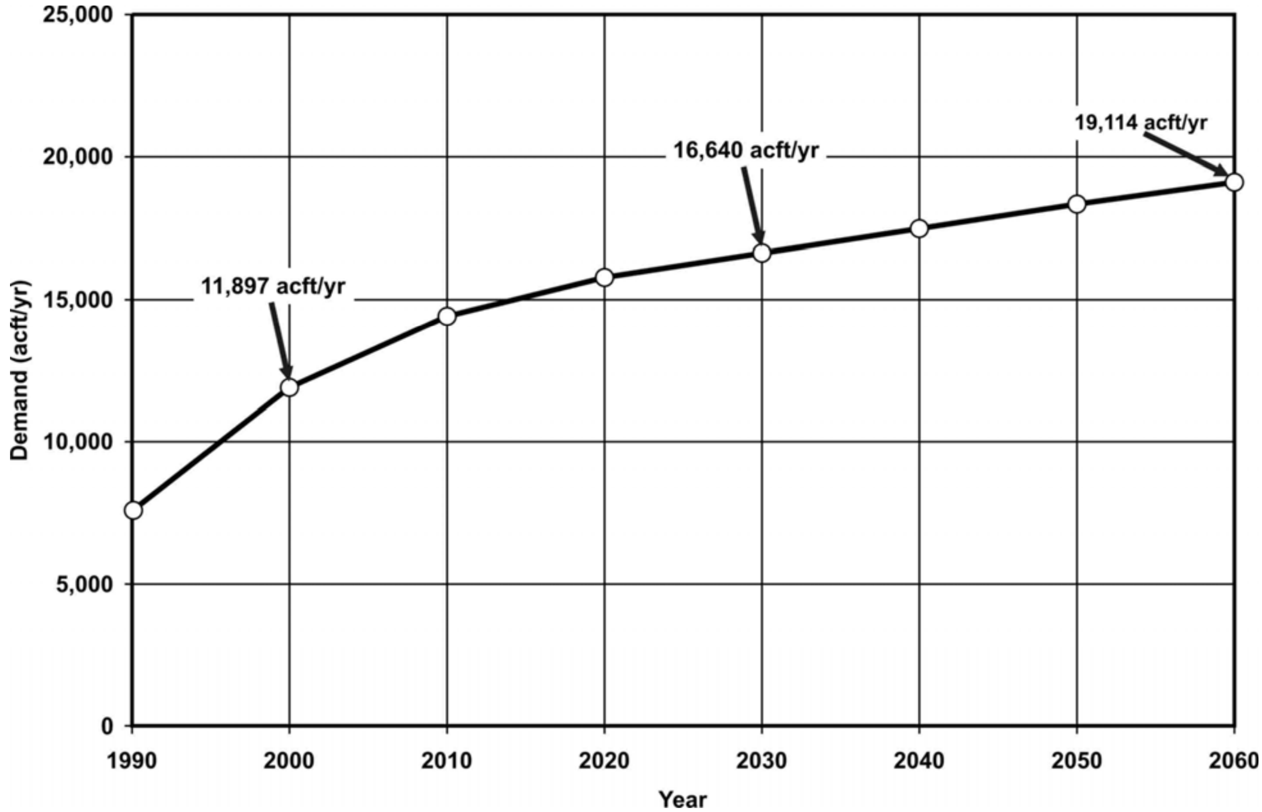

Figure 4C.4-1 Coastal Bend Region Mining Water Demand Projections

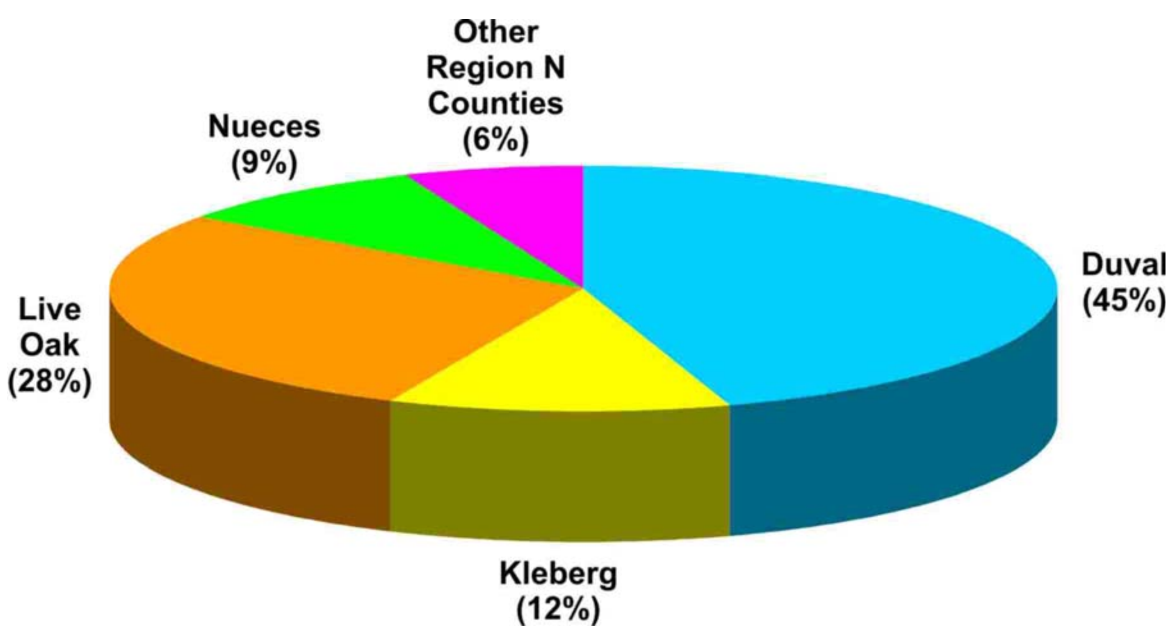

Figure 4C.4-2. 2060 Percentages of Mining Water Demand by County
Total Demand for Coastal Bend Region—19,114 acft

Table 4C.4-1.
Projected Water Demands, Supplies, and Water Needs (Shortages) for Mining Users Duval, Live Oak, and Nueces Counties

	Water Projections						
	2000 (acft)	**2010 (acft)**	**2020 (acft)**	**2030 (acft)**	**2040 (acft)**	**2050 (acft)**	**2060 (acft)**
Duval							
Mining Demand	4,544	5,860	6,630	7,119	7,610	8,108	8,553
Mining Existing Supply							
Groundwater	4,544	4,122	4,112	4,146	4,224	4,299	4,348
Surface water	—	—	—	—	—	—	—
Total Mining Supply	4,544	4,122	4,112	4,146	4,224	4,299	4,348
Mining Balance	—	(1,738)	(2,518)	(2,973)	(3,386)	(3,809)	(4,205)
Live Oak							
Mining Demand	3,105	3,894	4,319	4,583	4,845	5,108	5,341
Mining Existing Supply							
Groundwater	3,105	3,830	3,841	3,655	3,611	3,604	3,586
Surface water	—	—	—	—	—	—	—
Total Mining Supply	3,105	3,830	3,841	3,655	3,611	3,604	3,586
Mining Balance	—	(64)	(478)	(928)	(1,234)	(1,504)	(1,755)
Nueces							
Mining Demand	1,275	1,472	1,555	1,599	1,641	1,682	1,724
Mining Existing Supply							
Groundwater	74	85	90	93	95	98	100
Surface water	1,201	1,387	1,465	936	12	12	12
Total Mining Supply	1,275	1,472	1,555	1,029	107	110	112
Mining Balance	—	—	—	(570)	(1,534)	(1,572)	(1,612)

TWDB Rules for regional water planning require Regional Water Planning Groups to consider water conservation and drought management measures for each water user group with a need (projected water shortage). In addition, the Rules direct water conservation BMPs, as identified by the Water Conservation Implementation Task Force (Task Force), be considered in the development of the water conservation water management strategy.

4C.4.2 Available Yield

In March 2005, the CBRWPG recommended that counties with projected mining needs (shortages) reduce their mining water demands by 15 percent by 2060 using BMPs identified by the Task Force. A 15 percent reduction in irrigation water demand by 2060, results in a maximum savings of 2,343 acft, as shown in Table 4C.4-2.

Table 4C.4-2.
Projected Water Demands and Needs (Shortages) for Mining Users Considering a 15 Percent Demand Reduction by 2060 Duval, Live Oak, and Nueces Counties

	Water Projections					
	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)	2060 (acft)
Duval						
New Demand	5,714	6,299	6,585	6,849	7,095	7,270
Expected Savings	147	332	534	761	1,014	1,283
New Shortage	(1,592)	(2,187)	(2,439)	(2,625)	(2,796)	(2,922)
Shortage Reduction	8%	13%	18%	22%	27%	31%
Live Oak						
New Demand	3,797	4,103	4,239	4,361	4,470	4,540
Expected Savings	97	216	344	485	639	801
New Shortage	—	(262)	(584)	(750)	(866)	(954)
Shortage Reduction	100%	45%	37%	39%	42%	46%
Nueces						
New Demand	1,472	1,555	1,539	1,518	1,493	1,465
Expected Savings	—	—	60	123	189	259
New Shortage	—	—	(510)	(1,411)	(1,383)	(1,353)
Shortage Reduction	—	—	11%	8%	12%	16%
Total Savings	**244**	**547**	**938**	**1,369**	**1,841**	**2,343**

The Task Force report lists the following industrial BMPs that may be used to achieve the recommended water savings:[3]

1. Industrial Water Audit
2. Industrial Water Waste Reduction
3. Industrial Submetering
4. Cooling Towers
5. Cooling Systems (other than Cooling Towers)
6. Industrial Alternative Sources and Reuse and Recirculation of Process Water
7. Rinsing/Cleaning
8. Water Treatment
9. Boiler and Steam Systems
10. Refrigeration (including Chilled Water)
11. Once-Through Cooling
12. Management and Employee Programs
13. Industrial Landscape
14. Industrial Site Specific Conservation

The Task Force report describes the above BMP methods and how they reduce water use, however information regarding specific water savings and costs to implement conservation programs is generally unavailable. Conservation savings and costs are by nature facility specific. Since mining entities are presented on a county basis and are not individually identified, identification of specific water management strategies are not a reasonable expectation.

4C.4.3 Environmental Issues

The Task Force BMPs have been developed and tested through public and private sector research, and have been applied within the region. Such programs have been installed, and are in operation today, and are not expected to have significant environmental issues associated with implementation. For example, most BMPs improve water use efficiency without making changes to wildlife habitat. Thus, the proposed conservation practices do not have anticipated potential adverse effects, and in fact have potentially beneficial environmental effects.

[3] Water Conservation Implementation Task Force, Report to the 79th Legislature, Texas Water Development Board,

4C.4.4 Engineering and Costing

The Coastal Bend Region recommends implementing water conservation for mining users with shortages to reduce their water demand by 15 percent by 2060. The three counties with projected shortages (Duval, Live Oak, and Nueces) can save up to 2,343 acft in 2060. Costs to implement BMPs varies from site to site and the Coastal Bend Region recognizes that mining industries will pursue conservation strategies that are economically feasible with water savings benefits. For this reason, it is impractical to evaluate the costs of implementing mining water conservation strategies.

4C.4.5 Implementation Issues

Demand reduction through water conservation is being implemented throughout the Coastal Bend Region. The rate of adoption of efficient water-using practices is dependent upon public knowledge of the benefits, information about how to implement water conservation measures, and financing.

There is public support for mining water conservation and it is being implemented at a steady pace, and as water markets for conserved water expand, this practice will likely reach greater potentials. The TWDB has industrial water conservation programs including presentations and workshops for utilities who wish to train staff to develop local programs including water use site surveys, publications on industrial water reuse potential, and information on tax incentives for industries that conserve or reuse water. Future planning efforts should consider the use of detailed studies to fully determine the maximum potential benefits of mining conservation.

4C.4.6 Evaluation Summary

An evaluation summary of this water management option is provided in Table 4C.4-3.

Table 4C.4-3.
Evaluation Summary of Mining Water Conservation

Impact Category	***Comment(s)***
a. Water Supply 1 Quantity 2. Reliability	 1. Firm Yield: 2,343 per acft/yr 2. Cost: Highly variable based on BMP selected and facility specifics.
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. None or low impact. 2. None or low impact. 3. None or low impact. 4. None or low impact. 5. None. 6. No cultural resources affected. 7. None or low impact.
c. Impacts to State water resources	• No apparent negative impacts on water resources
d. Threats to agriculture and natural resources in region	• None
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Standard analyses and methods used
g. Interbasin transfers	• None
h. Third party social and economic impacts from voluntary redistribution of water	• None
i. Efficient use of existing water supplies and regional opportunities	• Improvement over current conditions by reducing the rate of decline of local groundwater levels.
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• None

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4C.5 Reclaimed Wastewater Supplies (N-5)

4C.5.1 Description of Strategy

A part of the quantity of water that is used for municipal and industrial purposes is consumed and a part is used for sanitary waste removal from homes, and for sanitary and process-related water use in commercial and industrial establishments. In the Coastal Bend Area, wastewater is collected, treated to acceptable standards as specified by regulatory agencies—Texas Commission on Environmental Quality (TCEQ) and U.S. Environmental Protection Agency (EPA)—and is either reused for non-potable purposes such as industrial uses or golf course irrigation or discharged to some receiving water. In the Corpus Christi area, significant treated effluent quantities are discharged into streams that flow into the bays and meet a part of the freshwater needs of the Nueces Estuary. The purpose of this section is to describe reclaimed wastewater reuse options and present estimates of the quantities of water supply that may be made available through: (1) wastewater reuse for municipal and industrial non-potable purposes; (2) wastewater diversions to the Nueces Delta to enhance biological productivity of estuarine marshes (in comparison to the present practice of direct discharge of wastewater into the bays and into streams that flow into the bays); and (3) discussions of wastewater reuse and water conservation effects upon estuarine inflows.

Both reuse and diversion to the Nueces Delta present opportunities to increase the Corpus Christi area water supply. In the Interim Order[1] of March 9, 1992, the TCEQ established temporary operational procedures for the City's reservoirs that included a monthly schedule of minimum desired inflows to Nueces Bay. The 1992 Interim Order directed studies of the effects of freshwater releases upon the estuary and the feasibility of relocating wastewater discharges to the upper estuary locations where increased biological productivity could justify an inflow credit computed by multiplying the amount of discharge by a number greater than one. These studies included development of the Allison Wastewater Treatment Plant (WWTP) Demonstration Project.

[1] Interim Order Establishing Operational Procedures Pertaining to Special Condition 5.B, Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, Nueces River Authority, and the City of Three Rivers, Texas Water Commission (now TCEQ), Austin, Texas, March 9, 1992.

On April 28, 1995, the TCEQ replaced the 1992 Interim Order with an Agreed Order[2] (1995 Agreed Order) amending the Choke Canyon Reservoir/Lake Corpus Christi (CCR/LCC) System operational procedures. The 1995 Agreed Order directed the Nueces Estuary Advisory Council (NEAC) to continue studying the development of a methodology using a multiplier system for granting credits for specific return flows that increase biological productivity.

On April 17, 2001, the TCEQ issued an amendment to the 1995 Agreed Order to revise operational procedures in accordance with revisions requested by the City of Corpus Christi. Changes included: (1) passage of inflows to Nueces Bay and Estuary at 40 percent and 30 percent reservoir system capacity upon institution of mandatory outdoor watering restrictions; (2) calculating reservoir system storage capacity based on most recently completed bathymetric surveys; and (3) provisions for operating Rincon Bayou diversions and conveyance facility from Calallen Pool to enhance the amount of freshwater to the Nueces Delta. Nueces Delta projects, such as Rincon Bayou and Allison WWTP Demonstration Projects, include the following potential benefits: increased water supply, increase positive flow events for Nueces Delta, and increased sources of nitrogen and lower salinity levels for the upper delta. To evaluate the potential benefits, the 2001 Agreed Order included implementation of an ongoing monitoring program to facilitate an adaptive management program for freshwater inflows to the Nueces Estuary. NEAC prepared a recommended monitoring plan in July 2002, which was initiated in 2003.[3]

These agreements and their history are very important and must be considered in water supply planning, water reuse options, and water management programs for the Corpus Christi area. In the following subsections of this report, estimates of the quantities of municipal and industrial wastewater currently discharged are presented, and wastewater reuse practices and plans by cities and industries, and potential wastewater diversion to the Nueces Delta are described.

4C.5.2 Inventory and Location of Existing Wastewater Sources

There are about 61 active, permitted domestic and industrial WWTP discharges that discharge to the Nueces Estuary System in the 11-county Coastal Bend Regional Water Planning

[2] Agreed Order Establishing Operational Procedures Pertaining to Special Condition 5.B., Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, Nueces River Authority, and the City of Three Rivers, Texas Natural Resource Conservation Commission, Austin, Texas, April 26, 1995.

[3] City of Corpus Christi, Final Integrated Monitoring Plan Fiscal Year 2005, January 2005.

Area (CBRWPA). These domestic and industrial discharges total about 95,937 acft/yr, based on the 2003 annual discharge from each WWTP (Table 4C.5-1). The Nueces River Authority and TCEQ compiled this list. Figure 4C.5-1 shows the location of the City of Corpus Christi WWTPs, which are the major municipal discharges into the system. Of the 95,937 acft, major municipal/domestic discharges generate about 44,971 acft/yr (47 percent), while industrial discharges generate about 50,966 acft/yr (53 percent).

In addition to the list of WWTP discharges to Nueces Estuary System, there are a few other effluent dischargers in the CBRWPA. These dischargers are summarized in Table 4C.5-2. These WWTPs discharged a total of 1,313 acft/yr in 2003. Of the effluent discharges by the permit holders in Table 4C.5-2, the majority of the effluent is from municipal/domestic users. These discharges combined with those into the Nueces Estuary System bring the combined effluent discharge in the CBRWPA to 97,250 acft in 2003.

4C.5.3 Choke Canyon/Lake Corpus Christi Yield Recovery through Diversion of the City of Corpus Christi Wastewater Treatment Plant Effluent to the Nueces Delta

The 1992 Interim Order established operational procedures and included a monthly schedule of desired inflows to Nueces Bay to be comprised of releases, spills, and return flows from the CCR/LCC System. The 1992 Interim Order directed studies of several topics including effects of releases upon the reservoir system and the feasibility of relocating wastewater discharges to locations where increased biological productivity could justify an inflow credit computed by multiplying the amount of discharge by a number greater than one.[4] Studies have been made of the increased productivity from diverting a combination of Nueces River water and wastewater through the Nueces Delta to Nueces Bay instead of releasing river and wastewater flows directly into the Nueces River. Prior to reopening the Rincon Bayou Demonstration Project in 2001, the Nueces River bypassed the Nueces Delta and flowed directly into Nueces Bay except during periods of high flow (Figure 4C.5-2). Studies have shown that diversions of both river water and treated wastewater to the Nueces Delta can be expected to increase primary production by factors of about three to five, respectively, when compared to allowing these waters to enter Nueces Bay via the Nueces River.[5]

[4] Interim Order Establishing operational Procedures Pertaining to Special Condition 5.b., Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, Nueces River Authority, and the City of Three Rivers, Texas Water Commission, Austin, Texas March 9, 1992.

[5] HDR Engineering, Inc. (HDR), et al., "Regional Wastewater Planning Study – Phase II, Nueces Estuary," prepared for the City of Corpus Christi, et al., Austin, Texas, June 1993.

Table 4C.5-1.
Summary of Annual Permitted Wastewater Discharges for 2003 into the Corpus Christi Bay and Nueces Bay System[1,2]

Facility	*Acre-Feet Discharged*
City of Woodsboro	132.54
City of Odem	114.40
City of Sinton	643.58
AEP-Central Power and Light (Lon Hill Power Station)	8.26
City of Corpus Christi – Allison Plant	3,609.32
San Patricio Co. Municipal Utility District #1	476.54
City of Orange Grove	143.73
Bishop Consolidated Independent School District	1.87
City of Agua Dulce	40.36
City of Driscoll	45.90
Coastal Bend Youth City	8.21
Nueces Co. Water Conservation & Improvement District #5	44.65
City of Rockport	1,378.24
Town of Bayside	12.06
City of Taft	580.78
Nueces Co. Water Conservation & Improvement District #4	580.98
U.S. Dept of Navy	968.79
City of Gregory	202.33
City of Ingleside	859.02
E.I. Dupont de Nemours & Co.	5,069.64
Occidental Chemical Corp.	1,245.48
City of Portland	1,513.85
Sublight Enterprises	2.24
Aker Gulf Marine	10.55
Aker Gulf Marine, Partnership	2.70
City of Aransas Pass	853.94
Williams Terminals Holdings, L.L.C.	107.00
Elementis Chromium, L.P.	10,041.29
Citgo Refining & Chemicals	30.19
Citgo Refining & Chemicals,	4,600.83
City of Corpus Christi – Broadway	5,413.52
Coastal Refining & Marketing	2,151.73

Continued on next page

Table 4C.5-1 (continued)

Facility	***Acre-Feet Discharged***
Diamond Shamrock	26.33
Encycle Texas, Inc.	119.51
Tesoro Marine Services	2.52
Javelina Company	242.15
Koch Refining Co.	80.87
Koch Refining Co.	18,549.67
Flint Hills Resources, LP	1,641.25
Neste Trifinery	25.71
Equistar Chemicals, L.P.	1,121.06
Valero Refining Company	4,893.29
City of C.C. Peoples Baptist Church	7.08
City of Corpus Christi – Oso Plant	13,861.86
City of Corpus Christi – Westside	4,801.89
City of Robstown	1,053.86
Tennessee Pipeline Co.	8.03
Texas A & M University System	0.56
City of Corpus Christi - Flour Bluff	2,257.47
City of Corpus Christi – White Cap	940.74
City of Alice	2,045.28
City of Alice	971.78
City of Kingsville	1,910.22
Kleberg County	1.30
Kleberg County	15.48
Rivera Water Conservation & Improvement District	33.87
U.S. Dept. of Navy	87.40
Ticoma Polymers	unknown
City of Bishop	96.33
City of Kingsville	195.77
Texas Ecologists	50.73
Total Discharges	95,936.53

[1] These wastewater dischargers are recognized by the Nueces River Authority and the TCEQ as contributors to freshwater inflows to the Nueces Estuary System.

[2] Annual wastewater discharged, in acft, for 2003. Total Municipal/Domestic discharges – 44,970.96 acft. Total Industrial Discharges – 50,965.57 acft.

Source: TCEQ and Nueces River Authority's 2003 Effluent Monitoring Report.

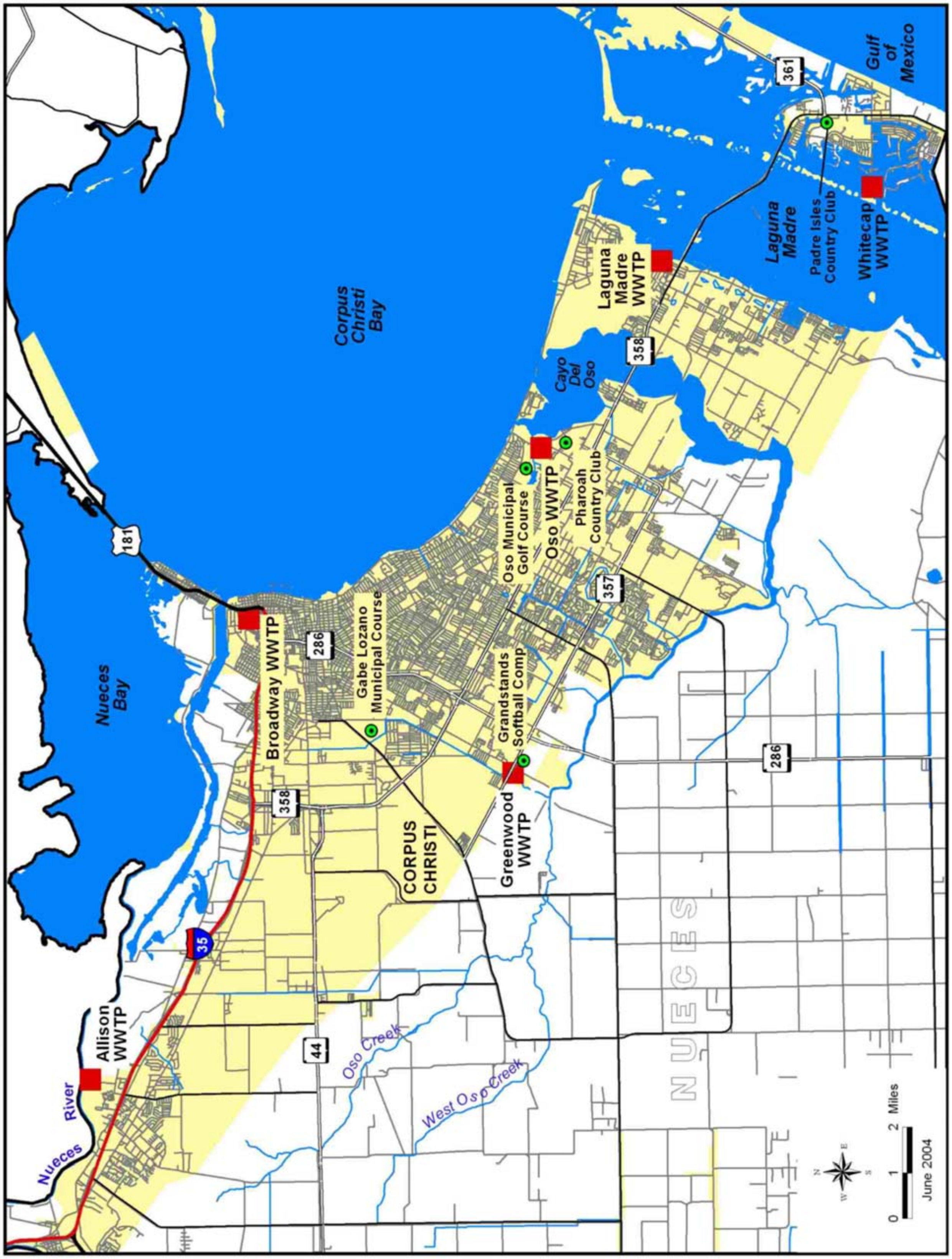


Figure 4C.5-1. City of Corpus Christi Wastewater Treatment Plants

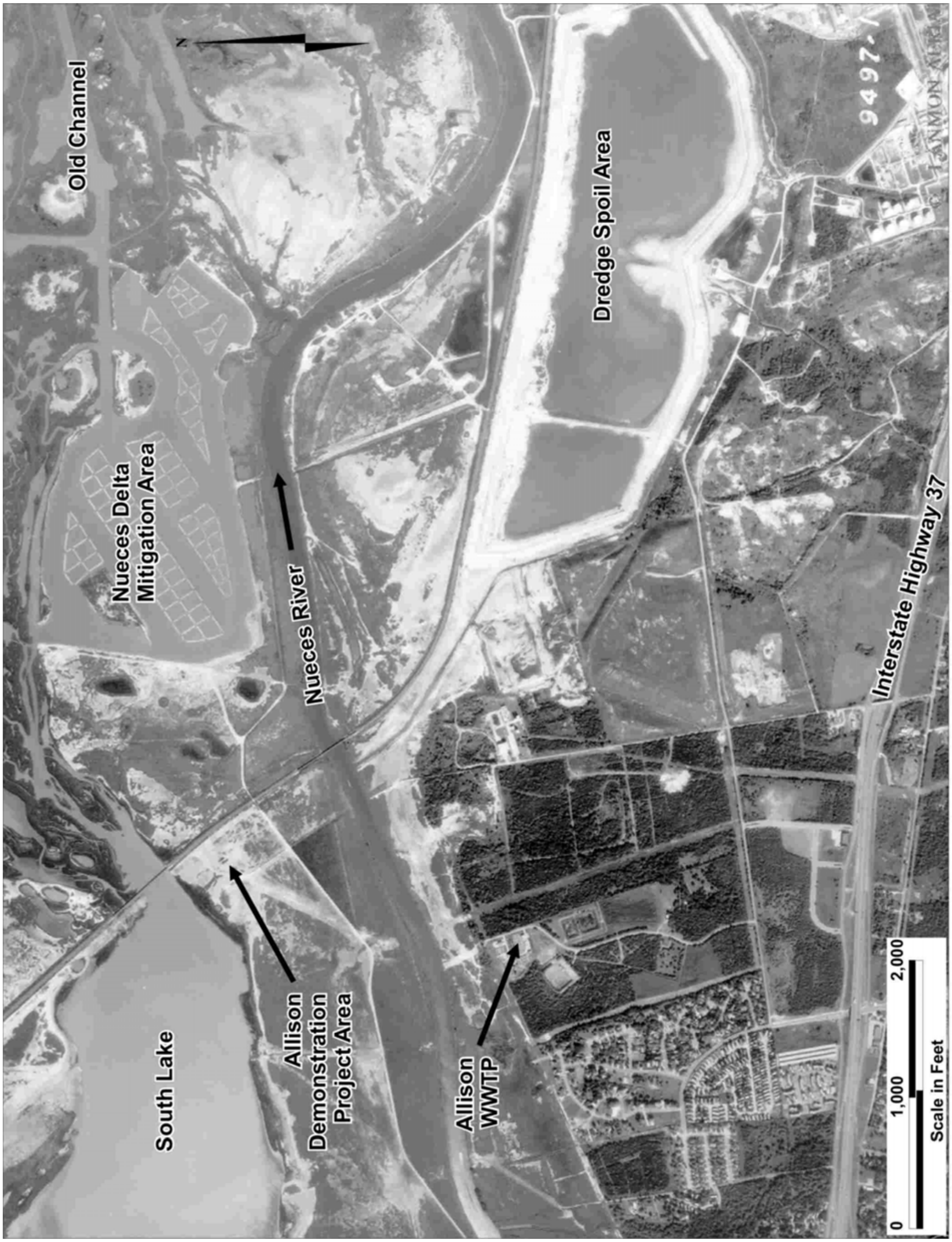
Table 4C.5-2.
Summary of Additional Permitted Wastewater Discharges in the Coastal Bend Regional Water Planning Area[1]

Facility	*Acre-Feet Discharged[1]*
City of Beeville	884.2
Pettus Municipal Utility District	21.0
City of San Diego	128.0
City of George West	52.7
City of Three Rivers	74.5
McMullen Co. Water Conservation & Improvement District #1	0.0[2]
Applied Industrial Materials	0.0[2]
City of Mathis	152.2
Total Discharges	1,312.6

[1] Annual wastewater discharged for 1999. Total municipal/domestic discharges – 3,880.3 acft. Total industrial discharges – 1.1 acft.
[2] Entities hold effluent discharge permits but did not discharge in 1999.
Source: TCEQ and Nueces River Authority's 2003 Effluent Monitoring Report.

In a study[6] performed in 1993, estimates were made of the increase in yield of the CCR/LCC System for alternative river and wastewater diversions under the 1992 Interim Order, considering the productivity increases from river and wastewater effluent diversions to the Nueces Delta (i.e., for river diversions the productivity increase factor used was three and for wastewater effluent diversion the productivity increase factor was five). Using the cost and yield data under the 1992 Interim Order, the diversion alternative which provided the highest yield recovery and lowest cost per acre-foot of yield recovered was the alternative which uses 8.8 MGD of wastewater from the Allison and Broadway WWTPs and a 70 MGD capacity river diversion from Calallen Reservoir to the Nueces Delta.

[6] Ibid.



Source: Naismith Engineering, Inc.

Figure 4C.5-2. Diversion of Corpus Christi WWTP Effluent to the Nueces Delta

This alternative was reevaluated under the 1995 Agreed Order with a productivity factor of three for freshwater diversions to the Nueces Delta and five for wastewater diversions to the delta.[7] The 2001 Agreed Order maintains the same monthly inflow requirements based on CCR/LCC storage capacities as the 1995 Agreed Order, with an added requirement to operate a conveyance facility to deliver up to 3,000 acft/mo from Calallen Pool to Upper Rincon Bayou. These potentials are applicable for the 2006 Plan time period from 2000 to 2060. Under this plan, 8.8 MGD of wastewater from Allison and Broadway WWTPs and 32 MGD or up to 3,000 acft/month river diversion from Calallen would produce an average annual yield recovery of 4,410 acft from year 2000 to 2060, as indicated in Table 4C.5-3. Two additional alternatives were analyzed to determine the potential increases in system yield for the same time period. In one alternative, the 32 MGD river diversion from Calallen Reservoir pool was eliminated and only the 8.8 MGD of wastewater from the Allison and Broadway plants was included with a productivity factor of five. The yield increase provided by this alternative averaged 3,000 acft/yr as shown in Table 4C.5-3. Finally, a third alternative utilized only the 8.8 MGD of wastewater from Allison and Broadway and the productivity factor was reduced to 1.0 to determine the sensitivity of the alternative to the productivity factor. The yield increase provided by this option averaged only 1,100 acft/yr as shown in Table 4C.5-3.

Table 4C.5-3.
Summary of Average Annual Yield Recovered for
Various Wastewater Transfer and River Diversion Alternatives

Diversion or Transfer Capability		Biological Productivity Factors		Average Annual Yield Recovered (acft)
River Diversion (MGD)	Allison and Broadway WWTP (MGD)	River Water	Wastewater	
32	8.8	3	5	4,140[1]
0	8.8	—	5	3,000
0	8.8	—	1	1,100

1 Estimated based on 70 MGD river diversion yielding 2,500 acft additional annual yield when compared to alternative two (8.8 MGD Allison and Broadway WWTP with Biological Productivity Factor of five).

[7] HDR et al., "Trans-Texas Water Program – Corpus Christi Study Area – Phase II Report," City of Corpus Christi, et al., September 1995.

Since the 1995 Trans-Texas Water Program Study, the City of Corpus Christi has initiated some programs related to their wastewater facilities plan that have changed the analyses of alternatives for diversions of effluent to the Nueces Delta. The changes include potentially closing the Broadway WWTP and pump all flows to the Greenwood WWTP, the construction and operation of the Allison WWTP Nueces Delta Demonstration Project, and assessing the diversion of Greenwood WWTP effluent to the Nueces Delta.

In mid-1997, the City began preparing a plan to work with State and Federal agencies involved with the Agreed Order that would provide the freshwater flow needs of the Nueces Bay System during drought conditions through diversions of treated wastewater effluent, rather than the passage of CCR/LCC System inflows. The strategy involved constructing and operating facilities to divert both industrial and municipal wastewater effluents to locations in the Nueces Delta based on the productivity benefits determined by the preliminary findings from the Allison WWTP Diversion Project.

In 1997 to 1998, the City constructed a pipeline from the Allison WWTP to the Nueces Delta as part of a demonstration project to assess the impact of the WWTP effluent on the estuary. The Allison WWTP Diversion Demonstration Project was completed and in October 1998, the City began diverting approximately 2 million gallons per day (or 2,240 acft/yr) of effluent from Allison WWTP to the Nueces Delta. Intensive data collection programs were conducted for 5 years (from 1999 to 2003) and the final summary report is currently being prepared.[8]

The City is considering closure of the Broadway WWTP due to its age. All wastewater flows from the Broadway WWTP service area would be diverted to the Greenwood (also called the Westside) WWTP. The 2001 Agreed Order allows the City relief from inflow requirements when the reservoir system is below 30 percent and Drought Condition III has been implemented, however return flows directed at the Nueces Bay and/or Nueces Delta shall continue. The changes in the operating plan increase the freshwater availability for Nueces Bay through return flows during drought conditions and increase the amount of dependable water supply available from the CCR/LCC System for municipal and industrial use.

An important issue associated with any diversion of domestic wastewater to the Nueces Delta is the level of wastewater treatment necessary for the wastewater diverted. Studies to date

[8] City of Corpus Christi, Final Integrated Monitoring Plan Fiscal Year 2005, January 2005.

have shown that the enhancement of productivity in the Delta is dependent upon the volume of freshwater flow and concentration of nutrients in the wastewater; therefore, effluent treated to a higher quality may prove to be less effective for primary production in the Delta. Thus, the cost savings in wastewater treatment to remove more nutrients would lower the overall costs of implementing projects to divert wastewater to the Nueces Delta and thereby further reduce the costs of yield recovered from the CCR/LCC System.

In January 2004, a study[9] was conducted to evaluate groundwater discharge to the Nueces Bay and quantify the potential nutrient flow to the Bay from groundwater. Nitrate concentrations were used to measure nutrients. The results indicated between 15,000 to 40,000 kg of nitrate are released to the Nueces Bay through groundwater discharge. This estimate is only exceeded as a source of nitrogen by treated wastewater return flows.

4C.5.4 Wastewater Reuse for Municipal and Industrial Purposes

4C.5.4.1 Texas Administrative Code, Chapter 210 – Use of Reclaimed Water

There are two general qualities of treated wastewater allowed for reclaimed water use under TCEQ rules, Chapter 210. These are grouped and defined as Type I and Type II uses.

Broadly defined, Type I reclaimed water quality is required where contact between humans and the reclaimed water is likely. The types of water uses for which Type I reclaimed water could be generally used are:

- Residential irrigation;
- Urban irrigation for public parks, golf courses with unrestricted public access, school yards or athletic fields;
- Fire protection;
- Irrigation of food crops where the reclaimed water may have direct contact with the edible part of the crop;
- Irrigation of pastures for milking animals;
- Maintenance of water bodies where recreation may occur;
- Toilet or urinal flushing; and
- Other similar activities where unintentional human exposure may occur.

Type I water can also be used for all Type II uses listed below.

[9] Breier, Edmonds, and Villareal, "Submarine Groundwater Discharge and Associated Nutrient Fluxes to the Corpus Christi Bay System," January 2004.

Type II water quality is where such human contact is unlikely. The types of water uses that would generally be considered as eligible for Type II reclaimed water are:

- Irrigation of sod farms, silviculture, limited access highway rights-of-way, and other areas where human access is restricted (restricted access can include remote sites, fenced or walled borders with controlled access, or the site not being used by the public when normal irrigation operations are in process);
- Irrigation of food crops where the reclaimed water is not likely to have direct contact with the edible part of the crop;
- Irrigation of animal feed crops, other than pasture for milking animals;
- Maintenance of water bodies where direct human contact is unlikely;
- Certain soil compaction or dust control uses;
- Cooling tower makeup water;
- Irrigation or other non-potable uses of reclaimed water at a wastewater treatment facility; and
- Any eligible Type I water uses.

At a minimum, the TCEQ requires that the reclaimed water will be of the quality specified in the rules (Table 4C.5-4).

Table 4C.5-4.
Quality Standards for Using Reclaimed Water (30-day Average)

Type I	
BOD_5 or $CBOD_5$	5 mg/L
Turbidity	3 NTU
Fecal Coliform	20 CFU/100 ml (geometric mean)
Fecal Coliform (not to exceed)	75 CFU/100 ml (single grab sample)
Type II Other than Pond Systems	
BOD_5	20 mg/L
Or $CBOD_5$	15 mg/L
Fecal Coliform	200 CFU/100 ml (geometric mean)
Fecal Coliform (not to exceed)	800 CFU/100 ml (single grab sample)
Type II Pond Systems	
BOD_5	30 mg/L
Fecal Coliform	200 CFU/100 ml (geometric mean)
Fecal Coliform (not to exceed)	800 CFU/100 ml (single grab sample)

mg/L = milligrams per liter
BOD_5 = Biochemical Oxygen Demand (5-day)
C/BOD_5 = Carbonaceous Biochemical Oxygen Demand (5-day)
CFU/100 ml = Colony Forming Units per 100 milliliter
Source: TNRCC, 1997

A summary of the existing municipal wastewater reuse projects currently in operation in the Coastal Bend Region is presented in Table 4C.5-5. Many of these projects are discussed in more detail in the subsequent sections.

Table 4C.5-5.
Existing Municipal Wastewater Reuse Projects in Coastal Bend Region

County	Entity	Use	Flow (MGD)
Aransas	City of Rockport	Golf course irrigation	0.6065[1]
Bee	City of Beeville	WWTP, irrigation, construction	0.6907[2]
Jim Wells	City of Alice	Golf course irrigation, Coastal Bermuda turf irrigation	0.1906[1]
Live Oak	City of George West	Local landowner irrigation	0.0056[2]
Nueces	City of Corpus Christi	Pharoah Valley Golf Course irrigation	0.107[3]
		Oso Golf Course irrigation	0.143[3]
		Gabe Lozano Golf Course irrigation	0.249[3]
		Baseball field irrigation	0.006[3]
		Padre Isles Golf Course irrigation	0.574[3]
San Patricio	City of Mathis	Local Landowner irrigation	0.0446[1]
	City of Aransas Pass	Wetlands enhancement (proposed)	0.0936[4]
		Irrigation of industrial land (proposed)	0.8424[4]

Sources:
1 Historical self-reporting reuse data compiled by TWDB (2001 data).
2 Historical self-reporting reuse data compiled by TWDB (2000 data).
3 Wastewater Reuse Study prepared for City of Corpus Christi by HDR Engineering, Inc. and correspondence with Carl Crull, February 2002.
4 Confirmed by Don Roach, San Patricio Municipal Water District, July 2004. Engineering Feasibility Report for Northshore Resource Conservation Project prepared for San Patricio Municipal Water District by Naismith Engineering, Inc., October 1999.

4C.5.4.2 City of Corpus Christi Wastewater Reuse

The City of Corpus Christi's present water conservation and reuse plans emphasize education and changes to the water rate structure to promote conservation and reuse. Water customers have been requested to reduce water usage wherever possible through the installation of more efficient plumbing fixtures and through landscape watering schedules. The City adopted plans to reduce water use by diverting a portion of its WWTP effluent to some public facilities for irrigation purpose; i.e., for golf course and park irrigation. This practice has some limitations, as the need for wastewater for irrigation is not continuous and is often highly variable. Thus, the wastewater is not reused in the same amount every month. For example, it is not used after heavy rains and it is not used during winter months when the grass is not growing and will not consume the wastewater. For example, in 2001, wastewater reuse from the City's WWTPs for golf course and baseball park irrigation was about 394 million gallons (or 1,210 acft/yr). In 2002, the wastewater reuse was reduced to 333 million gallons (or 1,020 acft).

Water conservation can impact the quantity of wastewater generated, and thus available for reuse and/or for credit to meet freshwater needs of the Nueces Estuary. Figure 4C.5-3 shows that while the general population of the City of Corpus Christi is growing, the total quantity of wastewater treated and discharged has remained relatively constant.

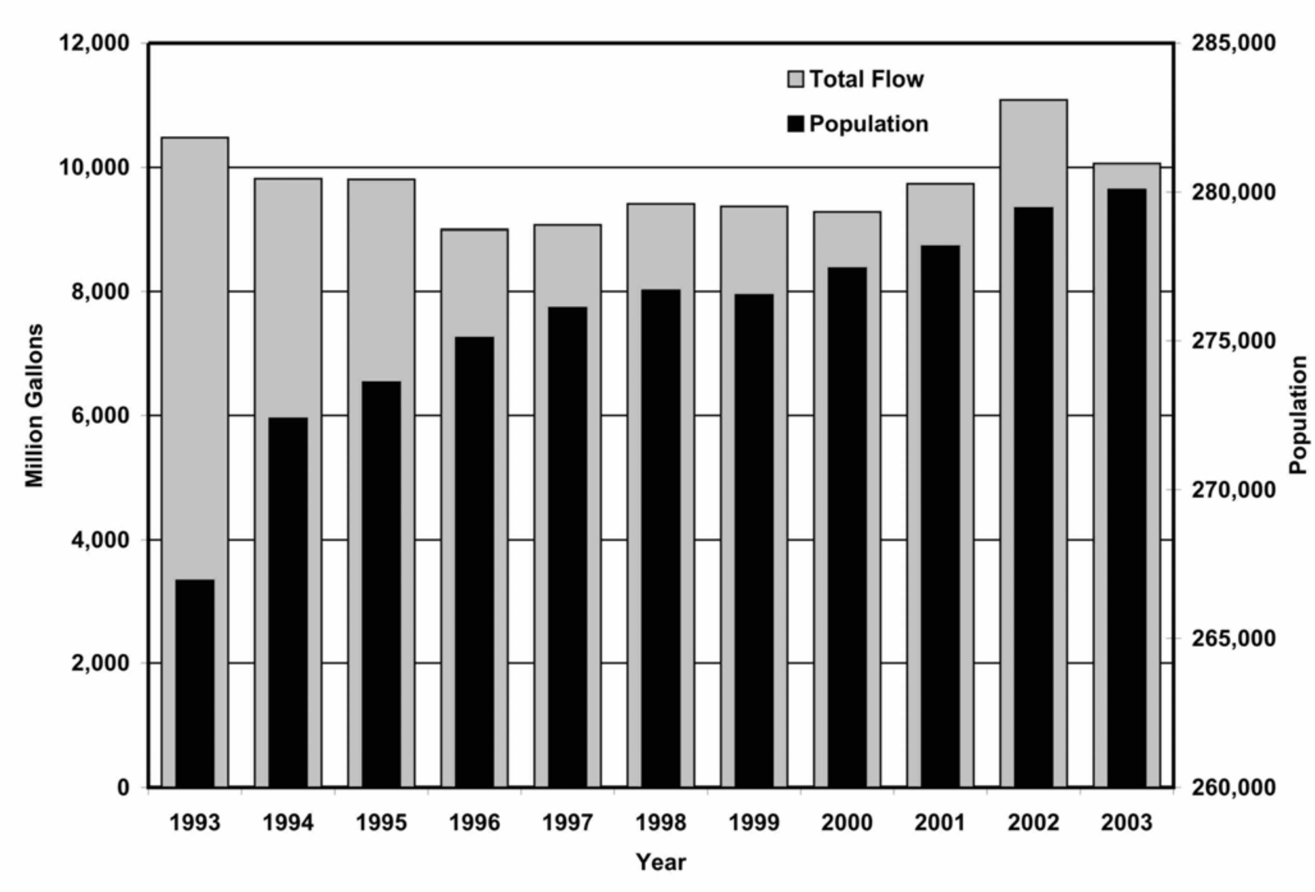


Figure 4C.5-3. City of Corpus Christi Wastewater Flows versus Population

During the 1984 drought, treated wastewater was made available to the public for use in irrigating lawns; this plan remains in effect within the City's operational framework and can be fully implemented in the event it is necessary. During the drought of 1984, the City considered diverting treated wastewater to local industrial facilities for cooling tower make-up water in an attempt to reduce the quantity of CCR/LCC System water needed for these purposes. However, this plan was severely limited as the WWTPs are not conveniently located and the discharge is not readily available to industrial plants, requiring the construction of extensive forcemains to deliver the wastewater to these facilities. In addition, high chloride concentrations existed in the wastewater effluent, particularly from the Broadway WWTP, making this source unattractive since high chloride concentrations require costly treatment before industries can use the water.[10]

Since the industrial facilities are large consumers of both raw and treated water from the CCR/LCC System, and since it was not possible to economically substitute significant quantities of wastewater for industrial uses during the drought, as noted above, the City asked industries to minimize water usage without seriously jeopardizing production. The industrial facilities in the area responded by carefully studying ways to more efficiently use and re-use the water they receive and by considering alternative sources of water. Many of the options studied by industry for reuse of their own wastewater have been implemented.

4C.5.4.3 Industrial Wastewater Reuse

4C.5.4.3.1 Process Descriptions and Water Use

In general, primary industrial customers utilize similar facility processes that are mainly responsible for water consumption, such as cooling towers and boilers. In addition, industry also uses freshwater for drinking water, sanitary use, and equipment washdown and fire protection. The primary differences in water usage, however, are product related. Process requirements influence the size and type of cooling systems and boilers needed for steam production. Process and product differences affect water quantity and quality needs. Depending on the industrial facility's plant size, age, and market conditions, different plants in the same industry category can have different water needs and water use efficiencies.

The petroleum refinery and petrochemical industries produce numerous products such as fuel oil, gasoline, petrochemicals and kerosene. The diverse chemical manufacturing industry served by the City of Corpus Christi water system produces various products such as high quality plastics, weather resistant paints, alumina, chromium compounds, Freon, adhesives, formaldehyde, synthetic resins, and pharmaceuticals. In general, the chemical manufacturing

[10] During the 1984 drought, one refinery used some wastewater from the City's Broadway Wastewater Treatment Plant. The treated wastewater was mixed with the treated water and the refinery's industrial wastewater but required 8 hours of chlorination to control viruses and lime softening to control hardness.

industry requires more water per unit production due to the nature of the chemical manufacturing process and the water content of certain produced chemicals.

In most area industries, heat dissipation is the single largest demand for water within a plant. Typically, water is used to remove heat from process streams. The heated water is cooled by a cooling water system. Cooling water systems in the study area are either recirculating freshwater cooling systems, which use cooling towers, or are once-through cooling systems. Once-through cooling systems in the study area are primarily steam-electric power plants that use very large volumes of seawater to cool the steam (for reuse) required to turn turbines for electric power generation. In order to prevent unacceptable build-up of minerals and salts, a portion of the cooling water from the cooling tower is discharged or blown down. Thus a continuous supply of new water (make-up) is required to supplement the freshwater lost due to evaporation and blow down.

Boiler-feed water is the second largest use of freshwater. This involves heating water to produce steam for process use. Steam is used to add heat to process streams and to power turbines for generating electricity. Steam is also used to drive pumps, compressors and fans, as well as in the process to facilitate fractionation in petroleum refineries and chemical plants. This steam is condensed and returned to the boiler feed water system to be reused.

The third largest industrial use of City water is in the process stream, where water is used as a feedstock, for example, in the reforming process to produce hydrogen in refineries and to scrub air contaminants (cleaning a contaminated airstream with a liquid), in digesters, or for chemical and product separation. The remaining use of freshwater within industry is primarily for drinking water, sanitary use, equipment washdown, and fire protection.

For most chemical and refining plants, cooling accounts for 60 to 75 percent of the water use, boiler water use accounts for 20 to 30 percent, process water accounts for 5 to 9 percent, and potable or sanitary use accounts for 1 percent. Chemical plants typically utilize more water in their process streams and in their products, while refineries, which produce steam for electrical generation, utilize more water for boiler use.

The following factors influence and control current water use, the potential for industrial water conservation, and the potential for area industries to use alternative sources of water, including treated municipal wastewater, brackish groundwater, and seawater. The list of important factors includes:

- The location of each water-using industrial plant in relation to a source or sources of water;
- The location of each water-using industrial plant in relation to streams or other features into which wastewater can be discharged;
- The type of industry, which determines the type of water use (i.e., refineries which use varying and/or different grades of crude petroleum, refineries which are producing reformulated gas, chemical plants which produce a range of chemicals and pharmaceuticals, and plants which extract compounds from ores to produce metals and other products); and
- The metallurgy of equipment in the cooling system that would come in contact with the cooling water.

4C.5.4.3.2 Industry Water Conservation and Water Quality Needs

During the 1984 drought, the City requested that its industrial water customers minimize water use from the CCR/LCC System without seriously jeopardizing production. Industry representatives responded by carefully studying ways to reduce water demands through increased efficiency in the use of existing supplies, reuse of available supplies, and development and use of alternative water supplies. In response to water shortages during the drought of 1984, concerns about rising costs of water, increased regulation and rising costs of wastewater treatment and disposal, and public interest in water conservation, Corpus Christi area industries implemented water conservation and water reuse measures that have significantly reduced quantities of water needed per unit of production. For example, Corpus Christi area petroleum refineries use between 35 and 46 gallons of water per barrel of crude oil refined, while refineries in Houston use 91 gallons, and refineries in Beaumont use 96 gallons.

As a result of these events, the major Corpus Christi area industrial customers have implemented various water conservation measures since the 1984 drought period and especially in the last 3 to 5 years, particularly during periods of plant expansion. Since 1984 there has been increasing quantities of water conserved by local industry. Provided in Table 4C.5-6 is a list of water conservation measures, which have been implemented by industry as well as future water conservation strategies, including wastewater reuse. In comparison to other Texas industry, the industries in Corpus Christi have one of the best records of water use efficiency based on results of the TWDB's "Pequod Survey."[11]

[11] Texas Industrial Water Usage Survey, Pequod Associates, Inc. and TWDB, Austin, Texas, August 1993.

Table 4C.5-6.
Water Conservation Measures
Corpus Christi Area Industry

Current Measures

- Recycling Cooling Tower and Boiler Blowdown
- Improved Control Systems
- Dry Cooling, Air Cooled Heat Exchangers
- More Efficient Drift Eliminators
- Changed Washdown Procedures
- Automatic Cooling Tower Blowdown
- Leak Detection/Repair
- Steam Condensate Recovery
- Reuse Wastewater Treatment Effluent for Firewater, Cooling Tower Make-up
- Cycling-Up Cooling Towers
- Stormwater Reuse
- Salt Water for Area Washdown
- Salt Water Lubrication of Circulating Water Feed Pumps
- Reverse Osmosis with Demineralization
- Voluntary Water Conservation Planning
- Regulatory Requirement to Consider Reuse
- Saltwater for Cooling

Future Measures

- Uniform blending of Lake Texana/Nueces River waters to provide consistently better water quality with less variation in dissolved minerals.
- Increased Evaluation of Alternative Water Sources to Replace Treated City Water
- Additional Application of Reverse Osmosis Treatment
- Increased Wastewater Treatment Plant Effluent Reuse
- Possible Side-Stream Softening
- New Process Changes
- Additional Steam Leak Repair
- New Chemical Treatment Technology
- Increased Water Audit by Industry
- Possible Water Conservation Incentives
- Possible Regulatory or Local Government Water Conservation Planning Goals
- Increasing Water Conservation Research and Education
- Additional Industry Pursuing Water Conservation Measures

The water quality requirements of industry in the area are determined by the water quality constraints for cooling tower make-up, boiler make-up, process water, and potable water. Since water used for cooling tower make-up and boiler make-up are the predominant industrial uses of water, the opportunities to substitute alternative water sources for cooling towers, and boiler make-up present the greatest potential opportunities to conserve existing freshwater supplies. Because cooling tower make-up can utilize water of poorer quality as compared to the high quality water required in a boiler, the reuse of wastewater effluent in cooling towers provides the best opportunity for this alternative water supply.

The quality of water used by an industry can have numerous impacts on their facilities. Industrial process equipment can degrade, cooling efficiency can be reduced, health and safety problems can develop, and permitted wastewater discharge limits can be exceeded if the water has undesirable qualities. The most frequent water quality problems within industrial water systems are scaling, corrosion, biological growth, fouling, and foaming. In addition, permitted wastewater discharge parameters, as well as cooling tower solid waste characteristics, are influenced by cooling tower water quality. Solid wastes generated from water treatment and control facilities such as cooling tower basin sludge, have characteristics that affect the costs of handling and disposal, triggering new regulatory requirements, and may affect waste minimization programs.

The high degree of purity required for boiler water is critical because it is used to make steam. If water quality is not properly controlled, contamination from minerals such as calcium and magnesium will be deposited on boilers, restricting the transfer of heat to the boiler water. In addition, boiler metal will corrode and deposits in the steam system will adversely affect the other equipment. Water sources, which have higher concentrations of minerals, create a greater potential for requiring costly pretreatment.

4C.5.4.4 Potential Industrial Reuse of Broadway Municipal Effluent Feasibility Study

The potential for industrial reuse of the City of Corpus Christi Broadway WWTP effluent was considered in a 1996 study[12] that evaluated the feasibility for major industries along the Corpus Christi Ship Channel to reuse the Broadway WWTP effluent. Since the Broadway WWTP is located in close proximity to a number of major industries, it was considered by the

[12] Feasibility Study of Industry Reuse of Broadway Municipal Wastewater Treatment Plant Effluent, prepared for the City of Corpus Christi and the Port of Corpus Christi, Board of Trade, July 1996.

City as the source of effluent to be evaluated for reuse. Since each industry has their own unique set of water quality needs and constraints that affect their ability to reuse municipal WWTP effluent, the type of industry and their needs influenced the feasibility of wastewater reuse.

The study identified conditions necessary to convey effluent from the Broadway WWTP to the major industries in the area. In addition, this study identified issues associated with industrial reuse in general.

The preliminary feasibility study determined that the Broadway WWTP effluent is a renewable alternative water supply which can be used by industry in their water supply mix. Particularly when drought conditions limit water supplies, the Broadway effluent can be a cost effective water supply option. Depending on the cost of Broadway WWTP effluent water, including pumping and piping delivery costs, operation and maintenance costs, and potential wastewater treatment equipment and chemical costs, reuse of the Broadway WWTP effluent might be an attractive water supply alternative. Coordination with each industry on a case-by-case basis would be necessary to determine the most cost-effective plan for industry reuse of the Broadway effluent. The study recommended that a plan for the providing Broadway effluent to industry be evaluated along with future plans for long-term operation of the Broadway WWTP. Since the Broadway WWTP is schedule to close, Greenwood WTP may be considered a more reliable effluent source for reuse projects.

4C.5.4.5 City of Corpus Christi Broadway Wastewater Treatment Plant Diversion Project

In 1997, an additional study[13] was undertaken regarding the City of Corpus Christi Broadway WWTP. This plant is the City's oldest WWTP. The plant service area has experienced an approximate 39 percent reduction in population due to an out-migration starting in 1960. The City's latest plan considers phased elimination of the Broadway WWTP, diverting flows to the Greenwood (Westside) WWTP, which is currently being expanded to treat additional wastewater flow. A feasibility study of Broadway to Greenwood implementation alternatives was completed in late 1999. The wastewater discharges from Greenwood WWTP have increased from 3,939 acft/yr in 1998 to 13,486 acft/yr in 2002. Although the Broadway WWTP is planned for closure, on March 23, 2005, the wastewater discharge permit was renewed for Broadway WWTP.

[13] "City of Corpus Christi Wastewater Facilities Implementation Plan, Oso & Greenwood Service Areas and Broadway Plant Diversion," City of Corpus Christi, February 1997.

With the potential diversion of wastewater flow from the Broadway WWTP to the Greenwood WWTP, the direct use of effluent from the Broadway WWTP site is not an economical option. Diversion of effluent from the Greenwood WWTP to the upper Nueces Delta is an alternative under consideration by the City of Corpus Christi. If the City proceeds with the facilities implementation plan recommendation, approximately 15 MGD of Greenwood WWTP effluent could be diverted to the Nueces Delta by the year 2025.[14]

4C.5.4.6 Oxy Petrochemicals Municipal Wastewater Reuse Feasibility Study

In 1996, Oxy Petrochemicals, Corpus Christi, Texas (now known as Equistar Chemicals, L.P.), conducted a feasibility study[15] to assess the reuse of the City of Robstown WWTP effluent to supplement their industrial water supply.

Equistar Chemicals, L.P. receives all of its water supply from the City of Corpus Christi. The City water is used for drinking, domestic use, fire suppression, cooling tower make-up, equipment washdown, and other small uses. The City of Robstown WWTP effluent would have been reused as cooling tower make-up water, thus reducing the use of water purchased from the City of Corpus Christi.

According to TWDB records, Equistar Chemicals, L.P. used 305 acft reclaimed wastewater supplies in 1998; 283 acft in 1999; 258 acft in 2000; and 234 acft in 2001.

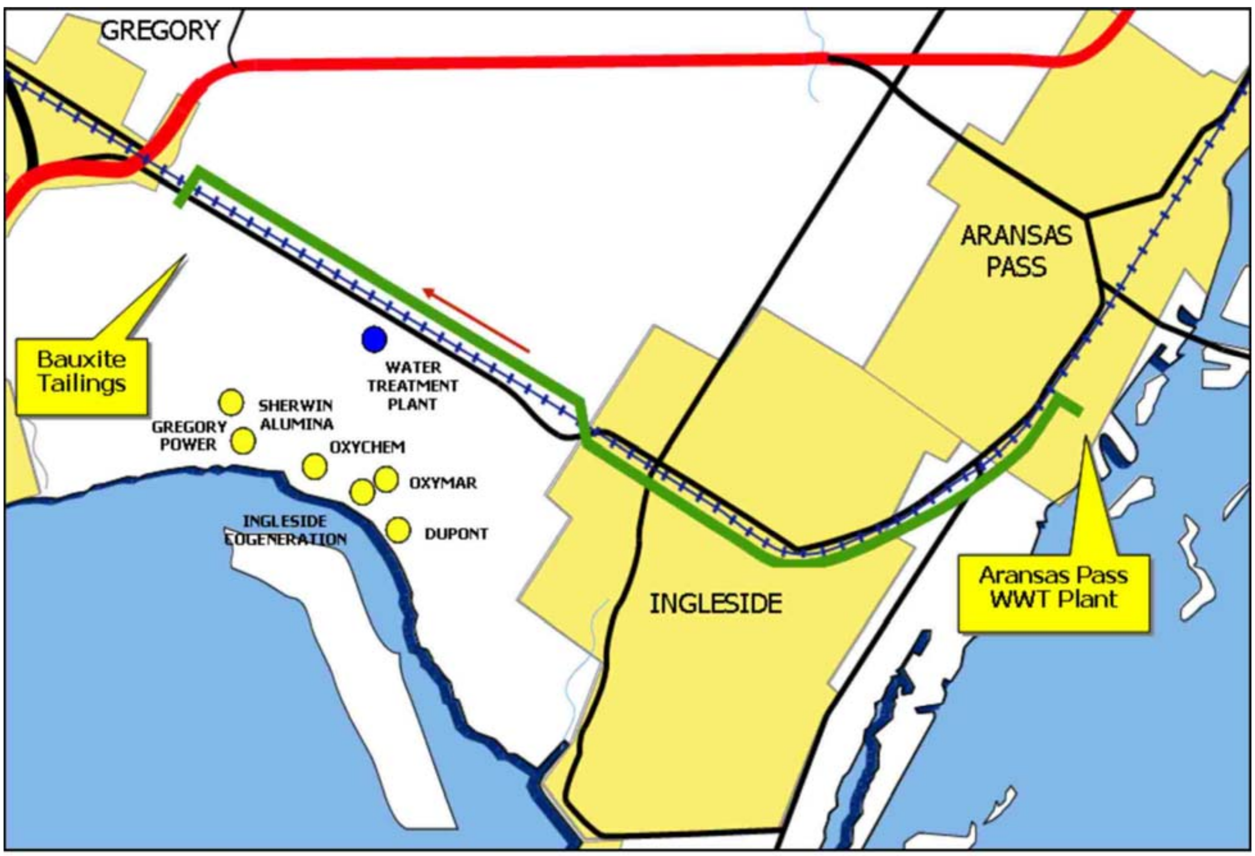
4C.5.4.7 Water Supply Effect of Northshore Regional Wastewater Reuse Project of San Patricio County

The Northshore area of San Patricio County includes the Cities of Portland, Gregory, Ingleside, Ingleside-on-the-Bay, and Aransas Pass. The Northshore Regional Wastewater Reuse, Water Supply, and Flood Control Planning Study indicated that municipal wastewater reuse was a cost effective water supply alternative. As a result, the Northshore Resource Conservation Project - Phase I[16] was implemented. This wastewater reuse project includes implementation of the reuse of treated effluent and sewage sludge from the City of Aransas Pass. This reuse project will reduce demands on existing freshwater supplies and help meet water conservation plan

[14] Ibid.
[15] “Municipal Wastewater Reuse Feasibility Study, Oxy Petrochemicals, Corpus Christi, Texas,” Oxy Petrochemicals, August 1996.
[16] “Engineering Feasibility Report and Environmental Assessment for the Northshore Resource Conservation Project – Phase I,” San Patricio Municipal Water District, June 1997 (Updated October 1999).

requirements for area industries. The City of Aransas Pass WWTP currently discharges to Redfish Bay and the effluent and sludge to Sherwin Alumina Company reuse project.

The Northshore Resource Conservation Project has been developed to implement two conservation measures: 1) beneficial reuse of municipal sewage sludge from the City of Aransas Pass; and 2) replacing some of the freshwater Sherwin Alumina Company uses with reclaimed municipal wastewater. A pipeline was constructed from the City of Aransas Pass WWTP to the Sherwin Alumina Company tailing beds. Figure 4C.5-4 shows the pipeline route and the North Shore area in the vicinity of this project. The pipeline is designed to deliver either wet sludge or a slurry of sludge and reclaimed water and replaces the current use of tanker trucks to transport the sludge, used as a soil amendment for the tailings. The reclaimed water has been used to establish vegetation on barren areas and irrigate areas where vegetation has previously been established.



Source: San Patricio Municipal Water District

Figure 4C.5-4. Pipeline Route and the North Shore Area

Sherwin Alumina Company (formerly Reynolds Metals Company), a major area industry located between the Cities of Portland and Ingleside, has been using municipal wastewater from the City of Aransas Pass for non-potable purposes since 1998 and has reduced water use from the CCR/LCC System. The SPMWD, who obtains both treated water and raw water from the CCR/LCC System, supplies municipal and industrial water to the area. In both 2001 and 2002, Sherwin Alumina Company reused 2,688 acft/yr. However, delivery of treated wastewater in 2003 was only 382 acft from the City of Aransas Pass due to wet weather.[17]

In addition, a small portion of the Aransas Pass WWTP effluent has been utilized at the Aransas Pass Nature Area for wetlands enhancement. This project is funded by a Coastal Management Program grant and is not a part of the Northshore Resource Conservation Project. Approximately ten percent (10 percent) of the current average daily flow of 0.8 MGD (or 80,000 gpd) has been made available for diversion. Additional funding for the Nature Area is being requested from the Texas Parks and Wildlife Department, Coastal Management Program, and the Coastal Bend Bays and Estuaries Program.

Recently, SPMWD estimated that they could reduce future water demands by 4 MGD (4,480 acft/yr) by implementing wastewater reuse programs with the City of Portland, Gregory, City of Ingleside, and Oxychem, in addition to continuing reuse projects with Sherwin Alumina Company.[18] In 2001, these entities discharged wastewater effluent totaling 3,500 acft to Nueces Bay, which was credited toward freshwater inflow requirements for Nueces Bay (specified in both the 1995 Agreed Order and 2001 Agreed Order). Since Sherwin Alumina Company is a no discharge facility, there are no return flows from its water use. Additional studies are necessary to evaluate the effects on yields from CCR/LCC System when eliminating 3,500 acft of wastewater flows to Nueces Bay. The 2001 Agreed Order gives credit of 54,000 acft of return flows from WWTPs. SPMWD and other regional entities should coordinate wastewater reuse projects to minimize impacts to CCR/LCC yield and reduce additional CCR/LCC releases to Nueces Bay to offset the loss of the wastewater effluent. The regional wastewater collection and treatment system described above may be implemented as a future project.

The SPMWD had previously requested assistance for two other reclaimed water reuse projects. A related project, reuse of reclaimed water from the City of Portland's WWTP, is on hold because of a potential conflict with the operational plan for the CCR/LCC System. Another

[17] Correspondence with Jim Naismith, SPMWD, June 2004.
[18] Conversation with Jim Naismith and Don Roach, SPMWD, February 2, 2005.

possible project involves reclaimed water reuse from the City of Ingleside WWTP. High chloride levels in the wastewater from Ingleside are currently preventing its reuse.

4C.5.5 Wastewater Reuse for Landscape and Agricultural Use

In 2002, the City of Corpus Christi studied the feasibility of irrigating City-owned landscape with reclaimed wastewater.[19] The following observations were made regarding specific uses of reclaimed water:

1. Golf course irrigation with reclaimed water was successful;
2. The capital and operating costs, both for treatment and delivery, of irrigating public areas with reclaimed water is, in general, higher than the cost of potable water. The cost of park maintenance will increase with the use of reclaimed water.
3. Agricultural use appears to be economical from a pure cost of water standpoint for supplies up to 7 MGD at a cost of approximately $83/acft (or $0.26 per 1,000 dollars). However, depending on the crop and rainfall amount, frequency and timing, demand may be sporadic. The cost of the water may not be offset by increased crop yields.

Within the City, various categories of public facilities and recreation areas/undeveloped areas have been identified where landscape irrigation could be applied (Table 4C.5-7).

In the assessing the feasibility of landscape irrigation, various factors must be considered. These factors affect the capital costs and annual maintenance costs. Such factors include:

- The additional wastewater treatment necessary to meet Texas Administrative Code, Chapter 210, Use of Reclaimed Water standards (Section 4C.5.4.1);
- Infrastructure (pumps, piping, distribution system) necessary to deliver the reclaimed wastewater to the site;
- Additional maintenance of irrigated areas (increased frequency of mowing); and
- Long-term potential for chloride build-up in clay soils and the addition of soil amendments.

The quantity of wastewater reused for golf course and/or public park irrigation in the CBRWPA is estimated to be a small percentage (less than 4 to 5 percent) of the total municipal wastewater flow. In 2001, the City of Corpus Christi diverted approximately 1,210 acft to area golf courses and a baseball park. This represents approximately 3 percent of the City's wastewater discharge from its six WWTPs. The City of Corpus Christi is considering providing

[19] HDR, Effluent Reuse Study, February 2002.

Table 4C.5-7.
City of Corpus Christi Public Facilities and Recreation/Undeveloped Areas with Landscape Irrigation Needs

Category	Number	Acres
Beach Parks	4	72
Baseball/Softball Fields	8	383
Golf Courses	2	370
Libraries	5	4.5
Street Medians	34	141
Parks	168	913
Pools	10	9
Road Right-of-Ways	57	51
Recreation Centers	7	2.5
Special Areas (T-Head, L-Head, wildlife area, City Hall, cemeteries, nursery, Botanical Gardens, bayfront areas, Oso Creek areas, etc.)	40	1,098
Senior Citizen Centers	11	19
	Total Acres	**3,063**
Source: City of Corpus Christi from 2001 Plan.		

reclaimed wastewater supplies to two golf courses, Corpus Christi County Club and King's Crossing County Club, with estimated water savings of 434 acft/yr.[20]

A possibility for municipal WWTP effluent reuse that would replace an existing potable water use and thus increase the available CCR/LCC water supply is nursery reuse. Nurseries in the City are wastewater reuse candidates but the capital costs associated with pump stations, piping, and distribution systems would necessitate a feasibility study of such a reuse system. In Corpus Christi, most nurseries are retail sellers, meaning they purchase their stock from wholesale growers. Based on a conversation with a retail nursery owner, the potential for reuse of municipal WWTP effluent for nursery irrigation would be limited. The retail nurseries use City water and typically only have containerized plants, purchased from wholesale sellers. With retail nurseries spread out across the City and the small demand, supplying effluent for reuse would very likely not be cost-effective.

[20] Ibid.

Wholesale nurseries would have the best potential for cost effective reuse of municipal WWTP effluent as they would use more water for irrigating acres of plants, sod, etc. for supplying retail nurseries. There is only one wholesale grower in Corpus Christi. The larger wholesale growers in this region are located in San Antonio, Houston, and the Rio Grande Valley. Logistically, this wholesale grower is approximately 5.5 miles from the nearest city WWTP (Laguna Madre WWTP). In a conversation with the wholesale grower, he indicated that he uses approximately 30,000 gpd of water during peak use. The water quality of the WWTP effluent would be a major concern. The growers' current water source is a mix of potable water (City of Corpus Christi) and untreated groundwater. The predominant use is groundwater. With the water quality issues, pump station and forcemain costs, and seasonal demand for the water minimizes the cost-effective use of the wastewater.

The groundwater is used to offset the expense of purchasing potable water and to dilute the salinity, total dissolved solids, and alkalinity concentrations of the potable water. The tropical plants grown at the wholesale nursery have specific water quality tolerances related to those parameters. The nursery owner expressed concern regarding the water quality of the WWTP effluent and the cost effectiveness of treatment or dilution to achieve an acceptable water quality.

4C.5.6 Analyses and Discussion of Consumptive Wastewater Reuse and Advanced Conservation as Related to Estuaries Inflow Requirements

4C.5.6.1 Introduction

Under the 2001 Agreed Order, effluent credits for discharges to Nueces Bay are applied on a one-to-one basis and effluent credits for the Nueces Estuary, excluding Nueces Bay, are set at 54,000 acft/yr until such time as it is shown that actual wastewater flows exceed this amount. If the discharge of treated effluent increases and/or multipliers are applied to compute credits for effluent discharge in the Nueces Delta, releases from the CCR/LCC System to meet monthly desired Nueces Bay inflows can be reduced with a consequent increase in system firm yield. Without implementation of water conservation measures, which restrict water use, wastewater flows are projected to increase at a rate of about 900 acft per year. If selected accelerated conservation measures are implemented, then wastewater flows could be expected to be reduced, depending on the type of conservation measures. For example, if conservation measures that accelerate the retrofit of existing plumbing fixtures to low-flow fixtures are implemented, then wastewater flows would be reduced to the degree the program is effective. However, if conservation measures were selected to limit or reduce summer season irrigation of lawn and landscaped areas, wastewater flows would be unaffected. Simply stated, the benefit of increased water supply associated with advanced conservation must be carefully weighed against the resultant reductions in the steady discharge of treated effluent containing nutrients to primary productivity in the Nueces Estuary.

4C.5.6.2 Environmental Aspect

It has been estimated that between 47 percent and 52 percent of the water diverted and used by the City is returned to various points in the estuary as treated wastewater.[21,22] Presently, the largest portion of these discharges flow into the Nueces River, the Corpus Christi Inner Harbor, Oso Creek, Corpus Christi Bay, and Oso Bay. This alternative involves reusing this treated wastewater 1) for the irrigation of municipal and residential properties (e.g., golf courses and lawns) and for meeting industrial needs (e.g., cooling water makeup), and 2) moving treated wastewater discharges from their present discharge points to the Nueces Delta (e.g., Rincon Bayou and associated shallow ponds). Since the needs for irrigating lawns and golf courses are sporadic and somewhat unpredictable, and because of the logistical problems inherent in redistributing treated wastewater for municipal and industrial needs as described earlier, it appears unlikely that large volumes of treated wastewater can efficiently be used for these purposes. Thus, the environmental effects of wastewater reuse for municipal irrigation and for meeting certain industrial water needs also would be relatively small. The discharge of treated wastewater to the Nueces Delta offers greater potential for benefits in terms of increasing freshwater availability to meet municipal and industrial requirements in Corpus Christi, while at the same time potentially enhancing the productivity of Nueces Delta. The CBRWPA supports several endangered species and the resources critical to their continued existence, migratory bird use areas, wetlands, and marine fish and invertebrate nursery areas. Because phytoplankton and emergent plants provide food and habitat for animals, especially during early developmental stages, and these in turn provide food for larger animals, changes in primary productivity and plant diversity can be expected to influence the assemblage of animals resident in the estuary. Previous studies indicate that the Nueces Delta and Nueces Bay are critically important as the site of much of the planktonic primary production that drives biological processes throughout the

[21] HDR, et al., Op. Cit., September 1995.
[22] 2003 survey results, as reported in Table 4C.5-1.

Nueces Estuary. These studies indicate that treated wastewater could have as much as a five-fold stimulatory effect on primary productivity if discharged into the Nueces Delta rather than being discharged into the Nueces River.[23,24] Therefore, it has been recommended that wastewater be diverted and discharged into the Nueces Delta to help meet the freshwater inflow requirement, as specified in the 2001 Agreed Order, under which the CCR/LCC System now operates. This proposed wastewater discharge to the Nueces Delta would increase water availability from the CCR/LCC System if credits at a greater than 1:1 ratio can be obtained, thereby reducing freshwater releases designed to meet Nueces Bay inflow requirements.

4C.5.6.3. Impact Assessment

The 2005 Integrated Monitoring Plan[25] presents a consolidated description of monitoring programs associated with Nueces Delta projects (i.e., Rincon Bayou and Allison Demonstration Projects). The Nueces Delta Mitigation Project, conducted by the United States Army Corps of Engineers (USCOE) and Corpus Christi Port Authority until August 1997, studied wetland losses due to dredging in the Corpus Christi Ship Channel. Studies designed to assess the effects of diverting wastewater to the Nueces Delta have been conducted by researchers from the University of Texas Marine Science Institute.[26,27] These studies involved determinations of monthly salinity, temperature, dissolved oxygen, dissolved inorganic nitrogen (that is available to support plant growth), phosphate, silicate, and water transparency at 25 sampling stations. Additionally, primary production was measured at five sites. Primary production and phytoplankton pigment biomass, and the biomass, species diversity and species abundance of emergent vegetation was measured at four sites in each of 1991 and 1992. These studies indicate that primary productivity is positively correlated with the concentration of nutrients in the water. Increased flow and nutrient concentrations appeared to increase the relative abundance and

[23] HDR et al., "Regional Wastewater Planning Study, Nueces Estuary, Phase I," City of Corpus Christi, et al., November 1991.
[24] HDR et al., "Regional Wastewater Planning Study, Nueces Estuary, Phase II," City of Corpus Christi, et al., March 1993.
[25] City of Corpus Christi, Integrated Monitoring Plan Fiscal Year 2005, January 2005.
[26] Whitledge, T.E. and D.A. Stockwell, "The Effects of Mandated Freshwater Releases on the Nutrient and Pigment Environment in Nueces Bay and Rincon Delta: 1990 – 1994," Water for Texas, Research Leads the Way (Jensen, Red.), Proceedings of the 24th Water for Texas Conference, 1995.
[27] Dunton, K.H., B. Hardegree, and T.E. Whitledge, "Annual Variations in Biomass and Distribution of Emergent Marsh Vegetation on the Nueces River Delta," In: Water for Texas, Research Leads the Way (Jensen, Red.), Proceedings of the 24th Water for Texas Conference, 1995.

species diversity of emergent vegetation.[28] The effects of wastewater on relative abundance and species diversity varied among study sites indicating that other factors, in addition to freshwater flows and nutrient concentrations (e.g., initial species composition and abundance, duration of flooding, and frequency of flooding), may affect the relative abundance and diversity of species. An intensive, 5-year study was conducted with the Allison Diversion Demonstration Project (1999 to 2003) to assess the potential effects of wastewater on the relative abundance and diversity of species in the Nueces Estuary. The summary report is currently being prepared.

The Rincon overflow channel was restored by the 2001 Agreed Order. In 2002, the Monitoring Subcommittee of NEAC developed a monitoring plan, which was initiated in 2003.

Also, a TMDL study is underway by TCEQ and Texas A&M University Corpus Christi to determine the distribution of zinc in water and sediment in Nueces Bay. The TCEQ has included the Nueces Bay on the 303(d) list of impaired waters of the State due to contamination of oysters with elevated levels of zinc.

4C.5.6.4 Implementation Issues

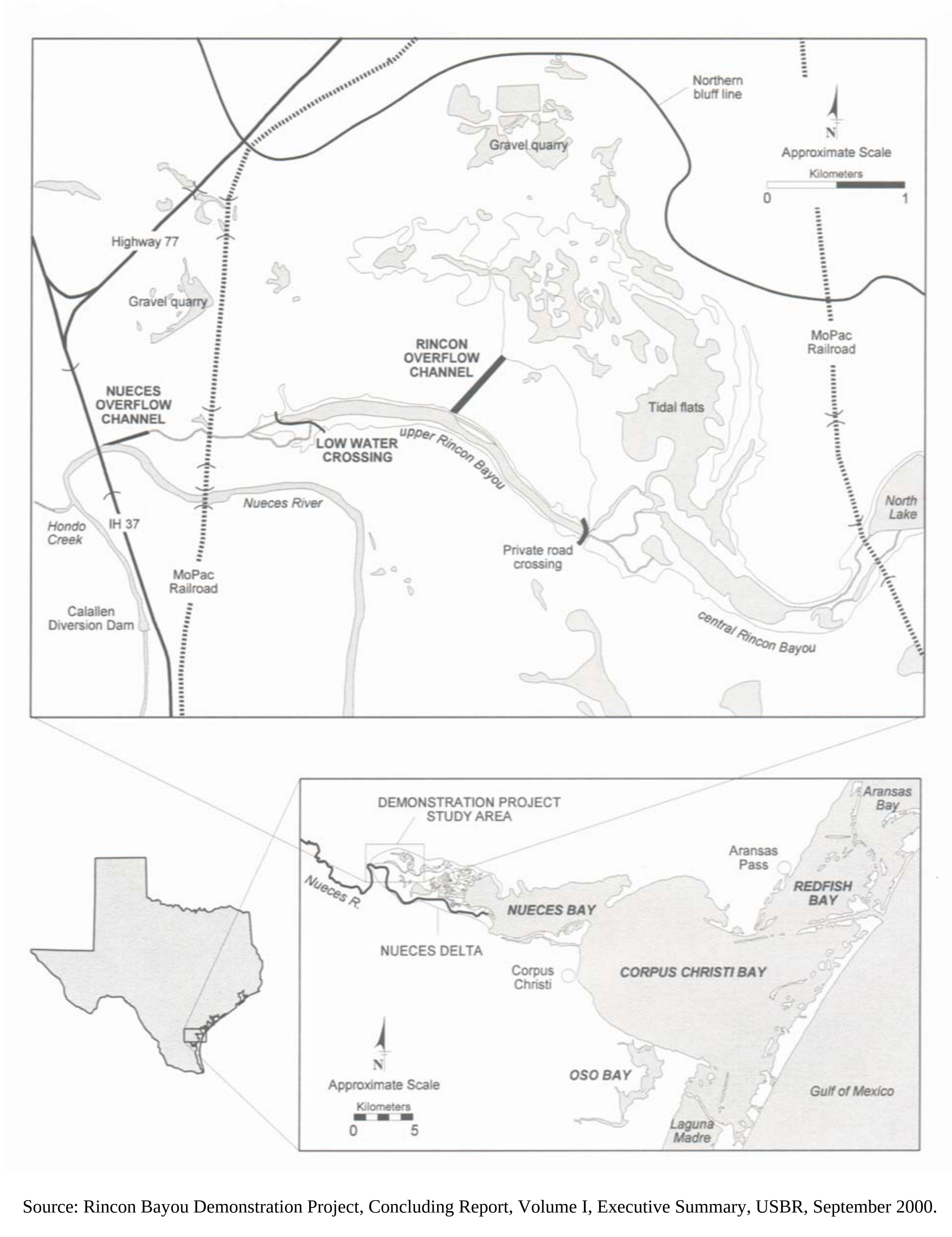
Major implementation issues include wastewater treatment levels required by regulatory agencies (TCEQ), wastewater discharge permit modifications to allow discharge in the Nueces Delta, and the impacts to the Nueces Delta from the diversion of wastewater. Cultural resources will also need to be investigated along the pipeline routes and avoided where possible. Implementation of this alternative should be considered in conjunction with the City's wastewater master plan as well as the results of studies from the U.S. Bureau of Reclamation's Rincon Bayou Demonstration Project. The Bureau of Reclamation constructed the Nueces River diversion (lowered the north bank of the Nueces River in the Delta area to increase periodic inundation of the Delta with river water) near the Interstate 37 bridge over the Nueces River in October 1995. The Bureau conducted water quality and biological studies of the Nueces Delta and Estuary from October 1994 to December 1999. The final report was released in late 2000. This project was initiated to demonstrate enhanced productivity in the Delta area from the diversion of Nueces River water to the Delta. A summary of the results of this demonstration project are highlighted below. These results should be evaluated in conjunction with the results of the Allison Diversion demonstration project in order to determine a long-term plan for diversion of river water and wastewaters to the Nueces Delta.

[28] Ibid.

Excerpts from the plan's Abstract and Executive Summary[29] are included below and the main features of the Demonstration Project are shown in Figure 4C.5-5.

> *Composing a complex array of channels, pools, marshes, and tidal flats, the Nueces Delta is one of the most extensive marsh ecosystems on the Texas Gulf Coast and an integral component of the Nueces Estuary. As part of the link between the riverine habitats of the Nueces River and the marine habitats of the Gulf of Mexico, the delta provides a critical transitional environment utilized by both estuarine and marine plants and animals. Functioning normally, the delta is inundated regularly by salt water from the bay via tides and wind, and occasionally by fresh water when the Nueces River spills over its banks. The periodic freshwater inundations by the river, which typically occur during the spring and fall, are essential in maintaining the ecological function of the delta. However, as regional municipal and industrial water demands from the Nueces River have increased, freshwater inflow to the delta has been greatly reduced.*
>
> *As regular exchange with the Nueces River has diminished, the Nueces Delta has ceased to function as a viable component of the estuarine ecosystem. The freshwater inflow events that do occur are too small and too infrequent to offset the natural importation of salt into the delta by tide, which is then concentrated by evaporation. Consequently, extensive areas of hypersaline water and soils have developed in the delta, resulting in a "reverse estuary" condition, where salinity values are lowest in Nueces Bay and increase with distance into Rincon Bayou. While many estuarine species can tolerate this harsher environment for short periods, prolonged conditions of salinity-caused stress have stunted active growth and reproduction, leading to lower biological productivity and less species diversity.*
>
> *In 1993, the U.S. Bureau of Reclamation (Reclamation) initiated a demonstration project with the following objectives:*
>
> *1) To increase the opportunity for freshwater flow events into the upper Nueces Delta, and*
>
> *2) To monitor subsequent changes in delta productivity.*
>
> *The primary features of the Rincon Bayou Demonstration Project were two excavated channels (the Nueces Overflow Channel and the Rincon Overflow Channel, which were completed in October 1995. Monitoring activities were conducted from October 1994 through December 1999,*

[29] U.S. Bureau of Reclamation, "Rincon Bayou Demonstration Project, Concluding Report," Volume 1, U.S. Dept. of the Interior, et al., September 2000.



Source: Rincon Bayou Demonstration Project, Concluding Report, Volume I, Executive Summary, USBR, September 2000.

Figure 4C.5-5. Location of the Nueces Delta (below) and of the Rincon Bayou Demonstration Project Features (above)

and were focused on the response of organisms in the water column, sediments and tidal flats of the delta.

The Rincon Bayou Demonstration Project significantly lowered the minimum flooding threshold of the upper Nueces Delta, thereby increasing the opportunity for larger, more frequent diversions of fresh water from the Nueces River. During the 50-month demonstration period, the amount of fresh water diverted into the upper Nueces Delta was increased by about 732%. Five freshwater inflow events were sufficient to activate the project's Rincon Overflow Channel and inundate, to varying degrees, the tidal flats of the upper delta. These tidal flats would not have otherwise been directly freshened. As a result, in a relatively short period of time (only 4.2 years after the opening of the project's Nueces Overflow Channel), the average salinity gradient in the upper delta reverted to a more natural form, with average salinity concentrations in upper Rincon Bayou becoming the lowest in Nueces Delta.

The effects of the demonstration project on the ecology of Rincon Bayou and the upper Nueces Delta were positive to the environment. Single-celled plant communities in the water column (phytoplankton) and on the surface of the sediments (microphytobenthos) evidenced increases in primary productivity with the reduction of salinity concentrations. Benthic communities (composed of bottom-dwelling organisms) evidenced increase in abundance, biomass and diversity. And, vegetation communities evidenced increases in plant cover and decreases in bare area. In summary, it was observed that freshwater inflow controlled, to a great extent, the ecological function of the upper delta ecosystem by regulating critical biological mechanisms.

A significant degree of ecological function was returned to the Nueces Delta and Nueces Estuary ecosystems by the demonstration project. Prior to the project, persistently high salinity concentrations severely inhibited the function of the Nueces Delta, and the delta's natural contribution to the greater estuary ecosystem was limited to infrequent periods when natural flow events occurred. With the restored regular interaction between the Nueces River and Rincon Bayou, fresh water and nutrients were more consistently introduced into the upper delta. As a result, estuarine habitat in the delta component of the Nueces Estuary improved in both quality and quantity, and foraging opportunities for many estuarine species were increased.

In response to the U.S. Bureau of Reclamation's study and 2001 Agreed Order, the City of Corpus Christi reopened the Rincon Bayou Overflow Channel. The Agreed Order also required operating conveyance facilities from Calallen Pool to deliver up to 3,000 acft/mo to the upper Rincon Bayou, and implement on-going monitoring program to evaluate freshwater inflows into the Nueces Estuary.

4C.5.7 Evaluation Summary

An evaluation summary of this regional water management option is provided in Table 4C.5-8.

Table 4C.5-8.
Evaluation Summary of the Reclaimed Wastewater Supplies

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Firm yield: Highly variable 2. Reliability: Poor to Good 3. Cost: Highly variable
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. Potential for environmental impacts to streams currently receiving wastewater effluent 2. Environmental impact to estuary in potential reduction of freshwater inflows 3. None or low impact. 4. None or low impact. 5. None or low impact. 6. Cultural resource investigations will be required for all pipeline routes 7. The City's Integrated Plan provides on-going studies of water quality issues of the Nueces Delta. 7a. Dissolved solids are a concern to be addressed with further studies. 7b. Salinity is a concern to be addressed with further studies. 7c. Bacteria is a concern to be addressed with further studies. 7d. Chlorides are a concern to be addressed. 7e-h. None or low impact. 7i. Alkalinity is a concern and will need to be addressed. Zinc in wastewater discharges into Nueces Bay is a concern to be addressed with further studies.
c. State water resources	• No negative impacts on other water resources
d. Threats to agriculture and natural resources in region	• Temporary damage due to construction of pipeline(s)
e. Recreational	• None
f. Comparison and consistency equities	• Standard analyses and methods used for portions
g. Interbasin transfers	• Authorization has been obtained for the Rincon Diversion Project
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Provides reuse opportunities of water supplies
j. Effect on navigation	• None.

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4C.6 Carrizo-Wilcox Aquifer Supplies (N-6)

4C.6.1 Description of Strategy

The City of Corpus Christi owns a standby groundwater supply system of four wells located near the City of Campbellton in Atascosa County (Figure 4C.6-1). This groundwater system is part of the Corpus Christi Drought Contingency Plan and is used to supplement the CCR/LCC System during times of critical drought. The Campbellton well field taps the Carrizo-Wilcox Aquifer and lies within the Evergreen UWCD, a special legislative district that has jurisdiction in Atascosa, Wilson, Frio, and Karnes Counties to regulate new wells, well spacing, and export of groundwater out of the district.

The wells were installed in 1951, and are not currently in use. During the 1950s, drought water was pumped from these wells into the Atascosa River for delivery to Lake Corpus Christi. Although no data are available to document the amount of water that actually reached the reservoir, local officials report that as much as 90 percent of the water pumped into the channel was lost to bank storage and evaporation. Recent analysis of the 63-mile reach of the Frio and Nueces Rivers downstream of Choke Canyon Reservoir to Lake Corpus Christi, including seepage losses within Lake Corpus Christi, can be as high as 37.8 percent.[1] For this reason, as well as the environmental issues involved with pumping relatively hot water into an active stream channel, this method of conveyance was not evaluated. Given the proximity of the Campbellton wells to Choke Canyon Reservoir, the option being considered in this section involves pumping water from the Campbellton well field and conveying it via pipeline to Choke Canyon Reservoir, approximately 20 miles to the south. In order to bring the wells online, they will need to be inspected and redeveloped to maximize productivity. Well pumps will need to be purchased and installed, and a well field collection system of pipelines must be constructed to deliver the water to a terminal storage tank. From this storage tank the water will be pumped via pipeline across the Atascosa River and over the Lipan Hills to Choke Canyon Reservoir.

A pipeline route in this vicinity was previously considered for the Trans-Texas study to convey San Antonio River water in addition to Campbellton well water. This pipeline route was evaluated and altered to reflect the differences in project scope. The route selected was changed to reflect different delivery rates, and to minimize the number of road and stream crossings.

[1] CCR/LCC updates, 2005.

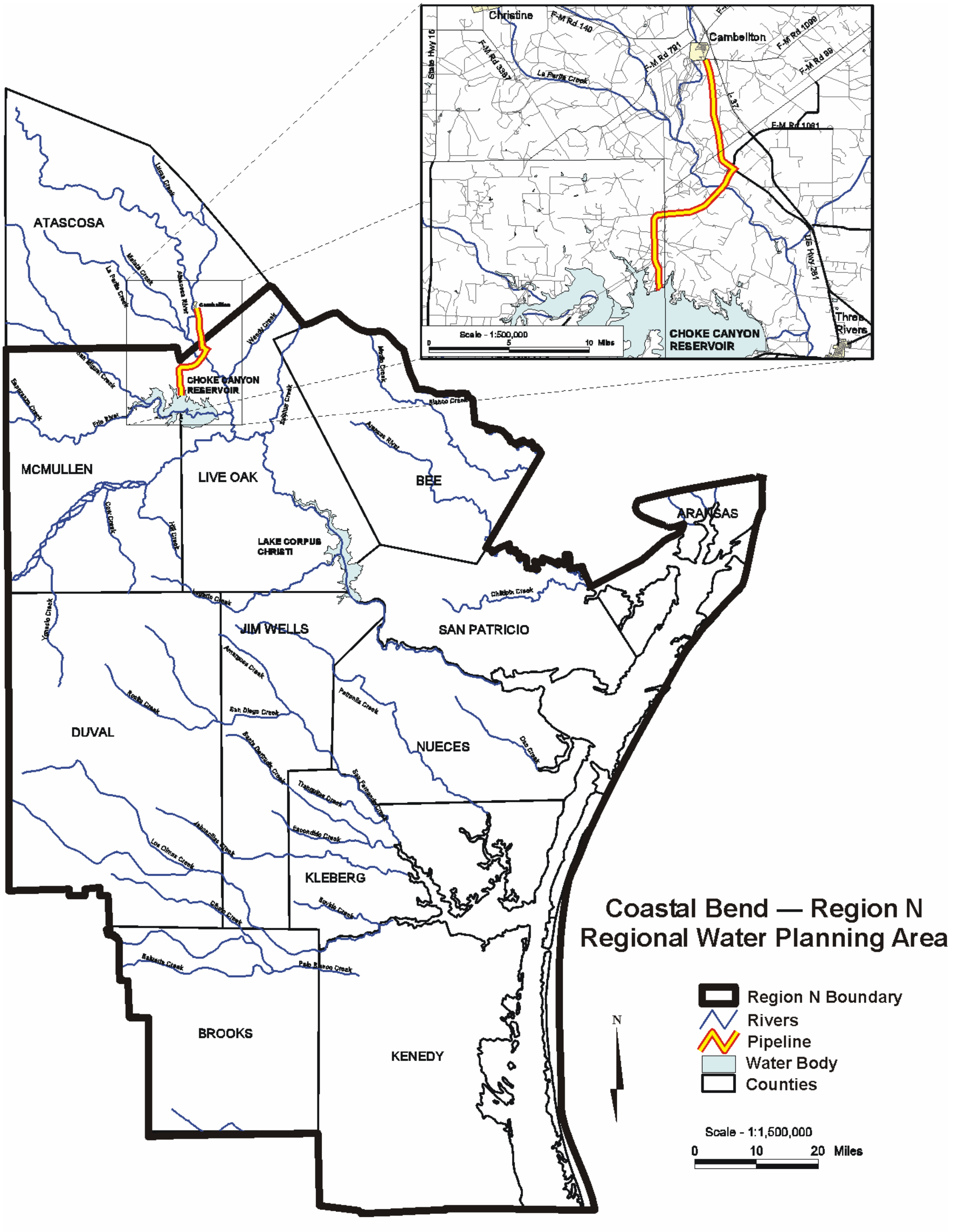

Figure 4C.6-1. Carrizo-Wilcox Supply Option

From the terminal storage tank south of the City of Campbellton, the pipeline will parallel the route of U.S. Route 281 south until the Town of Whitsett, where it will turn west and parallel Route 99 until it empties into Choke Canyon Reservoir.

Choke Canyon Reservoir delivers water through the Nueces River to Lake Corpus Christi for the City of Corpus Christi demand center. Another possibility is the sale or transfer of water to the South Central Texas Region (Region L RWPG) in exchange for other water. Region L is currently evaluating several options that involve transfer of water across the basin boundary with Region N. It is possible that water from the Campbellton well field could be included in these options in exchange for an equivalent replacement volume or outright purchase.

In June 2001, a study was conducted to evaluate the Campbellton wells as a standby groundwater supply for the City to utilize during emergency conditions to supplement their water supply. The study[2] concluded that although the Campbellton wells may no longer be needed by the City, they may have a value for local water use (i.e., City of Campbellton) and recommended that the City sell or transfer ownership of the Campbellton wells and associated properties. The City of Corpus Christi and Three Rivers are considering a contract revision, which may include: 1) a change in diversion point for Three Rivers to a location in Choke Canyon Reservoir, 2) removing requirement of the City to operate Campbellton wells during emergency conditions, and 3) transfer of ownership of the wells to City of Three Rivers.

4C.6.2 Available Yield

The Campbellton wells (TWDB Well Numbers AL-78-22-201, AL-78-22-202, AL-78-14-801, and AL-78-14-802) are screened in the Carrizo-Wilcox Aquifer, which underlies a wide belt of south central Texas. The aquifer consists of hydrologically connected sands of the Wilcox Group and the Carrizo Formation. The aquifer yields fresh to slightly saline water. Water quality analyses performed at the time of well construction indicate that the water has slightly elevated sodium levels, but is acceptable for most uses. The wells range in total depth from 3,663 to 4,132 feet. Due to the thermal gradient associated with these depths, groundwater from these wells is relatively hot, with temperatures up to 140 degrees Fahrenheit.

In 1993, during investigations concerning the Trans-Texas pipeline project, LBG-Guyton & Associates (LBG) was retained to conduct a preliminary investigation and computer analysis

[2] HDR Engineering, Inc., "City of Corpus Christi Standby Groundwater Supply Evaluation," June 2001.

of the aquifer properties around Campbellton to determine if pumpage of the Campbellton wells would result in unreasonable lowering of aquifer water levels. The results of LBG's preliminary analysis indicate that a maximum pumpage of 6 MGD (6,720 acft/yr) can likely be achieved from the Campbellton wells without unreasonably lowering water levels in the aquifer. Currently, the artesian head of the Campbellton wells is approximately 65 feet above ground surface. Water levels in the wells after one year of pumping are estimated to be more than 150 feet below ground surface and approximately 200 to 300 feet below ground surface after 50 years. These projections were based on specific yield values obtained during pump tests at the time of well installation, and assume a lowering of groundwater levels by 2 feet per year due to regional pumping from the Carrizo Aquifer. The computer simulation also indicated that water levels north of Campbellton near Jourdanton/Pleasanton and Poteet would be lowered by 8 to 15 feet during the next 50 years. Based on the results of their investigation, LBG estimates that pumping 6 MGD from the Campbellton wells would be a practical 50-year availability limit.

However, Choke Canyon Reservoir is not the final distribution point for the water. As mentioned previously, water from Choke Canyon is released downstream into the Nueces River to Lake Corpus Christi, and ultimately to Calallen Diversion Dam. The yield for the CCR/LCC System as a whole was evaluated with the additional 6 MGD input into Choke Canyon using the system model NUBAY, which accounts for evaporative and channel losses during transmission. The increases in firm yield of the CCR/LCC System are estimated to be approximately 3,200 acft/yr for both 2010 and 2060 conditions. This represents approximately 48 percent of the 6,720 acft/yr of water pumped annually into Choke Canyon Reservoir from the well field in Campbellton.

4C.6.3 Environmental Issues

Environmental issues related to transferring groundwater from the Campbellton wells to Choke Canyon Reservoir are:

- Effects related to pipeline construction and maintenance
- Effects related to increased flows to Choke Canyon Reservoir
- Effects related to water quality in Choke Canyon Reservoir due to the mixing of groundwater with surface water supplies

The Campbellton wells in Atascosa County would be connected by pipeline to Choke Canyon Reservoir through Live Oak and McMullen Counties. The estimated 17-mile pipeline would, to the extent possible, follow existing right of way along Highway 281 Alternate and State Route 99 to Choke Canyon Reservoir. Acreage impacted during construction and for maintenance following completion of the pipeline would be approximately 255 acres and 73 acres, respectively.

Increased flows to Choke Canyon would raise the average operational level of the lake only slightly, about three-tenths of a foot. Downstream effects would probably be undetectable. Blending Carrizo Aquifer water with water from Choke Canyon and Lake Corpus Christi will mitigate the slightly elevated sodium levels characteristic of the aquifer. Water quality changes in the reservoirs would be slight to undetectable and are not expected to affect aquatic life.

The predominant habitat type of concern along the proposed route of this option is mesquite-invaded pasture. The pipeline route traverses upland mesquite-blackbrush west of the Atascosa River until it terminates at Choke Canyon Reservoir.[3] Pipeline construction would affect an estimated 217 acres of brushland and 38 acres of cropland and grasslands if it is constructed entirely outside of the existing rights-of-way. The pipeline would cross the Atascosa River near the SH 99 Bridge. The river is approximately 50 feet wide bank to bank and well channelized, which would minimize the acreage of wetland and bottomland hardwood impacted. Vegetation along the banks included cedar elm, hackberry, pecan, green briar and black willow. The pipeline crossing at the Atascosa River would be constructed using directional drilling to minimize disturbance. The outflow structure construction at Choke Canyon would disturb approximately 2,500 square feet of littoral wetland. A pair of crested caracaras (*Polyborus plancus*), a rare to common resident of South and South-Central Texas, were observed perched in a tree during a spring reconnaissance survey. There are no recorded occurrences of protected species within the proposed pipeline corridor. Some dense brushland habitat suitable for the endangered ocelot (*Felis paradilis*) may be present in the vicinity of the pipeline corridor. State protected species that may be found in wetlands or temporarily wet areas are the Texas Garter Snake (*Thamnophis sirtalis annectens*), the Rio Grande lesser siren *(Siren intermedia texana*), and the sheep frog (*Hypopachus variolosus*). These may be found in the Atascosa River crossing corridor and the cove at Choke Canyon. The state protected Texas horned lizard (*Phrynosoma cornutum*) may be found in open arid and semi-arid regions with sparse vegetation including grass, cactus, scattered brush or scrubby trees. The mesquite-blackbrush and mesquite granjeno

[3] McMahan, C.A., Frye, R.G., and Brown, K.L., "The Vegetation Types of Texas," Texas Parks and Wildlife Department, Austin, Texas, 1984.

parks in the vicinity of the pipeline corridor can provide good habitat for the Texas tortoise (*Gopherus berlandieri*), Indigo snake *(Drymarchon corais erebennus*), and the Reticulate Collared Lizard (*Crotaphytus reticulatis*).

The slight increase in inflows to the Nueces estuary from the return flows enhance by groundwater import would not be enough to result in perceptible salinity changes or impacts to estuarine communities.

Although no National Register of Historic Places are recorded in the pipeline corridor, a systematic pedestrian survey of the entire corridor will be required to search for surface indications of cultural deposits. Additional studies including aquifer impacts are recommended prior to considering this as a recommended strategy.

4C.6.4 Engineering and Costing

Infrastructure needs for this project system will include:

- Pumps for the wells,
- Well field collection pipelines from each well to a common terminal storage tank located at the pipeline pump station intake,
- Pump station and intake structure to pump water from the storage tank into the pipeline,
- Construction of a transmission pipeline to carry the water from Campbellton to Choke Canyon Reservoir, and
- Outlet control in Choke Canyon Reservoir.

The proposed project was sized to convey 6 MGD of groundwater from the Campbellton well field to Choke Canyon Reservoir. This is equivalent to approximately 1,000 gallons per minute from each of the four wells on a continual basis. Separate hydraulic profiles were generated for the well field collection system and the transmission pipeline to Choke Canyon Reservoir. A cost estimate for the combined system was generated using methodology appropriate to a studies level analysis, which is consistent with other projects being evaluated under Senate Bill 1 projects.

In addition to capital costs detailed in the Table 4C.6-1, Evergreen UWCD collects export fees of $0.025 per 1,000 gallons exported. Since the 2001 Coastal Bend Regional Water Plan, Evergreen UWCD rules have been revised and no longer require “that permits for export outside the District be limited to an amount in acre-feet no greater than the acreage of land owner by the permittee within the district." Therefore, an entity can lease groundwater rights, which is

Table 4C.6-1.
Cost Estimate Summary
Campbellton Well Water Supply Project Option
Second Quarter 2002 Prices

Item	***Estimated Costs for Facilities***
Capital Costs	
Pump Station (6 MGD)	$1,721,000
Transmission Pipeline and Storage Tank (20" and 16" diameter, 17 miles)	5,836,000
Well Fields	2,408,000
Water Cooling Facilities and Outfall Structure	385,000
Total Capital Cost	**$10,350,000**
Engineering, Legal Costs and Contingencies	$3,350,000
Environmental & Archaeology Studies and Mitigation	534,000
Land Acquisition (Right of Way) and Surveying	630,000
Interest During Construction (2 years)	1,224,000
Total Project Cost	**$16,088,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$1,169,000
Operation and Maintenance:	
Wells, Pipeline, Pump Station	125,000
Groundwater Leases (6,720 acft/yr)	400,000
Water Cooling Facilities	5,000
Pumping Energy Costs (10,634,667 kWh @ $.06 per kWh)	638,000
Water Export Fee (2,180,000 gallons at $0.025/ 1000 gallons)	55,000
Total Annual Cost	**$2,392,000**
Available Project Yield (acft/yr)	**3,200**
Annual Cost of Water ($ per acft)	**$748**

significantly less expensive than purchasing 6,720 acres of land within the district for 6,720 acft of water, which was considered in the previous cost estimate included in the 2001 Plan. The cost summary in Table 4C.6-1 includes leasing land and groundwater rights rather than land purchases.

Results of the cost estimate indicate that total capital costs for infrastructure associated with the project would be approximately $10,350,000, as detailed in Table 4C.6-1. Annual costs would be on the order of $2,392,000. For the proposed project yield of 3,200 acft/yr, this is equivalent to a unit cost of water of $748 per acft.

4C.6.5 Implementation Issues

In order for this option to be implemented, the following issues will need to be addressed.

- Land Leasing/Groundwater Rights – Region N entities interested in pursuing Carrizo groundwater from Campbellton wells as a water supply option will need to negotiate groundwater leases. Evergreen UWCD assesses an export fee ($0.025 per 1,000 gallons) to use water outside the District. The Evergreen UWCD also requires emergency multiple system interconnections to be valved and metered at the District Boundary lines which may incur additional costs not included in the cost summary.
- Installation of pumps into the dormant well field will require permitting from the Evergreen UWCD.
- Environmental/Water Quality Issues – TCEQ concerns regarding raw water quality (chemical and thermal) from the Carrizo Aquifer and the potential impact on Choke Canyon Reservoir water quality will need to be addressed.
- Land easements along the proposed pipeline route will need to be purchased.
- Cultural resource surveys will be required when facilities need to be constructed.
- Water supply provisions for local water users (Campbellton area).

4C.6.6 Evaluation Summary

An evaluation summary of this water management option is provided in Table 4C.6-2.

Table 4C.6-2.
Evaluation Summary of
Campbellton Well Option to Enhance Water Supply Yield

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	1. Firm Yield: 3,200 acft/yr 2. Good, assuming ability to pump 6,720 acft/yr and recovery of 48 percent. 3. Cost: $748 per acft/yr.
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	1. Increase flows to Choke Canyon Reservoir. 2. Slight increase in bay and estuary inflows. 3. Pipeline construction may temporarily disrupt local wildlife. 4. Minimal impact (pipeline crossing Atascosa River.) 5. Minimal impact along pipeline route. 6. Cultural resources will need to be avoided when facilities are constructed. 7. May have impacts to Choke Canyon Reservoir due to mixing of groundwater with surface water supplies. b. Groundwater may be slightly saline. f. Groundwater may contain high sulfur content.
c. Impacts to State water resources	• Will result in lowering of groundwater levels in Campbellton area over time. No other apparent negative impacts on other water resources
d. Threats to agriculture and natural resources in region	• None
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Cost model for option is based on literature values
g. Interbasin transfers	• Potential for interbasin transfer or exchange for other water with Region L
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Slight improvement over current conditions
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• Potential impacts to wildlife habitat.

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4C.7 Gulf Coast Aquifer Supplies (N-7)

4C.7.1 Conjunctive Use of Groundwater Supplies from Refugio County

4C.7.1.1 Description of Strategy

The existing regional water system operated by the City of Corpus Christi has two supplies of water—CCR/LCC System in the Nueces Basin and Lake Texana in the Lavaca River Basin. Corpus Christi's O.N. Stevens Water Treatment Plant at Calallen Dam receives the Nueces River water via the 'bed and banks' of the Nueces River and the Lake Texana water via pipeline. In addition to supplying its own needs, Corpus Christi provides wholesale water to the South Texas Water Authority, to the San Patricio Municipal Water District, and numerous other municipal and industrial entities.

This option considers conjunctive use of groundwater with the existing surface water supplies and evaluates the feasibility of securing groundwater supplies from the Gulf Coast Aquifer in Refugio County. This analysis considers the operation of a new well field in western Refugio County (Figure 4C.7-1) to provide summer peaking supplies (June through September) and a much lower supply during the rest of the year. Other conjunctive use concepts could include the delivery of groundwater only when surface water supplies are low and as an emergency supply source.

Corpus Christi currently has contracts from Lake Texana for 41,840 acft/yr on a firm basis and 12,000 acft/yr on an interruptible basis. As part of a plan for future supplies, the pipeline was upsized and is capable of delivering up to 108,000 acft/yr. Potential surface water supplies that could be transported via this pipeline include Colorado River, Guadalupe River, and additional Lake Texana water as well as potential groundwater supplies from the Gulf Coast Aquifer. Along the pipeline, the greatest amount of undeveloped groundwater is in Refugio County.[1]

The Refugio Groundwater Conservation District was created in the 76th Texas Legislature and adopted Management Rules in July 2004. There are no drawdown limits or production maximums in rules. According to spacing requirements, new wells must be spaced at least 2 feet for every gallon per minute of the permitted flow from nearest existing or authorized well.[2] The spacing requirements were met for this water management strategy.

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[1] Dodson, Karen K., "Identifying Underutilized Groundwater Resources in the Coastal Bend Region of Texas," Master's Thesis in Environmental Science at Texas A&M University-Corpus Christi, 1997.
[2] Rules of Refugio Groundwater Conservation District, July 27, 2004.

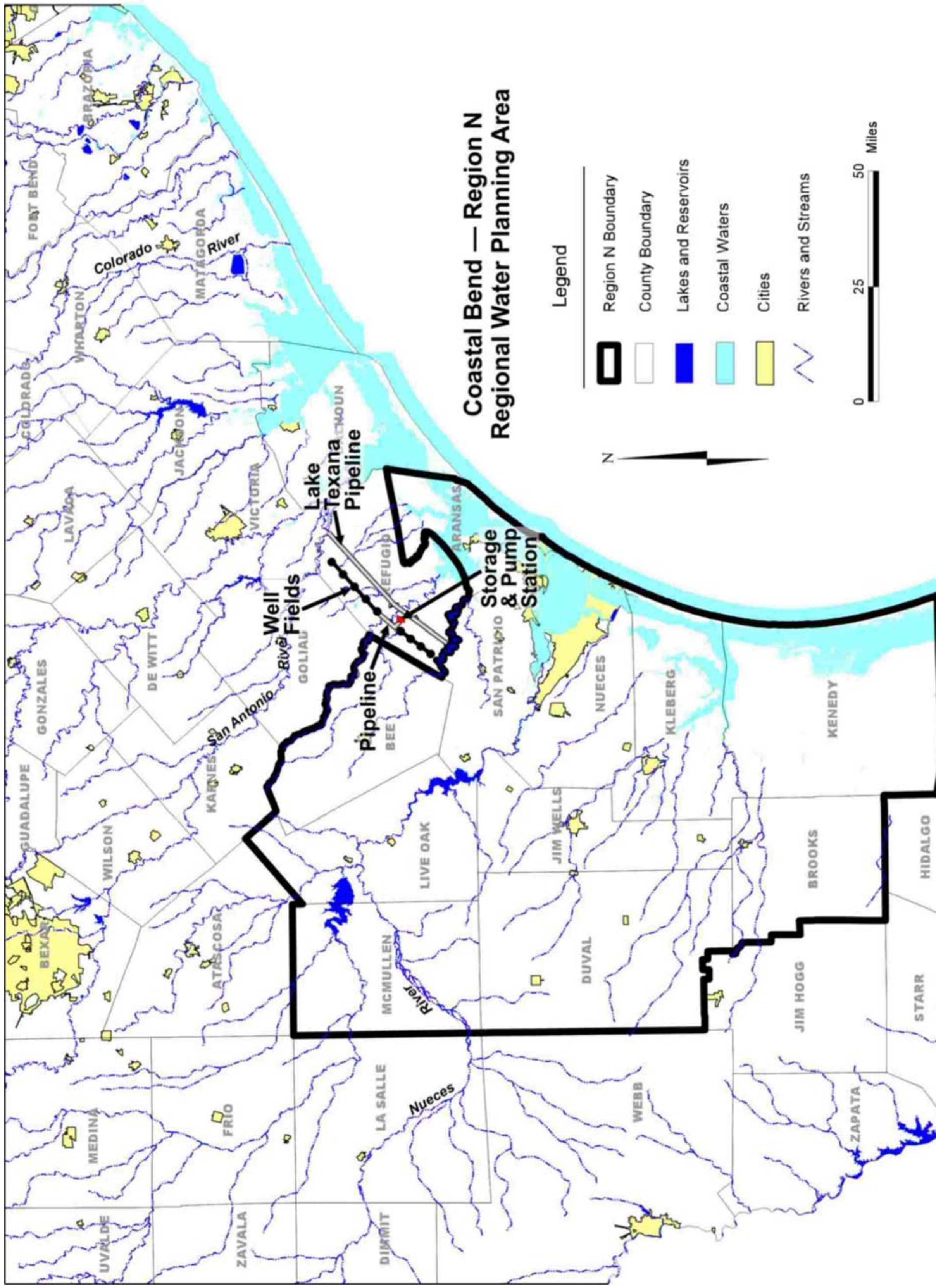

Figure 4C.7-1. Conjunctive Use of Groundwater Supplies from Refugio County

4C.7.1.2 Available Yield and Water Quality

The principle freshwater-bearing formations in Refugio County include the Goliad Sands, the Lissie Formation, and the Beaumont Clay. The Goliad Sands, called the Evangeline Aquifer, underlies the Lissie and Beaumont Clay, which are called the Chicot Aquifer. The sediments are non-marine in origin and consist chiefly of sand, clay, and gravel. The Goliad Sand can provide, by far, the greatest supply of water to wells. Its outcrop is located in Bee and Goliad Counties in a northeast-trending belt of 15 to 20 miles wide, dips to the southeast toward the coast at about 10 to 40 feet per mile, and ranges from 300 to 600 feet thick in the confined section.

The first major study of groundwater supplies in Refugio County estimated about 42,000 acft/yr of water containing less than 300 milligrams per liter (mg/L) of chloride could be pumped indefinitely from the Goliad Sand and Lissie Formation.[3] These computations were based on the ability of the aquifer to transmit water to the areas favorable for development without considering drawdown from pumping wells. The areas identified for either favorable for moderate or large-scale development are generally west of US Hwy 77 and 2 to 8 miles north of the Aransas River. In these areas, the chloride concentration of groundwater in the Goliad Sand is generally less than 300 mg/L and the concentration of total dissolved solids is generally less than 1,000 mg/L. Comparisons of these water quality parameters with both the Nueces River water and the Lake Texana water indicate a significantly higher level of dissolved solids that may be problematic to local industries in the region. However, the blended water from the well field is expected to meet secondary drinking water standards.

A 1979 statewide study of the availability of groundwater by the Texas Department of Water Resources (currently the Texas Water Development Board) used a one-layer groundwater model with a grid of 10-mile by 10-mile cells for the analysis.[4] By assuming an allowable 100 feet drawdown at a line located midway between the centerline of the outcrop and the freshwater and saltwater interface, groundwater availability was estimated to be about 30,000 acft/yr in the area between the San Antonio River and Nueces River Basins.

[3] Mason, Curtis C., "Ground-water Resources of Refugio County, Texas," Texas Water Commission Bulletin 6312, 48 pp., 1963.
[4] Muller, D. A. and Robert D Price, "Ground-water Availability in Texas, Estimates and Projections through 2030," Texas Department of Water Resources Report 238, 77 pp., 1979.

A 1991 large-scale regional aquifer system analysis of the Texas Gulf Coast Aquifer System included the development of a groundwater model.[5] The Texas coastal lowlands part of the model includes five permeable zones and two confining units. Analysis of the findings and results of the model tests suggest the western half of Refugio County as having the capacity for additional groundwater development.

For the previous 2001 Plan, a comprehensive groundwater model was developed for the Coastal Bend Regional Water Planning Group (RWPG) to test the availability of groundwater in the Gulf Coast Aquifer System. Several tests of a range of drawdown criteria were made to provide information for a decision on an acceptable decline of water levels. These tests were made for each of the four water-bearing units of the Gulf Coast Aquifer System. Based on a region-wide pumping used in the tests and adopted criteria, which included limiting drawdowns to 100 feet, about 27,300 acft/yr of groundwater is estimated to be available from the Goliad Sand and about 2,000 acft/yr from all other water-bearing formations in Refugio County.

The availability of groundwater for this option, after considering local demands, is estimated at 28,000 acft/yr and is based on the availability of groundwater estimated by the Coastal Bend RWPG (about 29,300 acft/yr) less the amount of estimated groundwater demands in Refugio County in year 2060 (1,302 acft/yr).

In the proposed well field, high-capacity wells drawing water from the Goliad Sand are about 1,000 feet in depth and commonly yield 1,000 to 1,500 gallons per minute (gpm). Limiting the total annual water production to 28,000 acft/yr, the withdrawals are set to a maximum production rate of 4,000 acft/month during the four summer months, and a base production rate of 1,500 acft/month during the other eight months of the year. Based on the summer demand, and with a contingency of 10 percent of the wells not in production, 28 wells would be required. The southwest well field would have about 12 wells and the northwest well field would have about 16 wells. The proposed wells, operating at a maximum production of 1,200 gpm, would be at a minimum 2,400 feet from existing wells to meet Refugio GCD spacing requirements.

[5] Ryder, Paul D. and Ann F. Ardis, "Hydrology of the Texas Gulf Coast Aquifer Systems," U.S. Geological Survey Open-file Report 91-64, 147p., 1991.

4C.7.1.3 Environmental Issues

A previous study estimates up to 25% of recharge to the Gulf Coast Aquifer in nearby Wharton and Matagorda counties ends up as freshwater discharge to near-coast waters.[6]

The pumping of groundwater from the Gulf Coast Aquifer could have a very slight negative impact on baseflow in the downstream reaches of streams in these areas. However, many of the streams are dry most of the time; thus, no measurable impact on wildlife along the streams is expected.

The proposed well field in western Refugio County would be bounded by the Aransas River on the south and the San Antonio River on the north (Figure 4C.7-1). This area is rangeland characterized by varying degrees of brush invasion. Plains Gumweed (*Grindelia oolepis*), which was considered for (but did not receive) federal protection, and Welder Machaeranthera (*Psilactis heterocapa*), which is a federal C2 candidate species, are reported to occur in the project area. Both of these species are considered by TPWD to be very rare and vulnerable to extirpation.

In addition to 28 wells, construction impacts would include 37 miles of collection and transmission lines. This pipeline collection system is expected to affect 141 acres. The wells and collection system would be located in such a way as to avoid or minimize impacts to sensitive resources. The water would be delivered to the Lake Texana pipeline via the proposed water transmission line from the well field in western Refugio County.

Because of the relatively small areas involved, construction and maintenance of surface facilities are not expected to result in substantial environmental impacts. Where environmental resources could be impacted by infrastructure development (e.g., disturbance to endangered species habitat or cultural resource sites), changes in facility siting or pipeline alignment would generally be sufficient to avoid or minimize adverse effects.

Subsidence as a result of continuous groundwater withdrawal could potentially cause changes in land use, drainage patterns, wetlands and other habitats in the affected area. While the generally expected result, an increase in wetland habitat, may be viewed as beneficial, actual impacts will be critically dependent on the location in which subsidence takes place. Changes in drainage patterns, for example, could result in vegetated wetlands being converted into open

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[6] Dutton, A.R., and Richter, B.C., 1990. "Regional geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a numerical model to estimate the impact of water management strategies", The University of Texas at Austin and Bureau of Economic Geology.

water habitat less valuable to wildlife and waterfowl, or freshwater wetlands could be converted to a brackish condition. Where endangered species habitat is present in a proposed well field area, potential changes as a result of subsidence could be both substantial and difficult to avoid or mitigate. Of the areas mentioned in the preceding discussion, all have some potential to harbor endangered species whose habitat is both limited in distribution and would be sensitive to the changes that could result from subsidence.

4C.7.1.4 Engineering and Costing

For the conjunctive use of groundwater from the Gulf Coast Aquifer in Refugio County option, groundwater would be developed from two well fields along a southwest-northeast line about 3 miles west of Refugio (Figure 4C.7-1). The line of wells has a blank section west of Refugio to reduce the impact of water level declines in Refugio's well field and to avoid an area where the groundwater salinity is slightly elevated.

Independent facilities would be constructed for each of the two well fields. These facilities include wells, collection and transmission pipelines, storage, and pump stations.

Cost estimates were computed for capital costs, annual debt service, operation and maintenance, power, land, and environmental mitigation for uniform and peak day delivery. These costs are summarized in Table 4C.7-1. As shown, the annual costs, including debt service for a 30-year loan at 6 percent interest, operation and maintenance costs, including power and the purchase of groundwater, are estimated to be $8,881,000 for 28,000 acft of water. This option produces raw water delivered to the O.N. Stevens Water Treatment Plant at an estimated cost of $317 per acft (Table 4C.7-1).

4C.7.1.5 Implementation Issues

The development of conjunctive water supplies from the Gulf Coast Aquifer (Goliad Sands) in Refugio County must address several issues. Major issues include:

- Impact on water levels in the aquifer, potential intrusion of saline groundwater into freshwater zones and land surface subsidence.
- Purchase of groundwater rights
- Competition for groundwater in the area
- Potential regulations by the newly created Refugio Groundwater Conservation District.

- U.S. Army Corps of Engineers Sections 10 and 404 dredge and fill permits for the pipelines.
- GLO Sand and Gravel Removal permit for pipeline stream crossings.
- GLO Easement for use of State-owned land (if any).
- TPWD Sand, Gravel, and Marl permit.
- Mitigation requirements would vary depending on impacts, but could include vegetation restoration, wetland creation or enhancement, avoidance of cultural resources, or additional land acquisition.

Table 4C.7-1.
Cost Estimate Summary
Conjunctive Use of Groundwater Supplies from Refugio County
(Second Quarter 2002 Prices)

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Field (28 wells; 1,200 gpm)	18,431,000
Well Field Collection Pipeline (12 to 36-inch dia.; 33 miles)	15,198,000
Transmission Pump Station	5,437,000
Transmission Pipeline (48-inch dia.; 3.5 miles)	2,708,000
Total Capital Cost	**$41,774,000**
Engineering, Legal Costs and Contingencies	$14,486,000
Environmental and Archaeology Studies and Mitigation	970,000
Land Acquisition and Surveying (141 acres)	1,328,000
Interest During Construction (2 years)	4,685,000
Total Project Cost	**$63,243,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$4,595,000
Operation and Maintenance:	
Pipeline, Pump Station, and Well Field	453,000
Pumping Energy Costs to Texana Pipeline (27,753,990 kWh @ $0.06 per kWh)	1,665,000
Purchase of Water (28,000 acft/yr @ $77.43 per acft)	2,168,000
Total Annual Cost	**$8,881,000**
Available Project Yield (acft/yr)	**28,000**
Annual Cost of Water ($ per acft)	**$317**

4C.7.1.6 Evaluation Summary

An evaluation summary of this regional water management option is provided in Table 4C.7-2.

Table 4C.7-2.
Evaluation Summary of the Refugio County Groundwater

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Firm Yield: 28,000 per acft/yr. 2. Water Quality: Fair. 3. Low cost: $317 per acft.
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. May slightly decrease instream flow and discharge of freshwater into coastal estuaries due to local groundwater-surface water interaction. 2. May slightly decrease instream flow and discharge of freshwater into coastal estuaries due to local groundwater-surface water interaction. 3. Negligible impacts. 4. Negligible impacts. 5. Negligible impacts. 6. Cultural resources will have to be surveyed and avoided. 7. Negligible impacts. 7a. Total dissolved solids are generally high and may require blending with higher quality water. 7b. High salinity is a potential concern to address during the early phases of project development. 7c. Negligible impacts. 7d-e. Groundwater may contain high chloride and bromide levels and may require blending with higher quality water. 7f-i. Negligible impacts.
c. Impacts to State water resources	• No negative impacts on water resources other than the Gulf Coast Aquifer. • Potential benefit to Nueces Estuary from increased freshwater return flows.
d. Threats to agriculture and natural resources in region	• May slightly increase pumping costs for agricultural users in the area due to localized drawdowns.
e. Recreational impacts	• None.
f. Equitable Comparison of Strategies	• Standard analyses and methods used.
g. Interbasin transfers	• Not applicable to groundwater sources.
h. Third party social and economic impacts from voluntary redistribution of water	• May require the purchase of groundwater rights.
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities.
j. Effect on navigation	• None.

4C.7.2 Groundwater Alternative for Small Municipal and Rural Water Systems and Irrigation, Mining, and Manufacturing Water Users for the Coastal Bend Region

4C.7.2.1 Description of Strategy

The Gulf Coast Aquifer underlies all counties within the Coastal Bend Region and yields moderate to large amounts of fresh and slightly saline water. The Gulf Coast Aquifer, extending from Northern Mexico to Florida, is comprised of four water-bearing formations: Catahoula, Jasper, Evangeline, and Chicot. The Evangeline and Chicot Aquifers are the uppermost water-bearing formations, are the most productive and, consequently, are the formations utilized most commonly. The Evangeline Aquifer of the Gulf Coast Aquifer System features the highly transmissive Goliad Sands. The Chicot Aquifer is comprised of many different geologic formations; however, the Beaumont and Lissie Formations are predominant in the Coastal Bend area.

Municipal water systems and other water user groups in the Coastal Plains area of the Coastal Bend Water Planning Region commonly use the Gulf Coast Aquifer for their supply. These sources may be a strong preference because the water is usually readily available, inexpensive, and often suitable for public water supplies with minimal treatment, although elevated concentrations of TDS are present in some areas.

The purposes of this option are to:

- Evaluate aquifers and existing well field(s) of each WUG to meet projected water supply requirements through the year 2060, based on groundwater supply estimates derived from reported well capacity for other wells in the area.
- If additional supplies are needed, identify whether or not additional wells are the most likely water management strategy, or whether an alternative strategy, such as purchase from a wholesale water provider, is recommended.
- If the water needs to be treated, estimate when the expansion is needed and how much the facilities will cost.

The evaluation of individual WUG water systems is at a reconnaissance level and does not include:

- An engineering analysis of the water system as to the current condition or adequacy of the wells, transmission system, and storage facilities;
- A projection of maintenance costs or replacement costs of existing wells and facilities;
- The potential interference of new wells installed by others near the city's wells or at locations identified for new well fields;

- Impact of potential changes in groundwater use patterns in the vicinity of the city's well field and the county;
- Changes in rules and regulations that may be developed and implemented by a groundwater conservation district or the State; nor
- Consideration of additional wells or water treatment for local purposes such as reliability, water pressure, peaking capacity, and localized growth.

The evaluation of each municipal water system consisted of the following steps:

1. Compiled information prepared for the Coastal Bend Regional Water Planning Group on current and projected population and water demand for each of the WUGs;
2. Estimated well depth and capacity for each WUG based on publicly available information for the water system from published groundwater reports and TCEQ and TWDB records;
4. If the estimated groundwater supply after adjustments was greater than the estimated groundwater demand in the year 2060, the evaluation concludes that the existing water supply is adequate;
5. If the estimated supply after adjustments was less than the estimated groundwater demand in the year 2060, the evaluation concluded that an additional water supply would be needed; and
6. If new wells are the most feasible water management strategy, estimated at what decade it is needed and the capital cost of adding the new wells to the water system.

The methodology presented in the following text deals specifically with those entities that show a projected unmet need that is likely to be met through development of local aquifer supplies; in other words, only those entities whose needs exceed the current estimation of local groundwater supply. These entities are shown in Figure 4C.7-2.

Because no specific project data regarding any of the local groundwater supply water management strategies is available, it is necessary to make a number of assumptions for costing and evaluation. For WUGs with needs to be met from local Gulf Coast Aquifers, characteristic well depth and well capacity (gpm) estimates were developed for costing purposes based on data from existing wells in the vicinity. For manufacturing and mining groundwater use, it was assumed that groundwater would be supplied at a constant annual rate, and that the water would be usable without treatment. For irrigation, it was assumed that all use would occur in 6 months of the year, so a peaking factor of two was used in estimating the number of wells necessary for cost estimation. In addition, it was assumed that irrigation water would be applied without treatment.

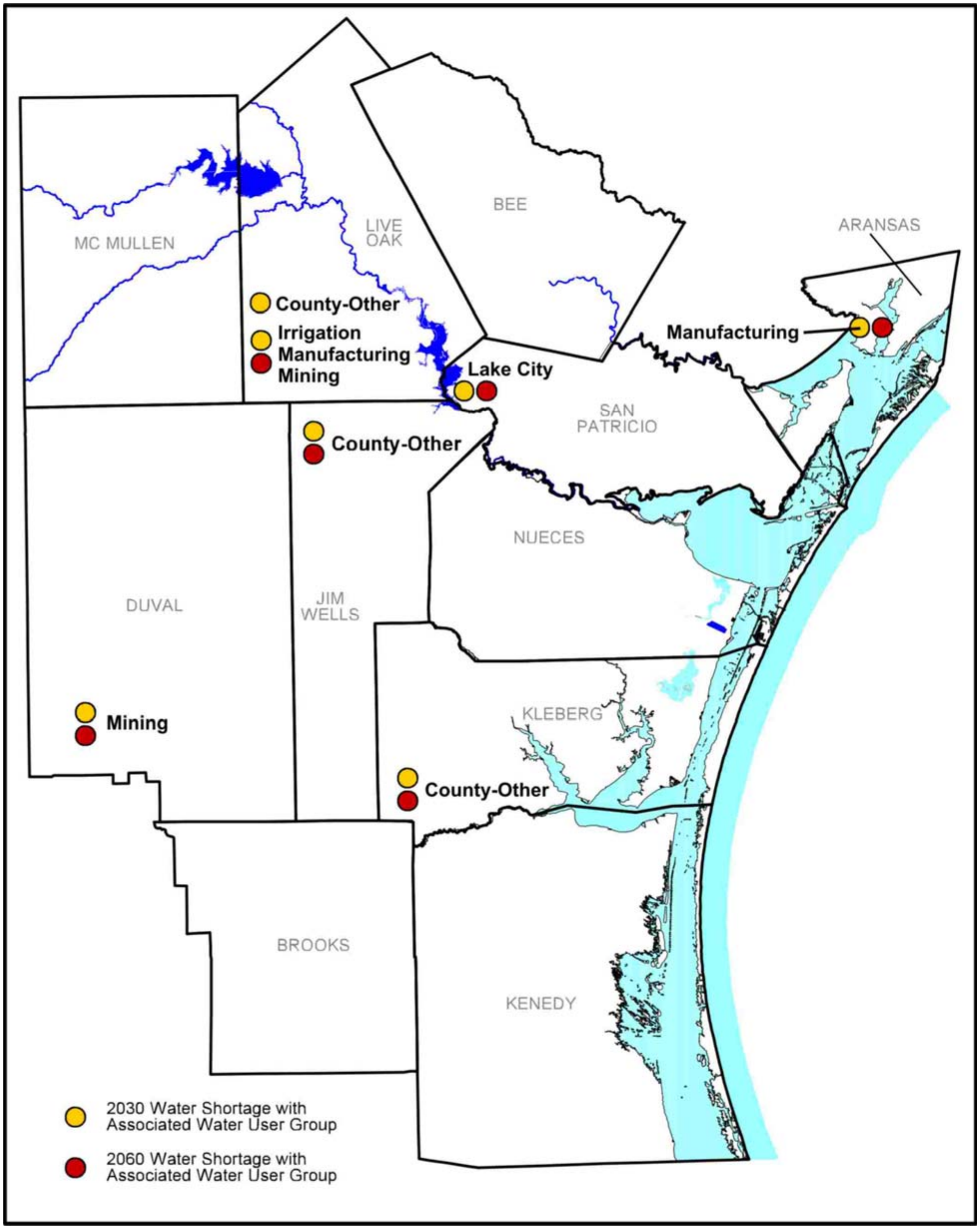

Figure 4C.7-2. Location and Type of Use for 2030 and 2060 Water Supply Shortages Relying on Groundwater Supplies

For county-other WUGs, which are understood to represent small rural water supply systems, it was assumed that the water suppliers would need to meet instantaneous peak demand rates of twice the annual average rate. Therefore, as in irrigation, twice the number of wells of a given capacity are required to meet the peak demand rate for costing purposes. No pipelines or pump stations were assigned for costing purposes. It was assumed that these proposed wells would connect directly to the demand center or local distribution system, and that the cost of any associated piping would be covered in the 35 percent project cost contingency factor. For the purposes of estimating well pumping power costs, a total dynamic head estimate of 300 feet was assumed—160 feet to bring water from pumping levels to the ground surface and 140 feet to pump into a pressurized distribution system maintained at 60 psi. This conservative estimate is intended to account for local drawdown and declining water levels with time. For municipal (and county-other) users it was also assumed, in the absence of any specific information to the contrary, that disinfection would be the only treatment needed to make the groundwater supply meet water quality standards, and that adequate treatment capacity would exist to meet peak demand rates.

All cost estimates were performed according to established HDR costing methodology. All costs were amortized over a 30-year loan period, with debt service and annualized O&M often being a significant proportion of costs. In addition, all wells are costed in present value, even if they are not scheduled to be needed until later decades. This is to maintain consistency in cost estimates with other projects. However, it should be noted that individual wells are not usually financed in this manner, and managers of affected WUGs may be more interested simply in the estimated capital cost for the wells. Also, cost estimates for new wells serving economic activities such as mining or irrigation are presented as a group with a single unit cost, although in reality these costs will be borne individually by multiple independent parties (farmers, mining operations, manufacturing plants, etc.) when and where the wells are needed and constructed.

4C.7.2.2 Water Availability Using the Central Gulf Coast GAM

In order to define groundwater availability for planning purposes, the following drawdown and water quality constraints were adopted by the CBRWPG during the previous planning process:

1. In the unconfined aquifer:
   a. Water level declines were limited to no more than 125 feet below predevelopment levels; and
   b. A minimum saturated thickness of 150 feet.
2. In the confined aquifer:
   a. Water level declines were limited to no more than 250 feet below predevelopment levels; and
   b. Water level declines were not to exceed 62.5 percent of the elevation difference between predevelopment flow heads and the top of the aquifer.
3. Total dissolved solids concentrations less than 1,500 ppm.

In order to determine if projected groundwater pumpage for local supply may exceed these criteria, the local groundwater demands for each user group were simulated using the publicly-released version of the Central Gulf Coast Groundwater Availability Model (CGCGAM), sponsored and developed by the TWDB, which represents the partially-penetrating thickness of the Evangeline Aquifer. The CGCGAM extends from Wharton and Colorado counties in the northeast to Hidalgo and Starr County in the southwest (Figure 4C.7-3). It should be noted that groundwater modeling using the CGCGAM is not appropriate for modeling changes in TDS or other water quality criteria. It is only appropriate for evaluating changes in groundwater elevations.

Drawdown from 2000 to 2060 was calculated by the CGCGAM. After the groundwater demands for local supply were simulated, the resulting water levels were compared to water levels simulated in the steady-state version of the CGCGAM which are representative of pre-development conditions. If drawdown from pre-development conditions exceeded any of the criteria, these locations are noted. Drawdown for the Chicot and Evangeline Aquifers are presented in Figures 4C.7-4 and 4C.7-5. The Chicot Aquifer shows no significant drawdown during this simulation period, with maximum drawdown of approximately 20 feet in Brooks County and south Bee County. The Evangeline Aquifer shows a large area of drawdown in Brooks County associated with mining activity (although this mining pumpage is attributed to Duval County in TWDB records). Figure 4C.7-6 shows that the drawdown associated with this mining enterprise is the only area in the Evangeline Aquifer within Region N that exceeds the drawdown criteria. Figure 4C.7-7 displays model simulation results that indicate four areas in the Jasper Aquifer which exceed the drawdown criteria. These areas are all associated with mining or manufacturing enterprises in the Region, and are partially an artifact of the methodology that was used to determine spatial distribution of pumping within each county. It is probable that these entities could avoid excessive drawdowns by spreading out the area of their wells, instead of concentrating them all in a small area represented by a cluster of adjacent cells.

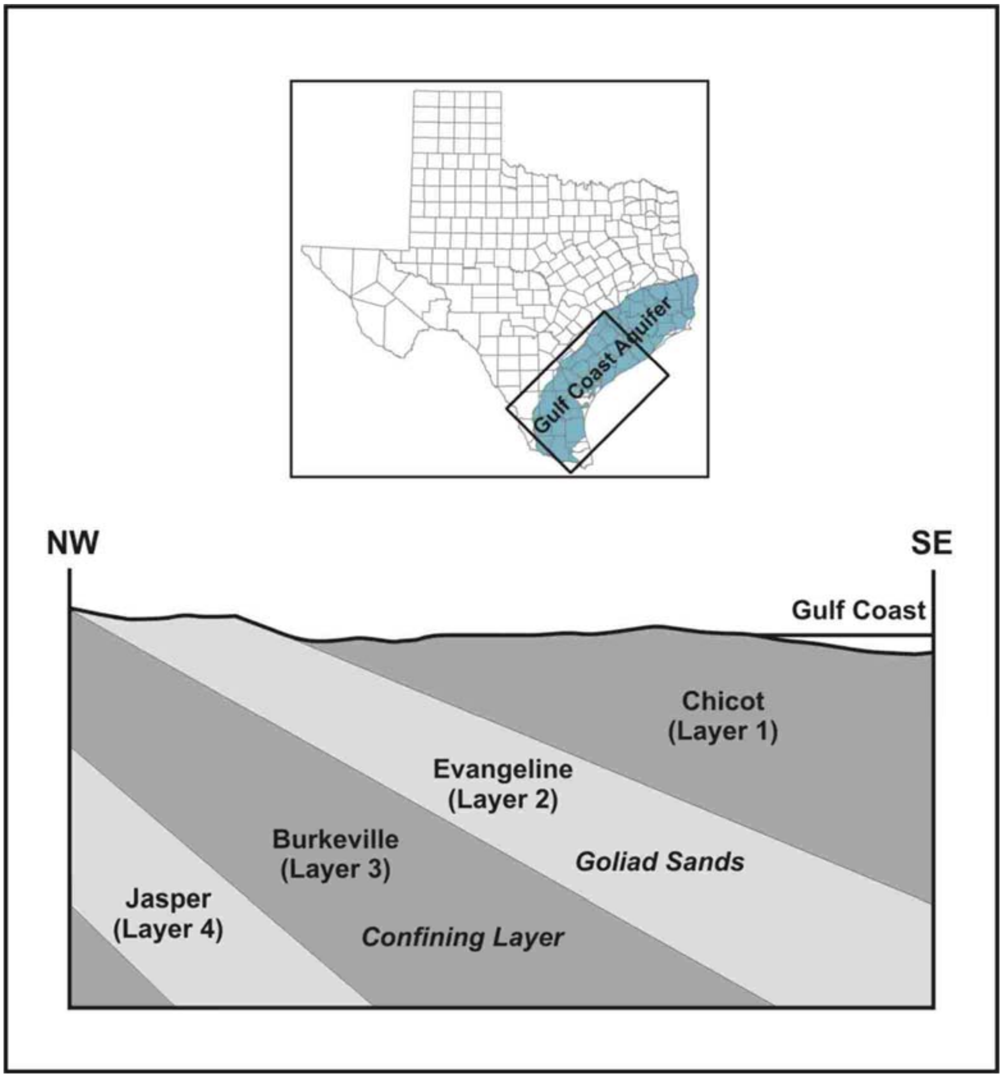

Figure 4C.7-3. Central Gulf Coast Groundwater Availability Model Boundaries and Layers

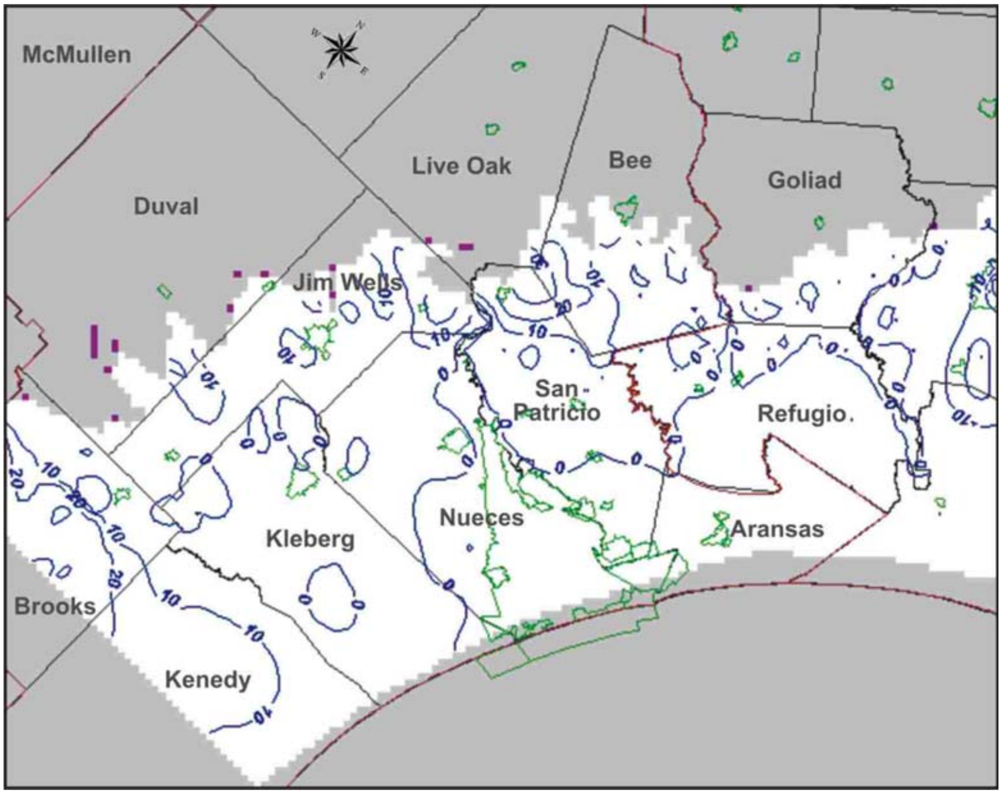

Figure 4C.7-4. 2000 to 2060 Chicot Drawdown

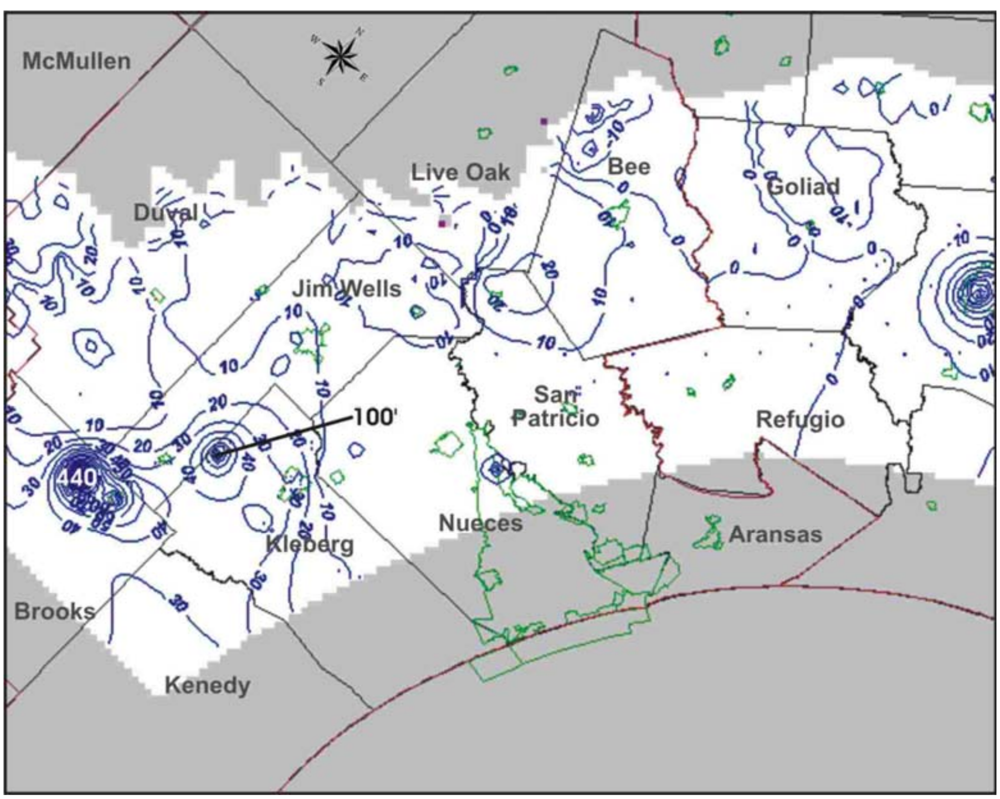

Figure 4C.7-5. 2000 to 2060 Evangeline Drawdown

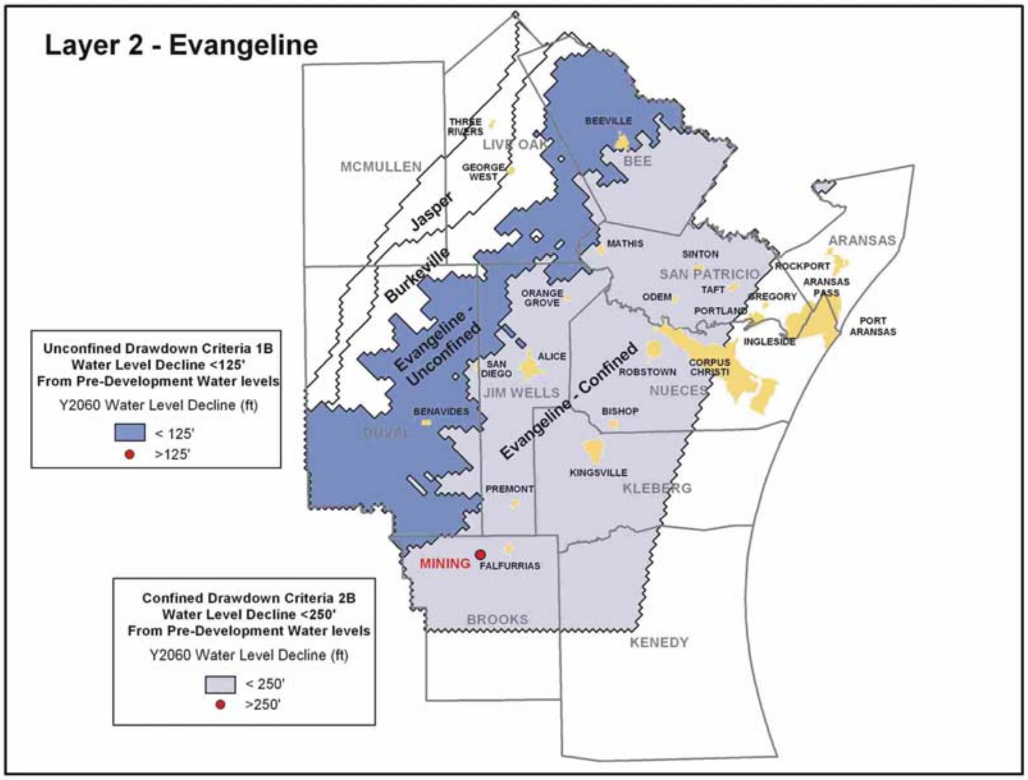

Figure 4C.7-6. Evangeline Aquifer Areas Exceeding Drawdown Criteria

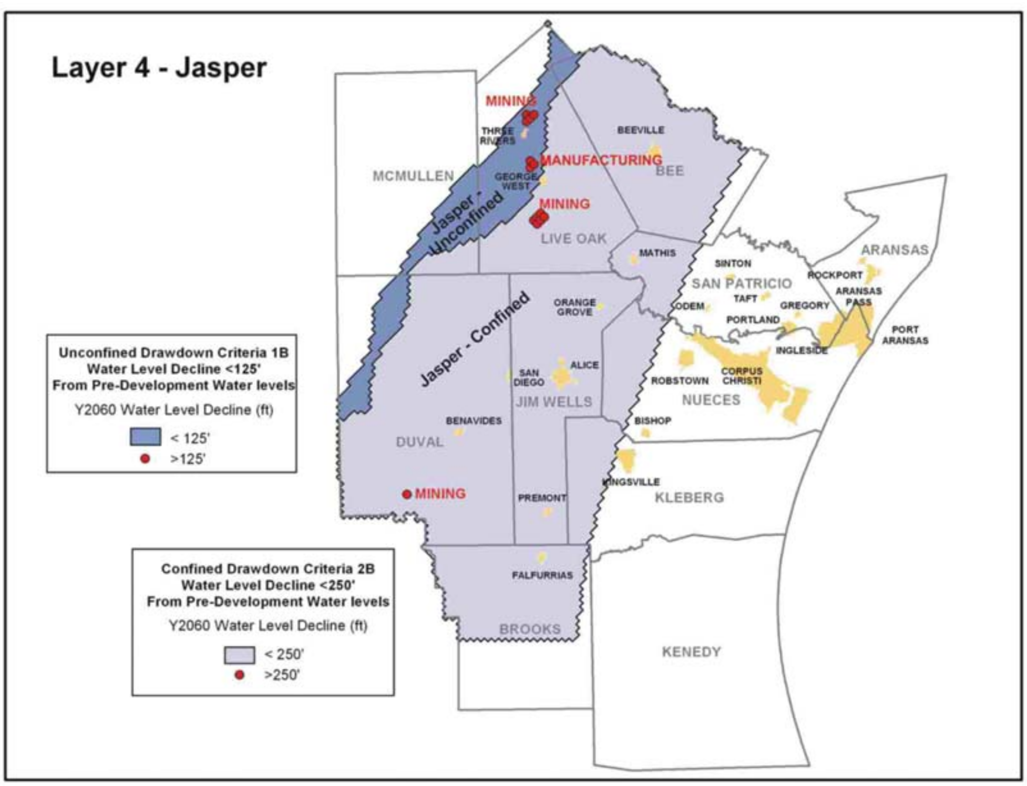

Figure 4C.7-7. Jasper Aquifer Areas Exceeding Drawdown Criteria

4C.7.2.3 Evaluation of Municipal Water Systems and Water Quality

The location of each municipal water system with a population in excess of about 500 that totally relies on local groundwater for a supply is presented in Figure 4C.7-8. The needs analysis indicate that none of the municipal systems identified had unmet needs within the planning period. However, there is some uncertainty as to the future water quality with prolonged pumping, since TDS exceeds drinking water standards throughout much of the planning region (Figure 4C.7-9). For drinking water supplies, the public drinking water standard for salinity is 1,000 mg/L of total dissolved solids.

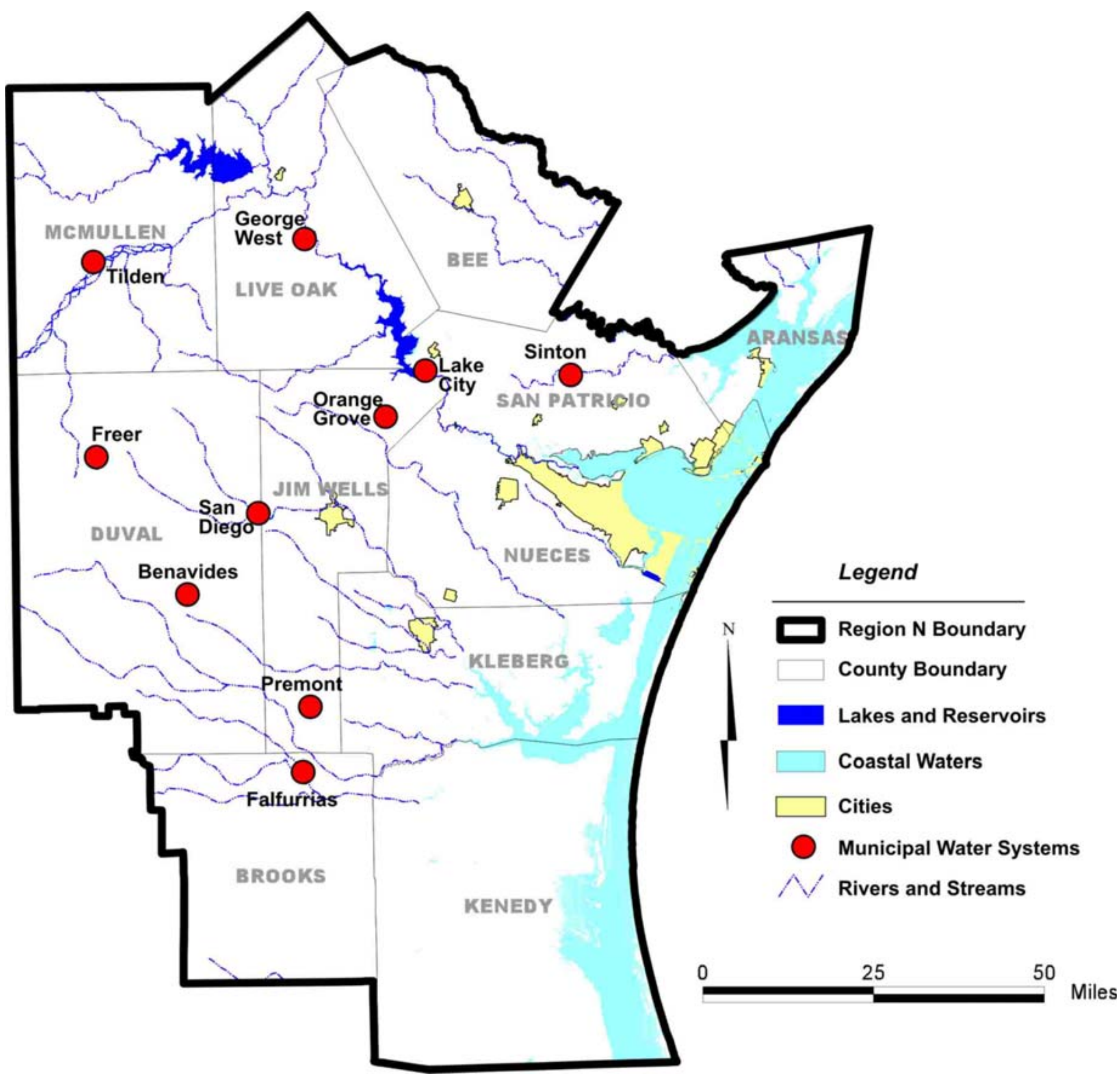

Figure 4C.7-8. Small Municipal Water Systems Relying Solely on Groundwater

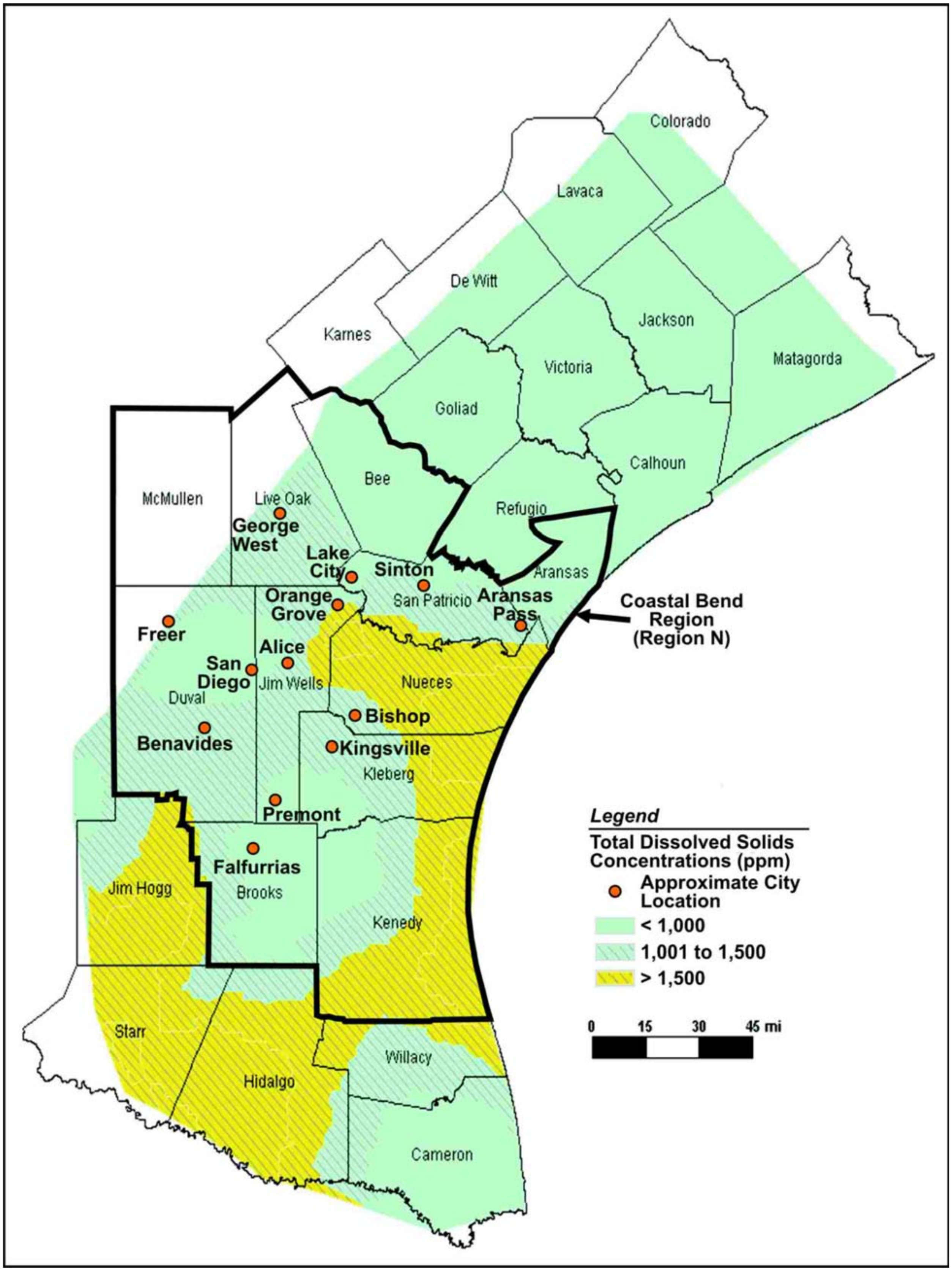

Figure 4C.7-9. TDS Concentrations in the Coastal Bend Region

If local utilities determine that a water treatment plant to desalinate the local brackish groundwater is needed, Table 4C.7-3 is provided to give an estimate of the capital cost for treating slightly saline water (up to 3,000 mg/L). This cost does not include connection to existing wells or the distribution system or the disposal of concentrate.

Freer is in an area of the Coastal Bend Water Planning Region and Duval County where the major water bearing zones of the Gulf Coast Aquifer are absent and where the Carrizo-Wilcox Aquifer is too deep, saline, and hot for a conventional public water supply. Locally, groundwater is produced for the city by the Freer Water Conservation and Improvement District from the Catahoula Tuff which is not classified as a major or minor aquifer by TWDB and is not included in the county's groundwater availability estimates. In this area, the Catahoula Tuff supplies slightly saline water and yields 100 to 200 gpm to large wells. The groundwater from the Catahoula Formation routinely has TDS concentrations greater than 1,000 ppm. Although projections indicate that Freer's current wells will produce adequate supply to meet their anticipated demand, there is local concern that the water quality of the water produced by the city's wells will decline to the point that advanced treatment will be necessary to stay in compliance with regulatory water quality guidelines. The proposed treatment for groundwater salinity is through a reverse osmosis membrane system. Costs for this incorporating this treatment into the Freer water system were developed using the HDR costing methodology employed in all other project evaluations (i.e., 30 year debt service, 35 percent contingency factor, etc.). Freer's maximum projected groundwater use is 663 acft/year in 2030. A peaking factor of two results in a maximum peak demand rate of 1.2 MGD. If no additional infrastructure is required, it is estimated that the total capital cost for a membrane WTP will be $3,599,000, and total project cost will be $5,297,000. Total annual cost will be $739,000, resulting in a unit cost of $550/acft, or $1.69/1,000 gallons, assuming full utilization of treatment plant.

Benavides in Duval County and San Diego in Duval and Jim Wells counties are areas of the Coastal Bend Water Planning Region supplied by Goliad Sands of the Gulf Coast Aquifer. Locally, groundwater is produced for the cities by Duval County Conservation and Reclamation District and San Diego Municipal Utility District. In these areas, the Goliad Sands supply slightly saline water with reported TDS concentrations ranging from 630- 1,280 ppm.[7] Although projections indicate that Benavides and San Diego's current wells will produce adequate supply

[7] TWDB Groundwater Monitoring database, May 2005.

to meet their anticipated demand, there is local concern that the water quality of the water produced by the city's wells will decline to the point that advanced treatment will be necessary to stay in compliance with regulatory water quality guidelines. The proposed treatment for groundwater salinity is through a reverse osmosis membrane system.

Costs for this incorporating this treatment into the Benavides and San Diego water systems were developed using the HDR costing methodology employed in all other project evaluations (i.e., 30 year debt service, 35 percent contingency factor, etc.). Benavides' maximum projected groundwater use is 334 acft/year in 2030. A peaking factor of two results in a maximum peak demand rate of 0.6 MGD. If no additional infrastructure is required, it is estimated that the total capital cost for a membrane WTP will be $2,377,600, and total project cost will be $3,568,800. Total annual cost will be $464,200, resulting in a unit cost of $691/acft, or $2.12/1,000 gallons, assuming full utilization of treatment plant. San Diego's maximum projected groundwater use for both Duval and Jim Wells counties combined is 587 acft/year in 2020. A peaking factor of two results in a maximum peak demand rate of 1 MGD. If no additional infrastructure is required, it is estimated that the total capital cost for a membrane WTP will be $3,280,000, and total project cost will be $4,844,000. Total annual cost will be $662,000, resulting in a unit cost of $591/acft, or $1.81/1,000 gallons, assuming full utilization of treatment plant.

4C.7.2.4 Evaluation of Rural Water Systems and Water Supply Corporations and Water Quality

For purposes of this alternative, the relatively small public water systems within the county-other classification by the TWDB are reviewed in consideration of the overall groundwater availability and quality within a county. A summary of the review and analysis is given in the following sections. If a water treatment plant to desalinate the local brackish groundwater is needed, Table 4C.7-3 is provided to give an estimate of the capital cost for treating slightly saline water (up to 3,000 mg/L). This cost does not include connection to existing wells.

Table 4C.7-3.
Desalination of Brackish Groundwater (3,000 mg/L TDS)
Cost Estimate Summary

Item	*Estimated Costs 0.1 MGD*	*Estimated Costs 0.5 MGD*	*Estimated Costs 1 MGD*	*Estimated Costs 3 MGD*	*Estimated Costs 5 MGD*	*Estimated Costs 10 MGD*
Capital Costs						
Source Water Supply[1]	$270,000	$500,000	$630,000	$1,530,000	$2,433,000	$5,218,000
Water Treatment Plant	$547,000	$1,309,000	$2,260,000	$4,413,000	$6,567,000	$11,950,000
Concentrate Disposal[1]	$158,000	$211,000	$232,000	$317,000	$370,000	$401,000
Distribution[1]	$79,000	$132,000	$158,000	$211,000	$238,000	$312,000
Total Capital Cost	**$1,054,000**	**$2,152,000**	**$3,280,000**	**$6,471,000**	**$9,608,000**	**$17,881,000**
Engineering, Legal Costs and Contingencies (35%)	$369,000	$753,000	$1,148,000	$2,265,000	$3,363,000	$6,258,000
Environmental & Archaeology Studies and Mitigation[1]	$114,000	$119,000	$129,000	$183,000	$267,000	$353,000
Land Acquisition & Surveying[1]	$109,000	$109,000	$109,000	$113,000	$118,000	$135,000
Interest During Construction (1 year)	$57,000	$117,000	$178,000	$350,000	$519,000	$966,000
Total Project Cost	**$1,703,000**	**$3,250,000**	**$4,844,000**	**$9,382,000**	**$13,875,000**	**$25,593,000**
Annual Costs						
Debt Service (6 percent, 30 years)	$124,000	$236,000	$352,000	$682,000	$1,008,000	$1,859,000
Operation and Maintenance						
Source Water Supply[1]	$5,000	$17,000	$25,000	$72,000	$119,000	$240,000
Water Treatment Plant	$45,000	$138,000	$254,000	$635,000	$1,017,000	$1,970,000
Concentrate Disposal[1]	$8,000	$11,000	$12,000	$16,000	$18,000	$20,000
Distribution[1]	$5,000	$13,000	$19,000	$32,000	$48,000	$92,000
Total						
Total Annual Cost	**$187,000**	**$415,000**	**$662,000**	**$1,437,000**	**$2,210,000**	**$4,181,000**
Available Project Yield (acft/yr)	**112**	**560**	**1,120**	**3,360**	**5,601**	**11,202**
Annual Cost of Water ($ per acft)	**$1,669**	**$741**	**$591**	**$428**	**$395**	**$373**
Annual Cost of Water ($ per 1,000 gallons)	**$5.12**	**$2.27**	**$1.81**	**$1.31**	**$1.21**	**$1.15**

[1]Costs for these items are site specific. Average costs used assume groundwater wells 1,000 ft deep, concentrate disposal to surface water, and distribution within 1 mile of treatment plant.

Live Oak, Jim Wells, and Kleberg Counties

For Live Oak, Jim Wells, Kleberg, and San Patricio Counties, the groundwater availability is insufficient to meet the demands of rural water suppliers. In addition, locally, the groundwater in these counties can vary from fresh (less than 1,000 mg/L) to slightly saline (up to 3,000 mg/L). To secure drinking water supplies that meet the salinity requirements, an alternative is desalination of local brackish groundwater. Entities can estimate the capital and operation and maintenance costs for a desalination water treatment plant from Table 4C.7-3.

Live Oak County has unmet needs likely to be supplied with local groundwater in the county-other category. Live Oak County also has a small need identified in the county-other category that appears in 2030, but declines and disappears by 2060.

Jim Wells County has a small need in the county-other category that starts in 2010, peaks at 262 acft/year in 2030, and declines after 2030. Two new wells are projected to meet these needs.

Kleberg County has a small need in the county-other user group beginning in 2020 and growing slightly and steadily through the planning period. This need can be met with a single well in 2020; no further wells are indicated after this time.

4C.7.2.5 Evaluation of Irrigation Water Users

Live Oak County is the only county which projects an unmet need in the irrigation sector. The largest immediate need is in the irrigation sector, which has a shortage of 627acft/year by 2010. This need can be met by eight new wells by 2010. However, irrigation demand declines after this time, and no further wells are needed after 2010.

4C.7.2.6 Evaluation of Mining Water Users

Live Oak County Mining needs are projected to grow steadily throughout the planning period to 1,755 acft/year by 2060, with additional wells needed in most decades.

Duval County has significant needs in the mining sector that are likely to be met through development of local Gulf Coast Aquifer supplies. Mining needs grow from 1,738 acft/year in 2010 to 4,205 acft/year in 2060, and will need 11 new wells to meet this supply, according to the methodology employed.

4C.7.2.7 Evaluation of Manufacturing Water Users

Live Oak County manufacturing needs more than double throughout the planning period to 764 acft/year in 2060; new wells are needed in 2010 and 2020.

Aransas County has a small need in the manufacturing sector that begins in 2010 and grows steadily to 136 acft/year by 2060. One new well is projected to meet this demand.

4C.7.2.8 Environmental Issues

A previous study estimates up to 25% of recharge to the Gulf Coast Aquifer in nearby Wharton and Matagorda counties ends up as freshwater discharge to near-coast waters.[8]

The pumping of groundwater from the Gulf Coast Aquifer could have a very slight negative impact on baseflow in the downstream reaches of streams in these areas. However, many of the streams are dry most all the time; thus, no measurable impact on wildlife along the streams is expected.

The desalinization of slightly saline groundwater produces a concentrate of salts in water that requires disposal. Depending upon location, environmental concerns can be addressed by discharging to saline aquifer by deep well injection, discharging to a salt-water body, or blending with wastewater.

Habitat studies and surveys for protected species may need to be conducted at the proposed well field sites and along any pipeline routes. When potential protected species habitat or other significant resources cannot be avoided, additional studies would have to be conducted to evaluate habitat use or eligibility for inclusion in the National Register for Historic Places, respectively. Wetland impacts, primary pipeline stream crossings, can be minimized by right-of-way selection and appropriate construction methods, including erosion controls and revegetation procedures. Compensation for net losses of wetlands may be required where impacts are unavoidable.

4C.7.2.9 Engineering and Costing

The entities that may need new local supply wells in the Gulf Coast Aquifer added to their system by the year 2060 are presented in Figure 4C.7-2 and summarized in Table 4C.7-4. Cost estimates for new wells were prepared according to the assumptions presented in the

[8] Dutton, A.R., and Richter, B.C., 1990. "Regional geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a numerical model to estimate the impact of water management strategies", The University of Texas at Austin and Bureau of Economic Geology.

previous section. Table 4C.7-4 displays the projected unmet needs, by decade, for each of these entities, and the decades in which additional wells are estimated to be needed. The capital cost, project cost, annual cost, yield, and unit cost (in $/acft and $/1000 gallons) for water obtained under this strategy are presented in Table 4C.7-5 through 4C.7-13 for each entity county.

Table 4C.7-4.
Region N Local Gulf Coast Aquifer Supply Water Management Strategy
Cost and Schedule Summary

County	User		Needs (acft/yr)[1]						Total Wells
			2010	2020	2030	2040	2050	2060	
Live Oak	County-Other	Projected Needs	0	0	32	44	14	0	1
		New Wells	—	—	1	—	—	—	
Live Oak	Manufacturing	Projected Needs	337	483	559	615	657	764	2
		New Wells	1	1	—	—	—	—	
Live Oak	Mining	Projected Needs	64	478	928	1,234	1,504	1,755	5
		New Wells	1	1	1	1	—	1	
Live Oak	Irrigation	Projected Needs	627	569	514	464	416	373	3
		New Wells	3	—	—	—	—	—	
Aransas	Manufacturing	Projected Needs	72	86	97	107	116	136	1
		New Wells	1	—	—	—	—	—	
Duval	Mining	Projected Needs	1,738	2,518	2,973	3,386	3,809	4,205	11
		New Wells	5	2	1	1	1	1	
Jim Wells	County-Other	Projected Needs	167	238	262	241	210	170	2
		New Wells	1	1	—	—	—	—	
Kleberg	County-Other	Projected Needs	0	31	81	108	153	155	1
		New Wells	—	1	—	—	—	—	
San Patricio	Lake City	Projected Needs	0	1	11	19	28	37	1
		New Wells	—	1	—	—	—	—	

[1] Indicates needs exceeding current estimate of local aquifer supply. See text for details.

Table 4C.7-5.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—Live Oak County County-Other

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields	$158,000
Water Treatment Plant (0.1 MGD)	12,000
Total Capital Cost	**$170,000**
Engineering, Legal Costs and Contingencies	$60,000
Interest During Construction (1 year)	10,000
Total Project Cost	**$240,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$17,000
Operation and Maintenance	
Pipeline	2,000
Water Treatment Plant	4,000
Pumping Energy Costs (15,487 kWh @ 0.06 $/kWh)	1,000
Total Annual Cost	**$24,000**
Available Project Yield (acft/yr)	**80**
Annual Cost of Water ($ per acft)	**$300**
Annual Cost of Water ($ per 1,000 gallons)	**$0.92**

Needs analysis indicates one well needed by 2030.
Cost estimate assumes County-Other delivery must meet seasonal peak rate of two times average annual rate.
Cost estimate assumes chlorine disinfection is the only treatment necessary for County-Other groundwater supply.

Table 4C.7-6.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—Live Oak County Manufacturing

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields	$282,000
Power Connection Costs	100,000
Total Capital Cost	**$382,000**
Engineering, Legal Costs and Contingencies	$134,000
Interest During Construction (1 year)	21,000
Total Project Cost	**$240,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$39,000
Operation and Maintenance	
Wells, Pipeline, Pumps	4,000
Pumping Energy Costs (154,867 kWh @ 0.06 $/kWh)	9,000
Total Annual Cost	**$52,000**
Available Project Yield (acft/yr)	**800**
Annual Cost of Water ($ per acft)	**$365**
Annual Cost of Water ($ per 1,000 gallons)	**$1.20**

Needs analysis indicates two wells needed by 2020.
Cost estimate assumes manufacturing groundwater supply delivered at uniform rate.
Cost estimate assumes no water treatment is necessary for manufacturing groundwater supply.

Table 4C.7-7.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—Live Oak County Mining

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields	$705,000
Power Connection Costs	250,000
Total Capital Cost	**$955,000**
Engineering, Legal Costs and Contingencies	$334,000
Interest During Construction (1 year)	52,000
Total Project Cost	**$1,341,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$97,000
Operation and Maintenance	
Wells, Pipeline, Pumps	10,000
Pumping Energy Costs (387,167 kWh @ 0.06 $/kWh)	23,000
Total Annual Cost	**$130,000**
Available Project Yield (acft/yr)	**2,000**
Annual Cost of Water ($ per acft)	**$65**
Annual Cost of Water ($ per 1,000 gallons)	**$0.20**

Needs analysis indicates five wells needed by 2060.
Cost estimate assumes mining groundwater supply delivered at uniform rate.
Cost estimate assumes no water treatment is necessary for mining groundwater supply.

Table 4C.7-8.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—Live Oak County Irrigation

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields	$423,000
Power Connection Costs	150,000
Total Capital Cost	**$573,000**
Engineering, Legal Costs and Contingencies	$201,000
Interest During Construction (1 year)	31,000
Total Project Cost	**$805,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$58,000
Operation and Maintenance	
Wells, Pipeline, Pumps	6,000
Pumping Energy Costs (232,300 kWh @ 0.06 $/kWh)	14,000
Total Annual Cost	**$78,000**
Available Project Yield (acft/yr)	**1,210**
Annual Cost of Water ($ per acft)	**$64**
Annual Cost of Water ($ per 1,000 gallons)	**$0.20**

Needs analysis indicates three wells needed by 2010; demand declines after this.
Cost estimate assumes irrigation groundwater supply delivered at seasonal peak rate of two times average rate.
Cost estimate assumes no water treatment is necessary for irrigation groundwater supply.

Table 4C.7-9.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—Aransas County Manufacturing

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields	$89,000
Power Connection Costs	50,000
Total Capital Cost	**$139,000**
Engineering, Legal Costs and Contingencies	$49,000
Interest During Construction (1 year)	8,000
Total Project Cost	**$196,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$14,000
Operation and Maintenance	
Wells, Pipeline, Pumps	1,000
Pumping Energy Costs (38,717 kWh @ 0.06 $/kWh)	2,000
Total Annual Cost	**$17,000**
Available Project Yield (acft/yr)	**200**
Annual Cost of Water ($ per acft)	**$85**
Annual Cost of Water ($ per 1,000 gallons)	**$0.26**

Needs analysis indicates one well needed by 2010.
Cost estimate assumes industrial groundwater supply delivered at uniform rate.
Cost estimate assumes no water treatment is necessary for industrial groundwater supply.

Table 4C.7-10.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—Duval County Mining

Item	*Estimated Costs for Facilities*
Capital Costs	
Well Fields	$1,551,000
Power Connection Costs	550,000
Total Capital Cost	**$2,101,000**
Engineering, Legal Costs and Contingencies	$735,000
Interest During Construction (1 year)	114,000
Total Project Cost	**$2,950,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$214,000
Operation and Maintenance	
Intake, Pipeline, Pump Station	21,000
Pumping Energy Costs (851,767 kWh @ 0.06 $/kWh)	51,000
Total Annual Cost	**$286,000**
Available Project Yield (acft/yr)	**4,400**
Annual Cost of Water ($ per acft)	**$65**
Annual Cost of Water ($ per 1,000 gallons)	**$0.20**

Needs analysis indicates 11 wells needed by 2060.
Cost estimate assumes mining groundwater supply delivered at uniform rate.
Cost estimate assumes no water treatment is necessary for mining groundwater supply.

Table 4C.7-11.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—Jim Wells County County-Other

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields	$500,000
Water Treatment Plant (0.6 MGD)	31,000
Total Capital Cost	**$531,000**
Engineering, Legal Costs and Contingencies	$186,000
Interest During Construction (1 year)	29,000
Total Project Cost	**$746,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$54,000
Operation and Maintenance	
Pipeline	5,000
Water Treatment Plant	13,000
Pumping Energy Costs (108,407 kWh @ 0.06 $/kWh)	7,000
Total Annual Cost	**$79,000**
Available Project Yield (acft/yr)	**565**
Annual Cost of Water ($ per acft)	**$140**
Annual Cost of Water ($ per 1,000 gallons)	**$0.43**

Needs analysis indicates one well needed by 2010.
Cost estimate assumes County-Other delivery must meet seasonal peak rate of two times average annual rate.
Cost estimate assumes chlorine disinfection is the only treatment necessary for County-Other groundwater supply.

Table 4C.7-12.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—Kleberg County County-Other

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields	$295,000
Water Treatment Plant (0.4 MGD)	23,000
Total Capital Cost	**$318,000**
Engineering, Legal Costs and Contingencies	$111,000
Interest During Construction (1 year)	18,000
Total Project Cost	**$447,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$32,000
Operation and Maintenance	
Pipeline	3,000
Water Treatment Plant	9,000
Pumping Energy Costs (77,433 kWh @ 0.06 $/kWh)	5,000
Total Annual Cost	**$49,000**
Available Project Yield (acft/yr)	**400**
Annual Cost of Water ($ per acft)	**$123**
Annual Cost of Water ($ per 1,000 gallons)	**$0.38**

Needs analysis indicates one well needed by 2030.
Cost estimate assumes County-Other delivery must meet seasonal peak rate of two times average annual rate.
Cost estimate assumes chlorine disinfection is the only treatment necessary for County-Other groundwater supply.

Table 4C.7-13.
Cost Estimate Summary
Water Supply Project Option
Second Quarter 2002 Prices
Region N Local Gulf Coast Supplies—San Patricio County – Lake City

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields	$178,000
Water Treatment Plant (0.066 MGD)	8,000
Total Capital Cost	**$186,000**
Engineering, Legal Costs and Contingencies	$65,000
Interest During Construction (1 year)	11,000
Total Project Cost	**$262,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$19,000
Operation and Maintenance	
Pipeline	2,000
Water Treatment Plant	2,000
Pumping Energy Costs (15,487 kWh @ 0.06 $/kWh)	1,000
Total Annual Cost	**$24,000**
Available Project Yield (acft/yr)	**80**
Annual Cost of Water ($ per acft)	**$300**
Annual Cost of Water ($ per 1,000 gallons)	**$0.92**

Needs analysis indicates one well needed by 2020.
Cost estimate assumes County-Other delivery must meet seasonal peak rate of two times average annual rate.
Cost estimate assumes chlorine disinfection is the only treatment necessary for County-Other groundwater supply.

4C.7.2.10 Implementation Issues

The development of additional wells and the installation and operation of brackish water treatment plant, may have to address the following issues.

- Disposal of salt concentrate from water treatment plant;
- Impact on:
  - Endangered and other wildlife species,
  - Water levels in the aquifer,
  - Baseflow in streams, and
  - Wetlands;
- Capital and operation and maintenance costs;
- Skilled operators of desalination water treatment plants;
- Competition with others for groundwater in the area;
- Detailed feasibility evaluation including test drilling and aquifer water quality testing; and
- The potential for regulations by groundwater conservation districts in the future, including the renewal of pumping permit at periodic intervals in counties where districts have been organized.

4C.7.2.11 Evaluation Summary

An evaluation summary of this regional water management option is provided in Table 4C.7-14.

Table 4C.7-14.
Evaluation Summary of the Alternative for
Small Municipal and Rural Water Systems

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost	 1. Firm Yield: Varies from 80 to 4,400 acft. 2. Good reliability, if adequate water quality. 3. Cost: Varies from $65 to $300 per acft.
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. May slightly decrease instream flow and discharge of freshwater into coastal estuaries due to local groundwater-surface water interaction. 2. May slightly decrease instream flow and discharge of freshwater into coastal estuaries due to local groundwater-surface water interaction. 3. Negligible impacts. 4. Negligible impacts 5. Negligible impacts. 6. Cultural resources will need to be surveyed and avoided. 7. Negligible impacts. a. Low to moderate impact. b. Low to moderate impact. c. No impact. d. Low to moderate impact. e. Low to moderate impact. f. Low to moderate impact. g-h. Low to moderate impact associated with mining. i. Boron may be a potential water quality concern.
c. Impacts to State water resources	• No negative impacts on water resources other than lowering Gulf Coast Aquifer levels
d. Threats to agriculture and natural resources in region	• May slightly increase pumping costs for agricultural users in the area due to localized drawdowns
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Standard analyses and methods used
g. Interbasin transfers	• None
h. Third party social and economic impacts from voluntary redistribution of water	• None
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities with local resources
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• None

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4C.7.3 Central Gulf Coast GAM Analyses for Future Water Supply Projects in Bee, San Patricio, and Refugio Counties

4C.7.3.1 Description of Strategy

In addition to baseline pumpage to meet local demand, several groundwater export projects have been proposed for the Gulf Coast Aquifer in the Coastal Bend Water Planning Region (Region N) as well as in the neighboring South Central Texas Regional Water Planning Area (Region L). These projects include the Lower Guadalupe Water Supply Project (LGWSP), the San Patricio Municipal Water District (SPMWD) well field, and the City of Corpus Christi well field (Figure 4C.7-10). The following are brief descriptions of the proposed simulated projects.

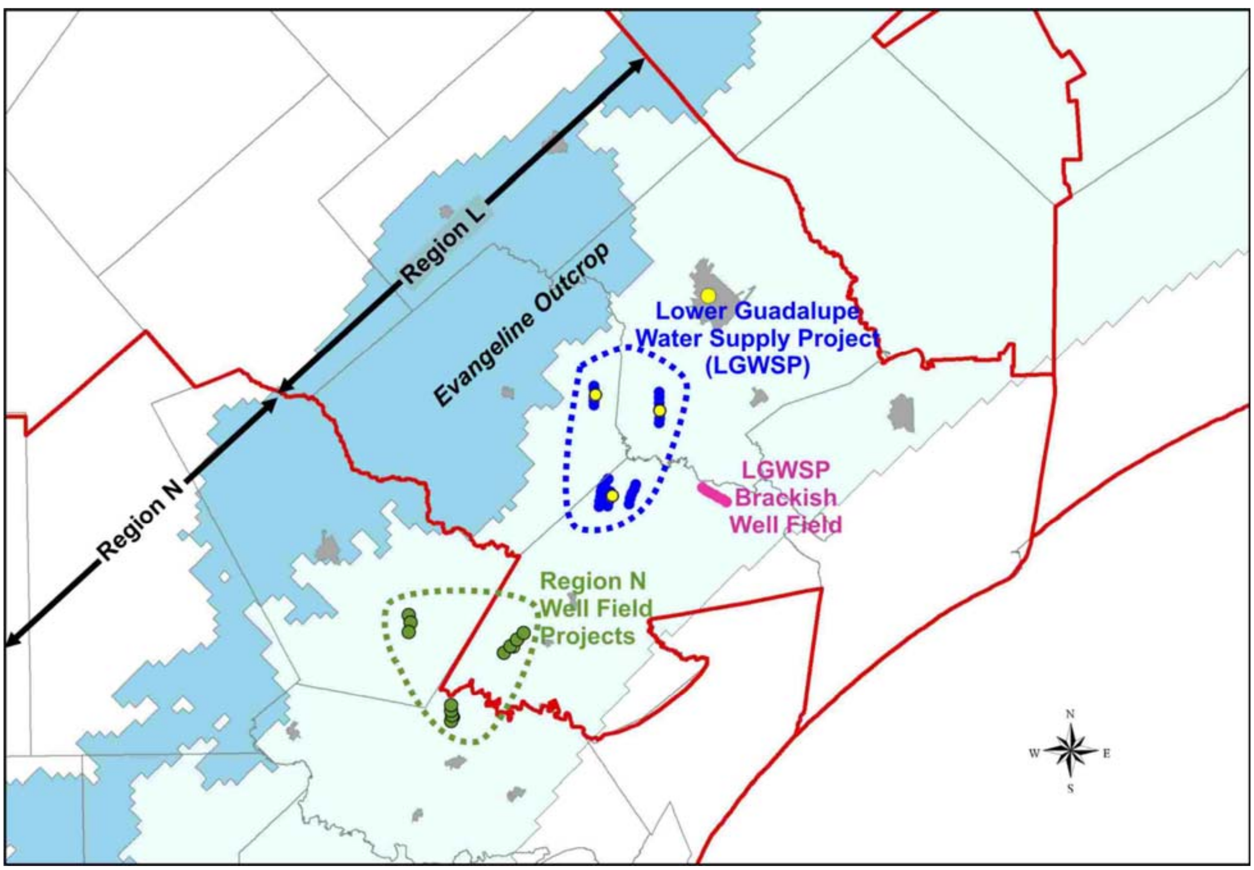

Figure 4C.7-10. Project Locations in the Evangeline Aquifer

LGWSP includes three well fields in Victoria, Goliad, and Refugio Counties. This project is envisioned as a conjunctive use project in which surface water flows from the Guadalupe River would be used when available, and groundwater would be used to supplement this source, which is reduced in times of drought. Groundwater would be pumped at a variable annual rate starting in 2015 depending on modeled surface water availability for each year. Water would be cumulatively pumped from the three well fields at and average rate of 15,529 acft/yr and at a maximum of 41,400 acft/yr during the drought of record. The well fields for this project are located in Region L counties. (The LGWSP brackish well field was not included in this simulation.)

SPMWD is currently evaluating two well fields in Bee and San Patricio Counties. Based on results of water quality and aquifer studies, one of the two sites will be selected to produce a total of 11,000 acft/yr at a constant annual rate starting in 2010.

The City of Corpus Christi project does not start until year 2056, and pumps a total of 7,000 acft per year by year 2060.

4C.7.3.2 Available Yield and Drawdown

In order to evaluate the effect of these projects on water levels in the primary aquifers serving the region, these projects were simulated for the predictive period 2000 to 2060 using the version of the Central Gulf Coast Groundwater Availability Model (CGCGAM) sponsored and developed by the TWDB which represents the fully penetrating thickness of the Evangeline Aquifer. After the simulation was complete, the drawdown associated with the export projects was added to the drawdown associated with baseline pumpage for local supply, and the cumulative drawdown was compared against the criteria for groundwater availability as described in the previous section.

A graph displaying the simulated pumpage for each export project through the 60-year simulation period is presented in Figure 4C.7-11.

The 2000 to 2060 cumulative drawdown for local pumpage and export projects is presented in Figure 4C.7-12 for the Chicot Aquifer and in Figure 4C.7-13 for the Evangeline Aquifer. The maximum drawdown in the Evangeline Aquifer near the SPMWD and the City of Corpus Christi well fields is approximately 50-feet in Bee, San Patricio, and Refugio Counties as shown in Figure 4C.7-13 and on the hydrographs in Figure 4C.7-14. The export projects do not exceed the drawdown criteria adopted by the CBRWPG.

Project	County	Average Pumpage (acft)
LGWSP	Goliad	2,329
	Refugio	9,473
	Victoria	3,727
	Refugio - Brackish	5,150
San Patricio	Bee	5,500
	San Patricio	5,500
Corpus Christi	Refugio	3,620

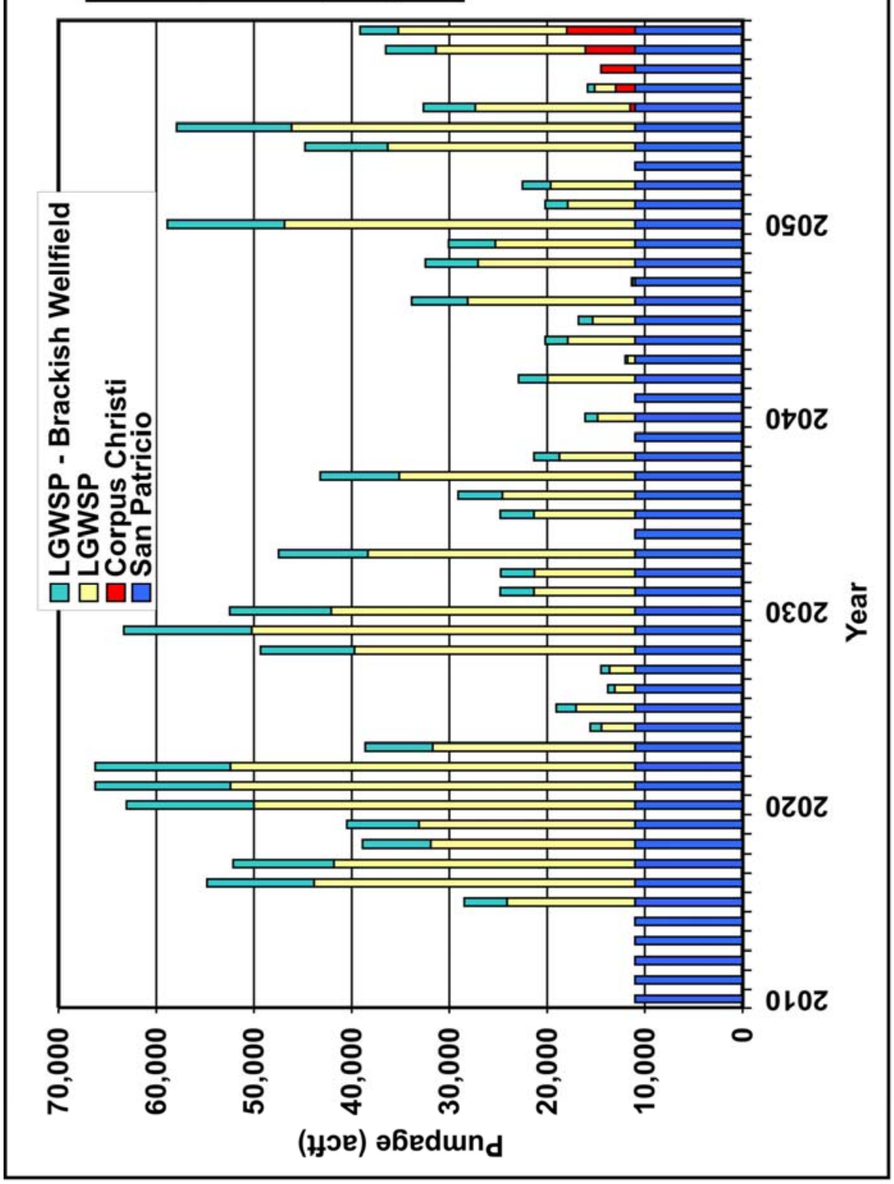

Figure 4C.7-11. Groundwater Export Projects Predictive Pumpage

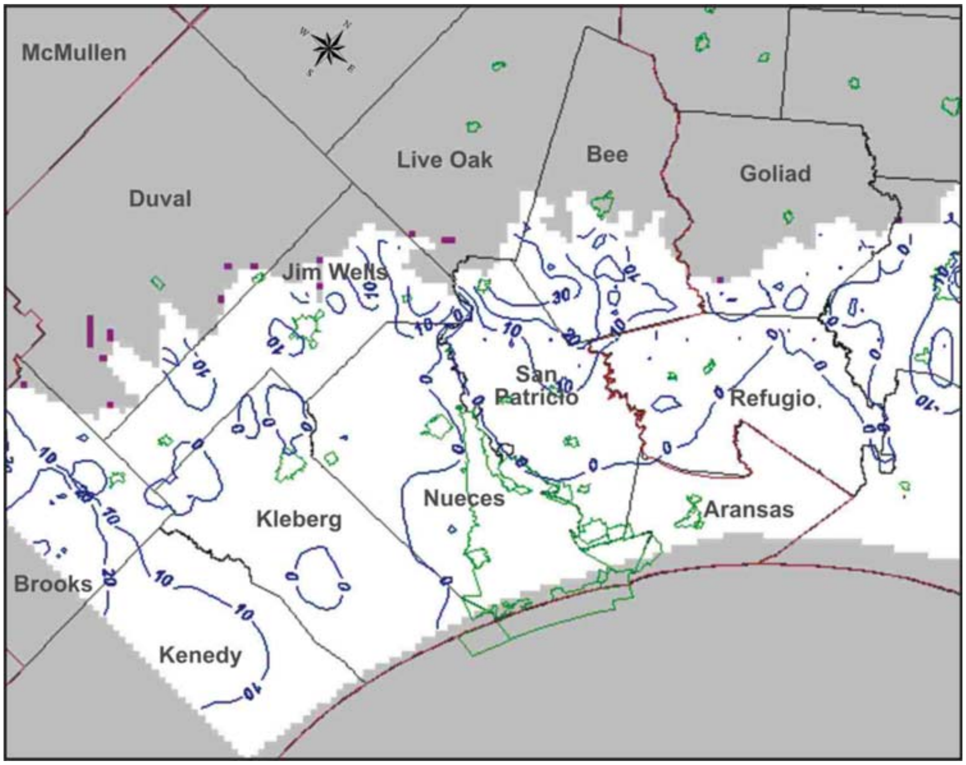

Figure 4C.7-12. 2000 to 2060 Drawdown for Local Pumpage and Export Projects in the Chicot Aquifer

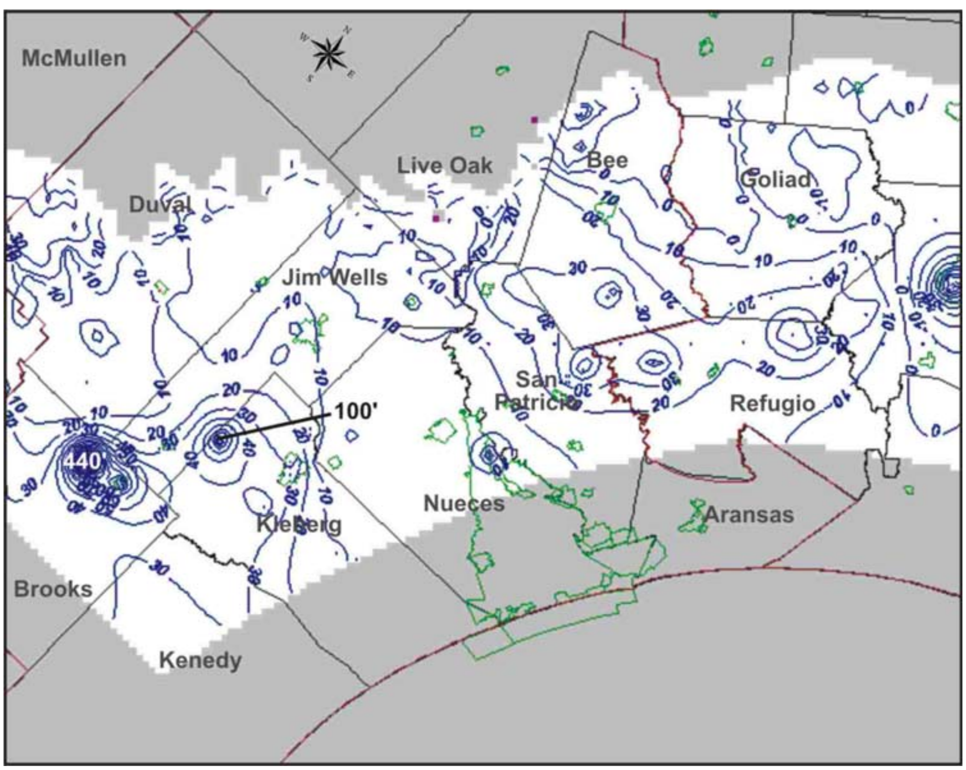

Figure 4C.7-13. 2000 to 2060 Drawdown for Local Pumpage and Export Projects in the Evangeline Aquifer

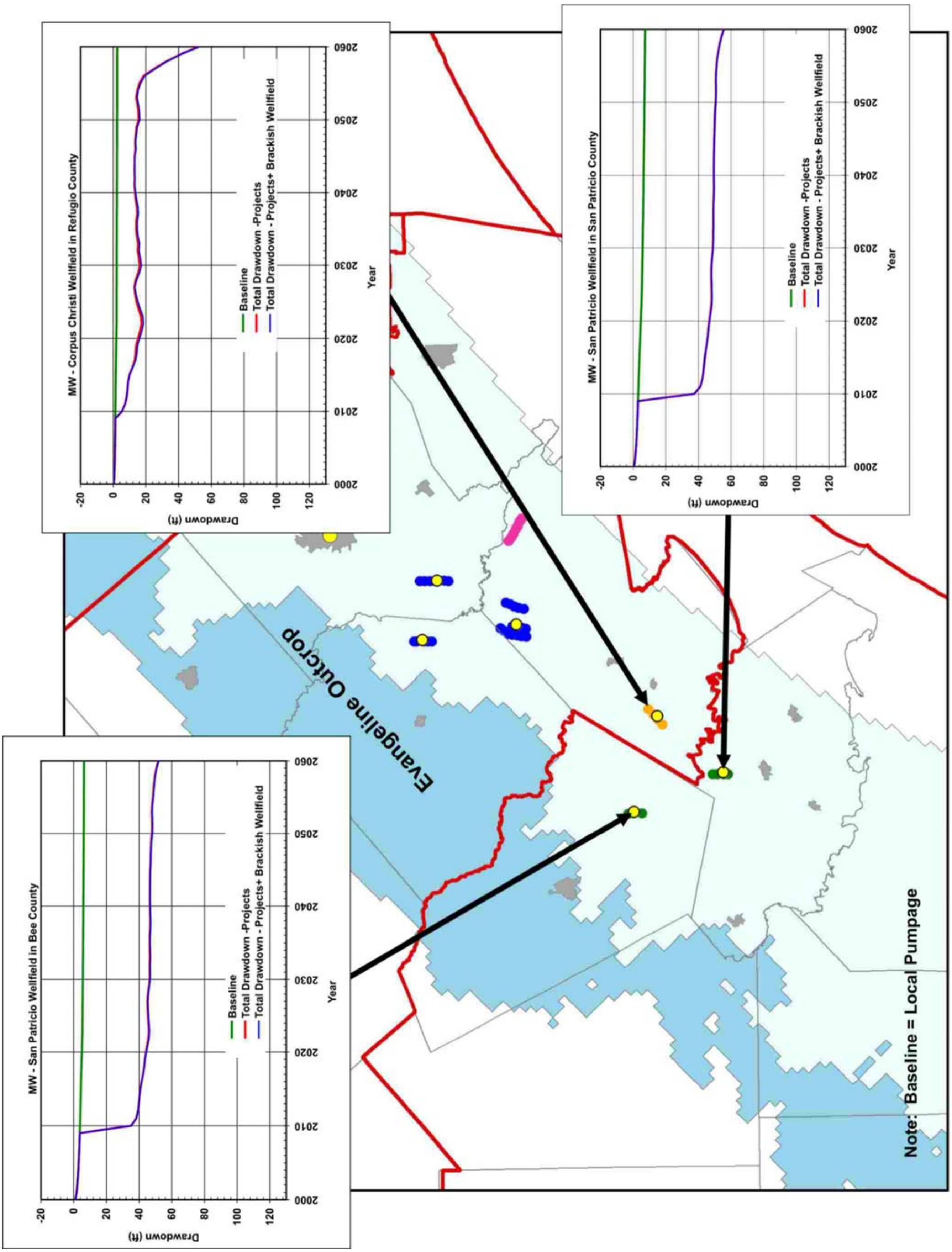

Figure 4C.7-14. Predictive Drawdown Hydrographs in the Evangeline Aquifer

4C.7.3.3 Environmental Issues

A previous study estimates up to 25% of recharge to the Gulf Coast Aquifer in nearby Wharton and Matagorda counties ends up as freshwater discharge to near-coast waters.[9]

The pumping of groundwater from the Gulf Coast Aquifer could have a very slight negative impact on baseflow in the downstream reaches of streams in these areas. However, many of the streams are dry most all the time; thus, no measurable impact on wildlife along the streams is expected.

The desalinization of slightly saline groundwater produces a concentrate of salts in water that requires disposal. Depending upon location, environmental concerns can be addressed by discharging to a saline aquifer by deep well injection, discharging to a salt-water body, or blending with wastewater.

Habitat studies and surveys for protected species may need to be conducted at the proposed well field sites and along any pipeline routes. When potential protected species habitat or other significant resources cannot be avoided, additional studies would have to be conducted to evaluate habitat use or eligibility for inclusion in the National Register for Historic Places, respectively. Wetland impacts, primary pipeline stream crossings, can be minimized by right-of-way selection and appropriate construction methods, including erosion controls and revegetation procedures. Compensation for net losses of wetlands may be required where impacts are unavoidable.

4C.7.3.4 Evaluation Engineering and Costing

Cost estimates for development of both the SPMWD and the City of Corpus Christi well fields were estimated to be similar to the conjunctive use of groundwater from the Gulf Coast Aquifer in Refugio County option discussed in Section 4C.7.1. These well field costs were updated to reflect the development of 11 wells rather than 28 wells as in the conjunctive use option. The costs presented in Table 4C.7-15, include deliver of raw water to the Mary Rhodes Pipeline.

[9] Dutton, A.R., and Richter, B.C., 1990. "Regional geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a numerical model to estimate the impact of water management strategies", The University of Texas at Austin and Bureau of Economic Geology.

Table 4C.7-15.
Cost Estimate Summary
Groundwater Supplies from Refugio, San Patricio, and Bee Well Fields
Second Quarter 2002 Prices

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Fields (11 wells; 1,200 gpm)	$7,241,000
Well Field Collection Pipeline	14,347,000
Transmission Pipeline (48-inch dia., 3 miles)[1]	2,708,000
Transmission Pump Station(s) [1]	5,437,000
Total Capital Cost	**$29,733,000**
Engineering, Legal Costs and Contingencies	$10,272,000
Environmental and Archaeology Studies, Mitigation, GW District Application Fees	936,000
Land Acquisition and Surveying (145 acres)	1,320,000
Interest During Construction (2 years)	3,381,000
Total Project Cost	**$45,642,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$3,316,000
Operation and Maintenance	
Pipeline and Pump Station	332,000
Pumping Energy Costs (27,753,990 kWh @ 0.06 $/kWh)	1,665,000
GW District Fees, Purchase of Water (18,000 acft/yr @ 77.428 $/acft)	1,394,000
Total Annual Cost	**$6,707,000**
Available Project Yield (acft/yr)	**18,000**
Annual Cost of Water ($ per acft)	**$373**
Annual Cost of Water ($ per 1,000 gallons)	**$1.14**

[1] Transmission pipeline distances and pipeline size from Section 4C.7.1.

Cost estimates were computed for capital costs, annual debt service, operation and maintenance, power, land, and environmental mitigation for uniform and peak day delivery. The annual costs, including debt service for a 30-year loan at 6 percent interest, operation and maintenance costs, including power and the purchase of groundwater, are estimated to be $6,707,000 for 18,000 acft of water. This option produces raw water at an estimated cost of $373 per acft (Table 4C.7-15).

4C.7.3.5 Implementation Issues

Implementation of the projects which are located in Region N are subject to the rules and management plans of local groundwater conservation districts. Bee County has a groundwater conservation district which limits production to 4 acft/acre of land. San Patricio County currently has no groundwater district. Rules for groundwater conservation districts in the Coastal Bend Region are presented in Appendix K.

The development of additional wells and the installation and operation of brackish water treatment plant, may have to address the following issues.

- Disposal of salt concentrate from water treatment plant;
- Impact on:
    - Endangered and other wildlife species,
    - Water levels in the aquifer,
    - Baseflow in streams, and
    - Wetlands.
- Capital and operation and maintenance costs;
- Skilled operators of desalination water treatment plants;
- Competition with others for groundwater in the area;
- Detailed feasibility evaluation including test drilling and aquifer water quality testing; and
- The potential for regulations by groundwater conservation districts in the future, including the renewal of pumping permit at periodic intervals in counties where districts have been organized.

4C.7.3.6 Evaluation Summary

An evaluation summary of this regional water management option is provided in Table 4C.7-16.

Table 4C.7-16.
Evaluation Summary of the Alternative for
Groundwater Export Projects for the Gulf Coast Aquifer

Impact Category	***Comment(s)***
a. Water Supply	
1. Quantity	1. Firm yield: 18.000 acft/yr.
2. Reliability	2. Water Quality: Fair.
3. Cost of Treated Water	3 Cost: $373 per acft
b. Environmental factors	
1. Instream flows	1. May slightly decrease instream flow and discharge of freshwater into coastal estuaries due to local groundwater-surface water interaction.
2. Bay and Estuary Inflows	2. May slightly decrease instream flow and discharge of freshwater into coastal estuaries due to local groundwater-surface water interaction.
3. Wildlife Habitat	3. Negligible impacts
4. Wetlands	4. Negligible impacts
5. Threatened and Endangered Species	5. Negligible impacts
6. Cultural Resources	6. Cultural resources will need to be surveyed and avoided
7. Water Quality	7. Negligible impacts.
a. dissolved solids	a. Low to moderate impact.
b. salinity	b. Low to moderate impact.
c. bacteria	c. No impact.
d. chlorides	d. Low to moderate impact.
e. bromide	e. Low to moderate impact.
f. sulfate	f. Low to moderate impact.
g. uranium	g-h. Low to moderate impact associated with mining.
h. arsenic	
i. other water quality constituents	i. Boron may be a potential water quality concern.
c. State water resources	• No negative impacts on water resources other than lowering Gulf Coast Aquifer. Potential benefit to Nueces Estuary from increased freshwater return flows.
d. Threats to agriculture and natural resources in region	• May slightly increase pumping costs for agricultural users in the area due to localized drawdowns
e. Recreational	• None
f. Equitable impacts comparison of strategies	• Standard analyses and methods used
g. Interbasin transfers	• Not applicable to groundwater sources.
h. Third party social and economic impacts from voluntary redistribution of water	• May require the purchase of groundwater rights.
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities with local resources
j. Effect on navigation	• None

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4C.8 Potential Aquifer Storage and Recovery (from the Gulf Coast Aquifer)(N-8)

4C.8.1 Description of Strategy

Aquifer Storage and Recovery (ASR) is useful to water utilities that have a surplus of water at times but do not have sufficient storage to save water for times of shortage. In other words, ASR is a way to store water in aquifers during times when water is available and recover the water when it is needed. ASR can be operated as a water management strategy on a seasonal or multi-year basis. If meeting high summer demands were the water supply issue, water would be injected into the aquifer during the fall, winter, and spring and pumped during the summer. Operating ASR on a seasonal basis strategy more fully utilizes the available capacities of the water treatment plant and, possibly, the availability of the supply to meet seasonal water demands. On the other hand, if ASR is operated on a multi-year basis for emergencies or drought, water would be stored in the aquifer for several years before it is recovered. ASR wells are designed to accommodate injection of treated water as well as recovery. For purposes of this evaluation, ASR is operated on a multi-year basis and uses a dual-purpose well, or well field, to inject treated water into an aquifer for storage. The water is recovered at a later date and evaluated for increased yield to the CCR/LCC/Lake Texana System on a long-term basis.

The option evaluated here would function as a regional facility. It would be located in the Robstown-Driscoll area, and is evaluated on a long-term cycle. Under this option, water would be stored in the aquifer for up to several years before being recovered. During wet—or surplus—times, water would be injected into the aquifer for storage. The facility would be idle during neutral times, and then the water would be pumped back for distribution during the drought times. The locations of the ASR system considered here are shown in Figure 4C.8-1.

4C.8.2 Robstown-Driscoll Regional Facility

A regional ASR system would serve the customers in the Corpus Christi area with a reserve of water for drought or emergencies. For this option, the ASR system would utilize the supply, water treatment, and water distribution facilities of the City of Corpus Christi and the regional water distribution system of the South Texas Water Authority (STWA). The water supply for the ASR facility during wet periods would come from surplus supply from the CCR/LCC/Texana System. This surplus supply would essentially result from over-drafting the

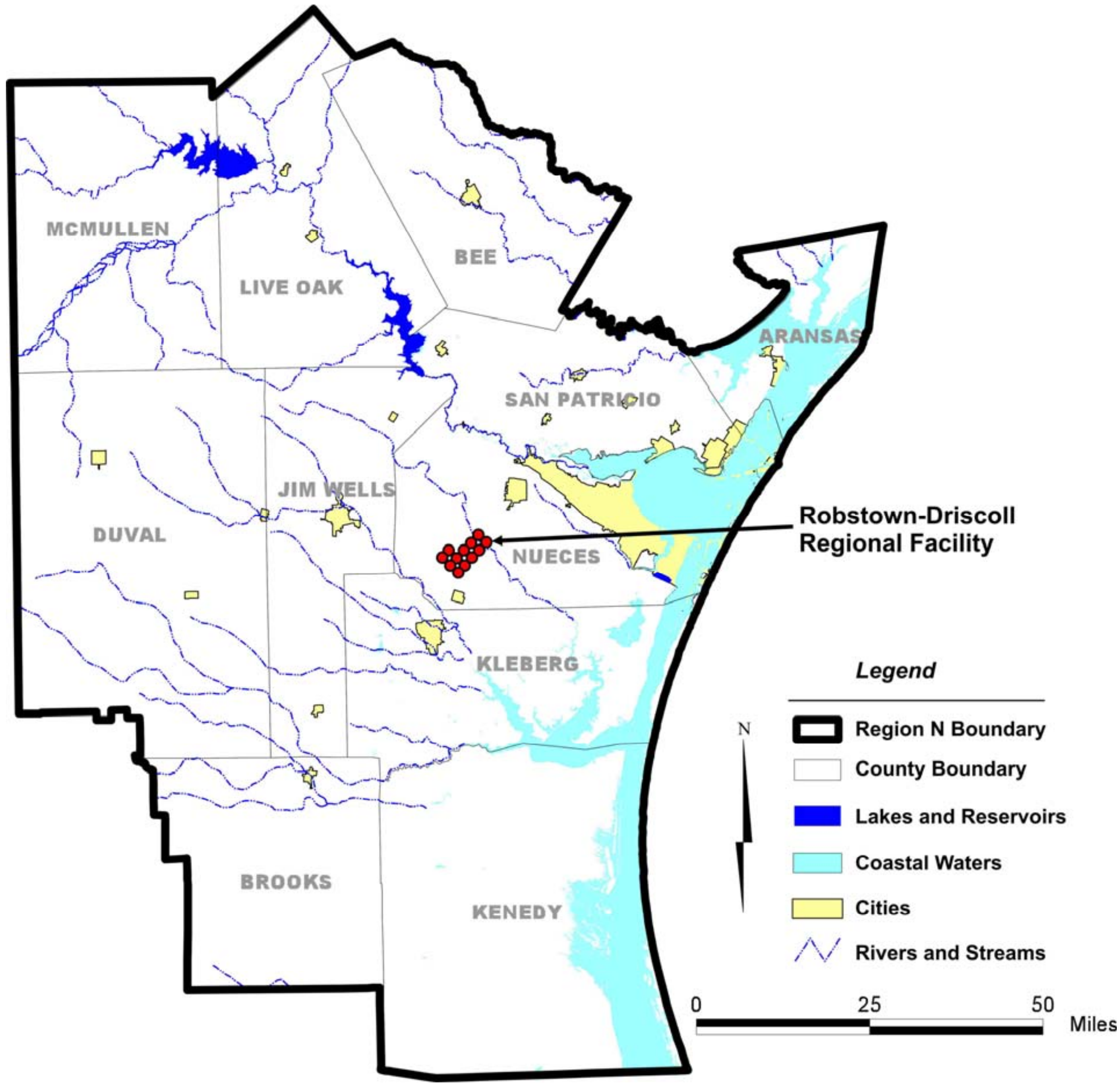


Figure 4C.8-1. Location of ASR Facility

reservoirs during wet times and recovering from ASR storage in the dry times. Water from the CCR/LCC/Lake Texana System would be treated by the City of Corpus Christi and then transported by the STWA's pipeline to the ASR regional facility between Robstown and Driscoll. When needed, the stored water would be pumped by the ASR wells and discharged into the STWA's pipeline for distribution to regional customers or back to pumping facilities at the O.N. Stevens Water Treatment Plant to supplement the City's distribution system. The ASR system would need to be sized to be within the constraints of capacity of the Corpus Christi Water Treatment Plant, the STWA's pipeline, reasonable limits of an ASR well field, and the storage capacity of the Gulf Coast Aquifer. For purposes of this analysis, a capacity of 10 MGD was selected, which meets the constraints for analysis.

The potential benefit of incorporating a regional ASR project into the City of Corpus Christi's water supply system was analyzed using an updated modified version of the NUBAY Model. The modifications allowed the user to set at what levels water would be diverted into and out of the ASR system. The levels were tied to percent of system storage. For example, during the simulation ASR can be turned on when the combined system storage of CCR and LCC exceeds 80 percent. During these periods, ASR would attempt to take the full 10 MGD to inject to the ASR system for that month. The model was developed so that any number of user-defined zones could be analyzed.

Typically there were two different scenarios with which the ASR simulations were performed. One involved a three-zone setup with one zone for filling ASR, another zone for no activity, and the last zone for depleting ASR and supplying the system. The other series of runs involved staggering the filling and depleting with four zones, two for filling and two for depleting. When the system storage was in the top zone, the ASR would attempt to fill at full capacity. Then when the system storage passed to the next zone, it would only fill at partial capacity. Then, into the third and fourth zones, the same pump rates for recovery as used in injection phase were kept. The advantage of the four-zone system is it keeps the ASR system continually active. Figure 4C.8-2 represents these two ASR operating scenarios graphically. With either set of operating rules, the ASR option essentially attempted to overdraft the system during wet times, and then ASR would attempt to supplement supply during the dry times, with a typically fill pattern of several years, followed by a shorter period of supplementing supply.

4C.8.3 Guidelines for an ASR System and Comparison to Robstown-Driscoll Regional ASR

HDR Engineering, Inc (HDR) has developed the following set of guidelines for important elements involved in determining the feasibility of adding ASR wells to a water supply system. These guidelines are for screening purposes only and not criteria for suitability.

Quality of Source Water to be Injected: When injecting water into an aquifer that is being used for drinking water supplies, TCEQ regulations require that the injected water be at least as

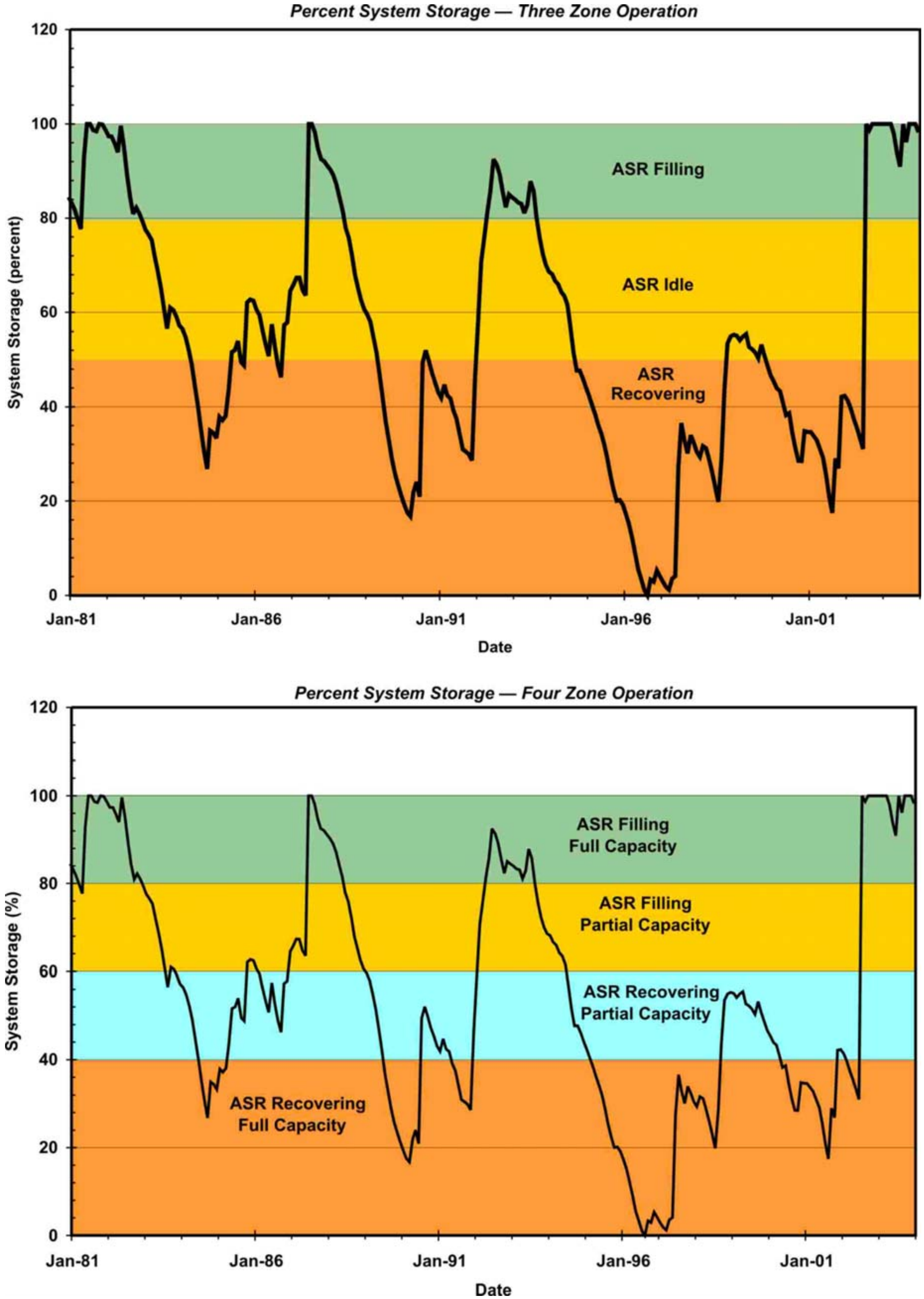


Figure 4C.8-2. ASR Operating Scenarios for Regional ASR Facility

good in quality as the water already in the aquifer (native water). This is generally interpreted to mean that the injected water has to be treated to Drinking Water Standards.

Availability of Water: Water for recharge must be available in sufficient quantities, durations, and frequencies to balance the recharge and recovery cycles. In general, water for recharge needs to be available more than half of the time.

Location of Facilities: ASR wells should be near the water treatment and distribution system in order to reduce the cost of constructing new pipelines and pumping the water to and from the ASR wells.

Productivity of the Aquifer: The water yielding characteristics of an aquifer typically should allow the construction of wells producing 700 gallons per minute (gpm) (about 1 MGD) or more to improve the prospects of being able to make the project cost effective. The lowest yield of an ASR well that is documented in the literature is about 200 gpm.

Aquifer Conditions: A confined water-bearing zone is preferable to a shallow water-table aquifer.

Aquifer Thickness: The most suitable thickness of a target water-bearing zone is generally between 50 and 200 feet.

Depth to Water-Bearing Zone: The most suitable depths are from 200 to 500 feet. However, depth to water-bearing zones up to 2,500 feet may prove to be cost-effective.

Aquifer Material: A formation having a strong resistance to dissolution, such as sand, gravel, limestone, and sandstone is preferable. In any case, geochemical analyses are necessary to determine if any negative water quality issues are evident that could affect operation of an ASR facility, such as cation exchange or mineral precipitation, which would result from a reaction with clay in the aquifer.

Water Quality: The most desirable aquifers have water quality that is at or near drinking water standards. However, successful ASR operations have been developed in aquifers with saline water in which the injection of freshwater would displace saline water and create a "freshwater bubble". In fact, aquifers with saline water may be preferable in some cases because of few or no other users of the aquifer, but the well design must consider the fact that freshwater is lighter than saline water and would tend to float to the top of water-bearing zones. Potential adverse geochemical processes such as precipitation, bacterial activity, ion exchange, and adsorption are possible and require a geochemical analysis to determine the expected reactions between the native water and injected water. On the positive side, ASR may improve water quality through reductions in disinfection byproducts, iron and manganese, and hydrogen sulfides.

Aquifer Water Levels and Wellhead Pressures: The desirable range in depth to water depends on the productivity of the aquifer. In aquifers with a high productivity, water levels can be near the land surface. For moderately transmissive water bearing zones, depth to water should be in the range of 100 to 300 feet below land surface. An existing cone of depression is desirable but not necessary. However, the formation of a water level mound that is above the land surface would increase springflows and cause uncapped wells to flow, which, in turn, would cause a waste of water and could damage existing property. In any event, well design and operational requirements must consider expected wellhead pressures of the project.

Data Availability: Existing and reliable geophysical logs, geologic characteristics, water quality data, data on aquifer properties, hydrogeologic reports, and groundwater models are very helpful.

Wells: Existing wells are often used, but many are unsuitable or would require modifications and more maintenance during operation. New wells, especially if constructed with PVC casing, are the most trouble free. Well screens should be stainless steel or PVC.

Other Groundwater Users: Natural or regulatory restrictions are needed to prohibit unauthorized withdrawals of stored surface water.

A comparison of the Robstown-Driscoll Regional ASR option with the HDR guidelines is presented in Table 4C.8-1. The guidelines are exceeded only for the slightly saline water in the target storage zone and by some groundwater use in the area. Each of these exceedances is believed to be manageable.

4C.8.4 Results of Modeling Analysis for Long-Term Regional ASR System

The regional long-term ASR facilities were evaluated using the NUBAY Model to determine their feasibility for becoming part of the City of Corpus Christi's water supply system. The assumption associated with the ASR facility is that when the system is operated in an over-draft mode during wet times to supply the ASR project that this water would be made available as additional supply to the system during drought times. It was initially believed that water savings would be achieved by reduced evaporation from the CCR/LCC Reservoirs and by recovery of water when the CCR/LCC System is spilling. However, after numerous model simulations, it was determined that this was not the case.

Table 4C.8-1.
Comparison of ASR Options with HDR's Guidelines for ASR Systems

Element	***Guideline***	***Robstown-Driscoll Regional Facility***
Quality of Source Water	Treated to Drinking Water Standards	Treated water from Corpus Christi Water Treatment Plant
Availability of Water	More than half the time	More than half the time
Location	Near water treatment and distribution facilities	Near distribution facilities
Productivity of Aquifer, as indicated by typical well capacities	700 gpm or more	About 750 gpm
Aquifer Conditions	Confined	Confined
Aquifer Thickness	50 to 200 feet	Two 100-foot zones
Depth to water-bearing zone	200 to 500 feet	About 500 feet
Aquifer Material	Resistance to dissolution	Mostly sand
Water Quality	At or near Drinking Water Standards, and Compatibility of injected water and aquifer materials	Slightly saline, and Appears to be compatible
Water Levels	100 to 300 feet below land surface	60 to 100 feet below land surface
Data Availability	Extensive reports and databases	Moderate detail in reports and databases
Wells	New	New
Other groundwater users	Limited	Few in potential well field, moderate number within 20 miles

The analysis indicated that the reason for this was twofold. The first observation indicated that the losses saved from lack of evaporation in the reservoir were not greater than the additional channel losses experienced when the over-drafted supply was released from LCC to be diverted at Calallen for delivery to the ASR system. In other words, the delivery of the additional water to ASR from LCC resulted in a larger amount having to be released from LCC to overcome the delivery losses down to Calallen. The second observation from the model analysis indicated that when the system was operated in over-draft mode for ASR, the system reservoirs entered the critical drawdown period sooner than in scenarios that did not include ASR operations. Therefore, even though there was additional supply available at the critical portion of the drought, the reservoirs entering the drought sooner, thereby reducing reservoir storage during the drought. Figure 4C.8-3 shows a section of the percent system storage trace through the recent drought of record both with and without project conditions. This figure illustrates how when ASR is turned on when the reservoir is full, ASR is filling, the overall system storage drops during the beginning of the drawdown. As the drawdown continues the two traces tend to parallel each other, and then towards the bottom of the drawdown the two lines come back together, with ASR providing supply. This shows that the best ASR can provide is a yield equal to the yield of the system without ASR. However, many of the simulations showed that with ASR turned on, that the overall system yield was actually slightly reduced.

The potential ASR project was also evaluated in conjunction with other proposed water management strategies, such as the CCR/LCC Pipeline, off-channel reservoir, and over drafting the system with interruptible water from Lake Texana. The results of the additional analysis were very similar to those developed when ASR was operated without any additional water management strategies. The same limitations were identified when operated conjunctively as those when it is operated independently. The ASR system as proposed in the analysis was unable to provide any meaningful water supply benefits whether operated in a stand-alone mode or conjunctively with other water management strategies. The additional yield in the conjunctive model runs was attributable to the other water management strategy not the ASR project.

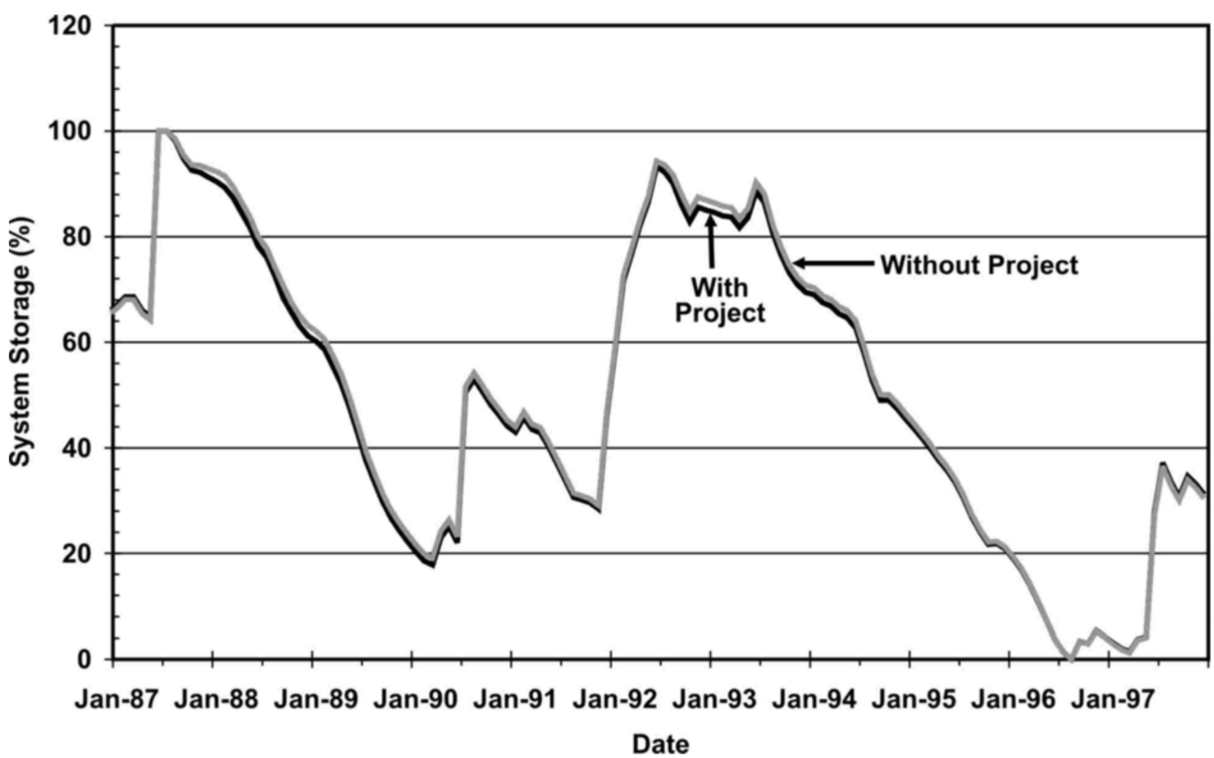


Figure 4C.8-3. CCR/LCC System Storage Traces With and Without ASR

Therefore, based on the results of the modeling analysis, ASR is not recommended as a viable management strategy to provide additional yield to the CCR/LCC/Texana water supply system. However, from an operational flexibility standpoint ASR could be utilized to store water during wet times that could be used during any catastrophic failure of the existing water supply system components. This would allow the city the ability to have a relatively "safe" water supply than can be relied upon during times of system failure. Also, seasonal ASR operations may prove to be beneficial to managing existing water supplies and providing additional water for peak demands.

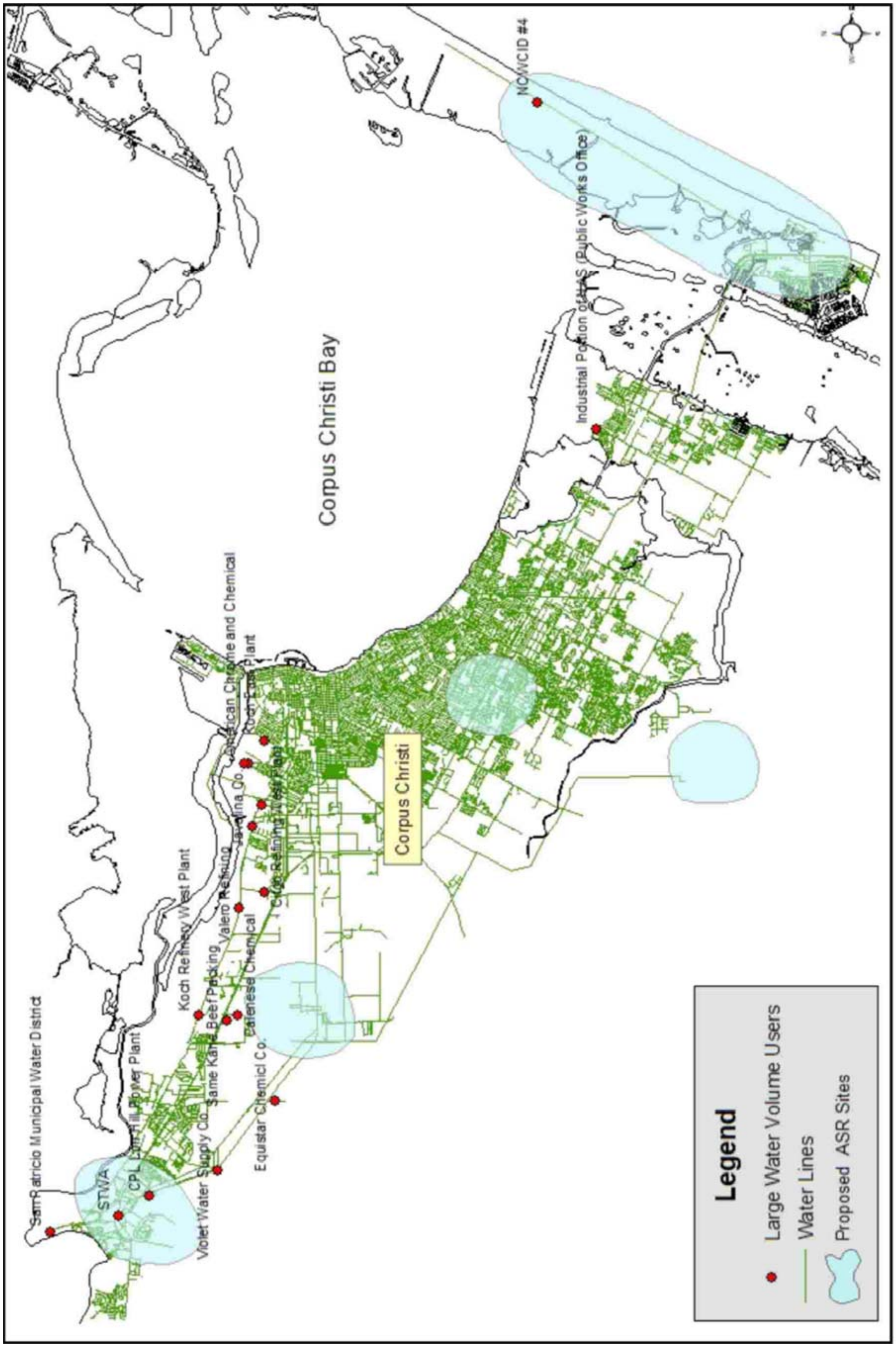
4C.8.5 Additional Studies Currently Underway by the City of Corpus Christi

The City of Corpus Christi is evaluating seasonal ASR to manage water supplies for seasonal, long-term, and possibly emergency water needs. The City is considering ASR projects at five different sites (Figure 4C.8-4). These studies are in the early phases of conceptual development.

4C.8.6 Environmental Issues

The ASR options involves the construction of well fields in the Gulf Coast Aquifer System that would support a regional facility for the Corpus Christi area. The injection of water into aquifers and the pumping of groundwater from aquifers where ASR is practiced would be expected to contribute to variations in aquifer levels. However, the water level changes are not expected to change the gain or losses of streams in the area.

Habitat studies and surveys for protected species would need to be conducted at the proposed well field sites and along any pipeline routes. When potential protected species habitat or other significant resources cannot be avoided, additional studies would have to be conducted to evaluate habitat use or eligibility for inclusion in the National Register for Historic Places, respectively. Wetland impacts, primarily pipeline stream crossings, can be minimized by right-of-way selection and appropriate construction methods, including erosion controls and revegetation procedures. Compensation for net losses of wetlands would be required where impacts are unavoidable.



Source: City of Corpus Christi

Figure 4C.8-4. Locations of City of Corpus Christi ASR Studies

4C.8.7 Engineering and Costing

The multi-year ASR operation is not recommended as a viable management strategy to provide additional supply to the CCR/LCC/Texana water supply system. Costs are not included in this writing.

4C.8.8 Implementation Issues

Implementation of the ASR concepts includes the following issues:

- Suitable supplies of water for injection;
- Water treatment prior to injection;
- Uncertainty about the compatibility of the injected water with native groundwater and aquifer materials;
- Disposal of saline water during construction, development, and maintenance;
- Availability of access to local aquifers for an efficient application of ASR;
- Regulations by the TNRCC;
- Controlling the loss of injected water to neighboring groundwater users;
- Initial cost;
- Developing a management plan to efficiently use the ASR wells with balanced injection and recovery cycles, and/or
- Cultural resource surveys will need to be performed in order to avoid disturbance of any significant sites.

4C.8.9 Evaluation Summary

An evaluation summary of the Robstown-Driscoll Regional ASR Facility is provided in Table 4C.8-2.

Table 4C.8-2.
Evaluation Summary of the
Robstown-Driscoll Regional ASR Facility

Impact Category	***Comment(s)***
a. Water Supply	
1. Quantity	1. Very limited firm yield
2. Reliability	2. Not applicable
3. Cost of Treated Water	3 Unit cost would be high
b. Environmental factors	
1. Instream flows	1. Minor impacts during construction of wells and pipelines
2. Bay and Estuary Inflows	2. None or low impact.
3. Wildlife Habitat	3. None or low impact.
4. Wetlands	4. None or low impact.
5. Threatened and Endangered Species	5. None or low impact.
6. Cultural Resources	6. Cultural resource survey will be needed to avoid impacts to any site
7. Water Quality	7. None or low impact.
a. dissolved solids	7b. The proposed Robstown-Driscoll Regional Facility has slightly saline water. This is not expected to significantly affect recovery of water.
b. salinity	
c. bacteria	
d. chlorides	
e. bromide	
f. sulfate	
g. uranium	
h. arsenic	
i. other water quality constituents	
c. State water resources	• No negative impacts
d. Threats to agriculture and natural resources in region	• Negligible
e. Recreational	• None
f. Equitable impacts comparison of strategies	• Not applicable
g. Interbasin transfers	• None
h. Third party social and economic impacts from voluntary redistribution of water	• None
i. Efficient use of existing water supplies and regional opportunities	• Increases utilization of water treatment and transmission facilities
j. Effect on navigation	• None

4C.9 Modify Existing Reservoir Operating Policy and Safe Yield Analyses (N-9)

4C.9.1 Description of Strategy

In the late 1800s, the Corpus Christi Water Supply Company built a small dam near Calallen, Texas, to keep the saline waters of Nueces Bay from intruding into the fresh waters of the Nueces River and began to develop surface water supplies from the Nueces River. As the City grew and more and more water was needed, the dam at Calallen was raised several times and today the dam has a height of approximately 5.5 ft-msl and a capacity of about 1,175 acft. The City continued to expand and in 1934, La Fruta Dam was constructed on the Nueces River about 35 miles upstream of the Calallen Dam and initially it impounded approximately 60,000 acft of water. In 1958, Wesley Seale Dam was completed just downstream of the old La Fruta Dam, and the new Lake Corpus Christi was formed, which engulfed the old dam and reservoir and expanded storage to about 302,000 acft.

In the late 1960s, following an extreme drought that occurred from 1961 to 1963, planning began for an additional water supply for the City and its growing number of water customers. For more than a decade, studies were performed to evaluate alternative water supply options. Following considerable debate, Choke Canyon Reservoir, located on the Frio River 63.3 river miles upstream of Lake Corpus Christi, was constructed. Choke Canyon Dam was constructed by the United States Bureau of Reclamation (USBR). The dam was completed in 1982 and the reservoir first filled to capacity in 1987. Choke Canyon Reservoir has approximately 690,000 acft of conservation storage capacity, based on original USBR estimates. The TWDB has conducted volumetric surveys for Lake Corpus Christi and Choke Canyon Reservoir. In 2002, an updated volumetric survey of Lake Corpus Christi was completed by the TWDB and reported the capacity at 256,961 acft. The volumetric survey performed by the TWDB in 1993 reported the capacity of Choke Canyon Reservoir to be 695,271 acft. Today, the City operates these three reservoirs (Calallen, Lake Corpus Christi, and Choke Canyon Reservoir) and Lake Texana as a system to supply water for municipal and industrial users of the Coastal Bend Region.

The physical and hydrologic data for the three reservoirs in the Nueces Basin and two river reaches affecting the delivery of raw water from the Nueces River Basin to the City and its customers is summarized in Table 4C.9-1. As indicated in this table, approximately 94 percent of the demand occurs at the Calallen Reservoir pool, while 74 percent of stored water is located 98 miles upstream at Choke Canyon Reservoir, with the remaining 26 percent of the stored water being located 35 miles upstream in Lake Corpus Christi. Water stored in Choke Canyon Reservoir is released into the river channel and delivered to Lake Corpus Christi. Water is then released from Lake Corpus Christi into the Nueces River channel, by which it flows to the Calallen pool. At the Calallen pool, the City and some of its customers divert raw water to their respective treatment plants, from which it is then distributed for use. Studies[1,2,3,4,5] performed throughout the years have indicted that a significant portion of the water that is released from Choke Canyon Reservoir and Lake Corpus Christi is lost to evaporation, evapotranspiration, and seepage along the river channels as it travels from one reservoir to the next.

Table 4C.9-1
Summary of Physical and Hydrologic Data
for Three Reservoirs and Two River Reaches

Reservoir or River Reach	*1990 Capacity (acft)*	*Percent of Total System Storage*	*Average Annual Reservoir Evaporation (feet)*	*River Reach Distance (miles)*	*Estimated Delivery Losses (percent)*	*Percent of System Demand in Area of Reservoir*
Choke Canyon Reservoir	689,314	74%	3.26	—	—	1%
River Reach between Choke Canyon Reservoir and Lake Corpus Christi	—	—	—	63.3	37.8[1]	—
Lake Corpus Christi	239,473	25.9%	2.85	—	—	4%
River Reach between Lake Corpus Christi and Calallen	—	—	—	35	11[2]	
Calallen Reservoir	1,175	0.1%	2.85	—	—	94%
Total	929,962	100%	—	98.3	—	100%

[1] Includes losses from Lake Corpus Christi to local aquifer, and represents average percentage lost, updated in 2005.
[2] Represents average percentage lost. River reach between Lake Corpus Christi and Calallen was updated to reflect new channel loss information, 2005.

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[1] U.S. Bureau of Reclamation (USBR), "Nueces River Basin: A Special Report for the Texas Basins Project," U.S. Dept. of the Interior, December 1983.
[2] USBR, "Nueces River Project, Texas: Feasibility Report," U.S. Dept. of the Interior, July 1971.
[3] HDR Engineering, Inc. (HDR), et al., "Nueces River Basin Regional Water Supply Planning Study – Phase I," Vols. 1, 2, and 3, Nueces River Authority, et al., May 1991.
[4] Rauschuber and Associates, Inc., "Potential for Development of Additional Water Supply from the Nueces River Between Simmons and Calallen Diversion Dam," Subcommittee on Additional Water Supply from the Nueces River Watershed, December 1985.
[5] United States Geological Survey (USGS), "Water Delivery Study, Lower Nueces River Valley, Texas, TWDB Report 75," in cooperation with the Lower Nueces River Water Supply District, May 1968.

As shown in Table 4C.9-1, losses from Choke Canyon Reservoir downstream to, and including losses from, Lake Corpus Christi average 37.8 percent, while losses downstream of Lake Corpus Christi to the Calallen pool average about 11 percent. In addition, under a 2001 Agreed Order from the TCEQ,[6] the City is required to pass specified volumes of inflows to the reservoirs in accordance with a monthly schedule to mitigate the impacts of Choke Canyon Reservoir and maintain the health of the Nueces Estuary. Appendix J includes a summary of ecological studies supporting the benefits of freshwater diversions to the Nueces Delta. In the 2001 Agreed Order, the City is not required to release when combined reservoir storage is less than 30 percent. All of the above items are significant factors that must be taken into account in the operation of the reservoir system.

The City of Corpus Christi initially had a four-phased operation plan for the CCR/LCC System. The objective of each phase was to provide the people of the Coastal Bend area with a dependable water supply as their needs grow, while at the same time, attempt to meet the need for consistent quality raw water by proper management of the two reservoirs. Additionally, recreational uses of the reservoirs as related to water surface elevations are a concern, as well as adherence to the TCEQ Order that specifies target inflows to the downstream bays and estuaries from wastewater return flows and spills, or releases of inflows from the reservoirs.

The initial operation plan consisted of four phases, with the first phase (Phase I) having been applicable prior to the initial filling of Choke Canyon Reservoir. Under each of the City's operation plan phases, a minimum of 2,000 acft/month is to be released from Choke Canyon Reservoir to meet the instream flow requirements within the water rights permit for Choke Canyon Reservoir.[7] In 1987, Choke Canyon Reservoir officially filled and the operating policy shifted to Phase II. The Phase II policy was intended to apply to the CCR/LCC System until water user demand is more than 150,000 acft/yr. The operational guidelines under this policy are as follows:

1. When conditions are such that the water surface elevation in Lake Corpus Christi is at or below 88 ft-msl and the water surface elevation in Choke Canyon Reservoir is above 204 ft-msl, releases will be made from Choke Canyon Reservoir to maintain the water surface elevation at Lake Corpus Christi at 88 ft-msl; and

[6] Texas Commission on Environmental Quality (TCEQ), Agreed Order Establishing Operational Procedures Pertaining to Special Condition B, Certificate of Adjudication No. 21-3214, Held by City of Corpus Christ, et al., April 28, 1995.
[7] TCEQ, Certificate of Adjudication No. 21-3214, Held by the City of Corpus Christi, et al.

2. When Lake Corpus Christi's water surface elevation is at or below 88 ft-msl and Choke Canyon Reservoir's water surface elevation is below 204 ft-msl, the Choke Canyon Reservoir release made for the current month will be equal to the release made at Lake Corpus Christi in the previous month.

The Phase II release rules were devised in an effort to minimize the drawdown of Lake Corpus Christi, primarily to ensure a consistent quality of water by mixing the Choke Canyon Reservoir releases with the stored water in Lake Corpus Christi, but also for recreation considerations.

The third operational policy (Phase III) was initially intended to apply to the system when water use is between 150,000 and 200,000 acft annually. This operational policy was promulgated by the USBR and is very similar to the Phase II policy. Under Phase III, when the water surface elevation at Lake Corpus Christi is at or below 88 ft-msl, steps are taken to draw the two reservoirs down together.

The fourth operation policy (Phase IV) is the maximum yield policy and was initially intended to apply to the system when water user demand exceeds 200,000 acft annually. Under this policy, the system is operated as follows:

1. When Lake Corpus Christi's water surface elevation is at or below 76 ft-msl and the water surface elevation in Choke Canyon Reservoir is above 155 ft-msl, releases are made from Choke Canyon Reservoir to maintain Lake Corpus Christi at 76 ft-msl; and
2. When Lake Corpus Christi's water surface elevation is at or below 76 ft-msl and Choke Canyon Reservoir's water surface elevation is below 155 ft-msl, Lake Corpus Christi is allowed to draw down to its minimum elevation and Choke Canyon Reservoir releases are made only to meet water supply shortages.

In April 1995, in response to requirements in the water rights permit for Choke Canyon Reservoir,[8] a bay and estuary release order (1995 Agreed Order) was adopted governing freshwater pass-through requirements to the Nueces Estuary. The major provisions of the 1995 Agreed Order are as follows:

1. The water passed through from the CCR/LCC System to satisfy the TCEQ bay and estuary release requirement in a given month is limited to no more than the inflow to Lake Corpus Christi as if Choke Canyon Reservoir did not exist; and
2. When the System storage is above 70 percent, the monthly bay and estuary release schedule provides for a target of 138,000 acft/yr of water to Nueces Bay and/or the Nueces Delta by a combination of return flows, reservoir releases and spills, and

[8] Ibid.

measured runoff downstream of Lake Corpus Christi. When the system storage is less than 70 percent but more than 40 percent, the target schedule is reduced so as to provide 97,000 acft/yr to Nueces Bay and/or the Nueces Delta. In any month when the System storage is less than 40 percent but great than 30 percent, the target Nueces Bay inflow requirement may be reduced to 1,200 acft/month when the City and its customers implement Condition II of the City's Water Conservation and Drought Contingency Plan (Plan). If System storage drops below 30 percent, bay and estuary releases may be suspended when the City and its customers implement Condition III of the Plan.

3. In April 1995, in response to requirements in the water rights permit for Choke Canyon Reservoir,[9] a bay and estuary release order (1995 Agreed Order) was adopted governing freshwater pass-through requirements to the Nueces Estuary.

On April 17, 2001, the TCEQ issued an amendment to the 1995 Agreed Order to revise operational procedures in accordance with revisions requested by the City of Corpus Christi. The major provisions of the new 2001 Agreed Order are as follows:

1. Revisions to passage of inflows to Nueces Bay and Estuary at 40 percent and 30 percent reservoir system capacity upon institution of mandatory outdoor watering restrictions. In any month when the System storage is less than 40 percent but greater than 30 percent, the target Nueces Bay inflow requirement may be reduced to 1,200 acft/month when the City and its customers implement Condition II of the City's Water Conservation and Drought Contingency Plan (Plan). If System storage drops below 30 percent, bay and estuary releases (except for return flows) may be suspended when the City and its customers implement Condition III of the Plan.
2. Supported calculating reservoir system storage capacity based on most recently completed bathymetric surveys; and
3. Included provisions for operating Rincon Bayou diversions and conveyance facility from Calallen Pool to enhance the amount of freshwater to the Nueces Bay and Delta.

4C.9.2 Available Yield

During the mid-1990s, in response to drought conditions, the City of Corpus Christi changed the Reservoir Operating Plan to Phase IV (i.e., Maximum Yield Policy) in order to maximize the yield of the CCR/LCC System. In addition, the City modified the Phase IV Policy making elevation 74 ft-msl Lake Corpus Christi's target elevation and brought in Lake Texana water supplies in late-1990s. A summary of the firm yield of the system in 2010 and 2060,

[9] Ibid.

assuming Phase IV operations, including water supplies from Lake Texana, and the 2001 Agreed Order, and computed by the NUBAY Model[10] is provided in Table 4C.9-2.

Table 4C.9-2.
CCR/LCC/Lake Texana System Firm Yields
(Phase IV Policy)

Reservoir Sedimentation Year	*CCR/LCC/Lake Texana System Firm Yield (acft/yr)*
2010	227,000
2060	219,000

The reservoir system yields tabulated in Table 4C.9-2 are essentially the maximum yields available under the City's current reservoir operating policies and existing schedule governing freshwater pass-throughs to the bay and estuary.

In March 2005, the CBRWPG adopted the use of safe yield analyses for the CCR/LCC/Lake Texana System. Safe yield supply represents a more conservative approach to determining minimum annual availability in areas where the severity of droughts is uncertain. Safe yield supply is the amount of water that can be withdrawn from a reservoir such that a given volume remains in reservoir storage during the critical month of the drought of record. The surface water availabilities for the largest water rights in the Nueces Basin (i.e., City of Corpus Christi and their customers) are based on safe yield analyses and assume a reserve of 75,000 acft

[10] In 1990, the need for a tool that could be used to evaluate the effects of water supply options in the region, as well as the need to evaluate various reservoir operation policies, led to the development of the Lower Nueces River Basin and Estuary Model – NUBAY (HDR, et al., "Nueces River Basin Regional Water Supply Planning Study – Phase I," Vols. 1, 2, and 3, Nueces River Authority, et al., May 1991). This model originally operated on a monthly timestep over the 1934 to 1989 period of record, which includes significant droughts in the 1950s, 1960s, and 1980s. Computations in the model simulate evaporation losses in the reservoirs, as well as channel losses in the rivers associated with water delivery from Choke Canyon Reservoir to Lake Corpus Christi, and from Lake Corpus Christi to the City's water supply intake at the Calallen diversion dam. In addition, due to sediment deposition in Choke Canyon Reservoir and Lake Corpus Christi, the model allows for a variety of sediment conditions ranging from the 1990 storage volumes in the lakes to the projected 2060 system storage capacities. The model has been developed and updated through a series of projects since 1991. During this planning cycle, the model was updated to include the new drought of record and currently operates on a 1934 to 2003 period of record (HDR, et al., "Nueces Estuary Regional Wastewater Planning Study, Phase 1," City of Corpus Christi, et al., November 1991; HDR, et al., "Nueces Estuary Regional Wastewater Planning Study, Phase 2," City of Corpus Christi, et al., March 1993; HDR, "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999; HDR, Supplemental Funding Work Item for 2006 Coastal Bend Regional Water Plan, 2005).

(i.e., 7 percent LCC/CCR System storage) for future drought conditions. Figure 4C.9-1 shows how 3-year average annual inflows for the major reservoir system have been reduced for each of the past four significant droughts.

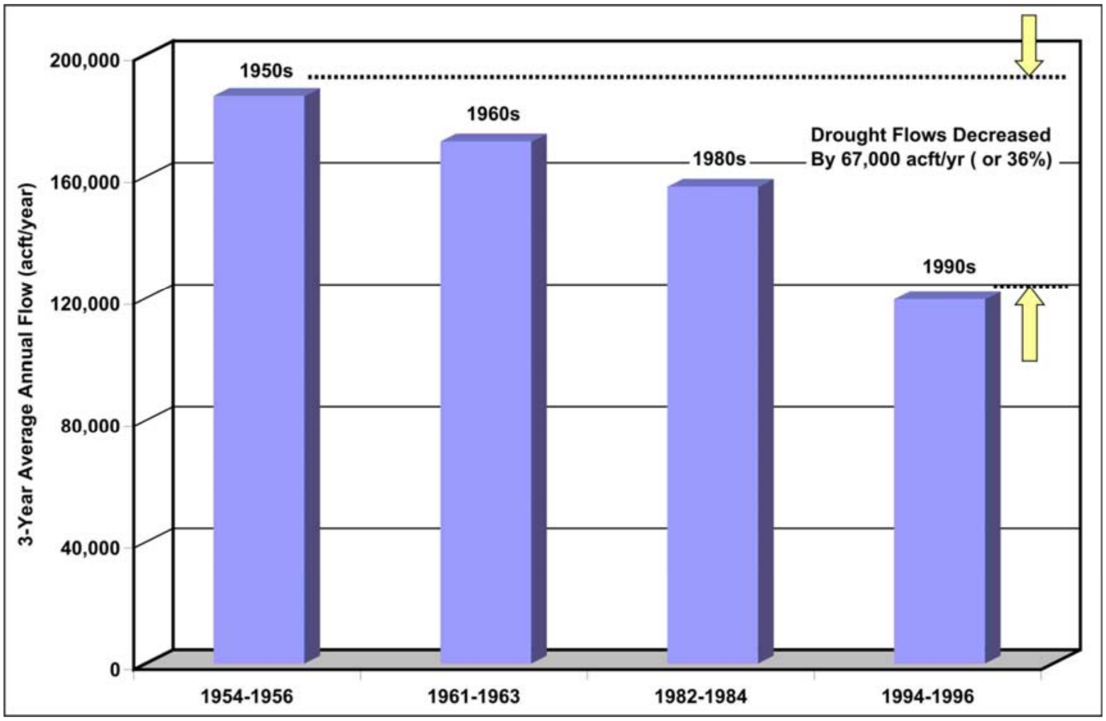


Figure 4C.9-1. 3-Year Reservoir Inflows

A summary of the safe yield of the system in 2010 and 2060, assuming Phase IV operations, including water supplies from Lake Texana, and the 2001 Agreed Order, and computed by the NUBAY Model[11] is provided in Table 4C.9-3.

[11] In 1990, the need for a tool that could be used to evaluate the effects of water supply options in the region, as well as the need to evaluate various reservoir operation policies, led to the development of the Lower Nueces River Basin and Estuary Model – NUBAY (HDR, et al., "Nueces River Basin Regional Water Supply Planning Study – Phase I," Vols. 1, 2, and 3, Nueces River Authority, et al., May 1991). This model originally operated on a monthly timestep over the 1934 to 1989 period of record, which includes significant droughts in the 1950s, 1960s, and 1980s. Computations in the model simulate evaporation losses in the reservoirs, as well as channel losses in the rivers associated with water delivery from Choke Canyon Reservoir to Lake Corpus Christi, and from Lake Corpus Christi to the City's water supply intake at the Calallen diversion dam. In addition, due to sediment deposition in Choke Canyon Reservoir and Lake Corpus Christi, the model allows for a variety of sediment conditions ranging from the 1990 storage volumes in the lakes to the projected 2060 system storage capacities. The model has been developed and updated through a series of projects since 1991. During this planning cycle, the model was updated to include the new drought of record and currently operates on a 1934 to 2003 period of record (HDR, et al., "Nueces Estuary Regional Wastewater Planning Study, Phase 1," City of Corpus Christi, et al., November 1991; HDR, et al., "Nueces Estuary Regional Wastewater Planning Study, Phase 2," City of Corpus Christi, et al., March 1993; HDR, "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999; HDR, Supplemental Funding Work Item for 2006 Coastal Bend Regional Water Plan, 2005).

Table 4C.9-3.
CCR/LCC/Lake Texana System Safe Yields
(Phase IV Policy)

Reservoir Sedimentation Year	CCR/LCC/Lake Texana System Safe Yield (acft/yr)
2010	205,000
2060	200,000

With safe yield supplies, the yield of the system is reduced by 22,000 acft/yr in 2010 and 19,000 acft/yr in 2060, based on sedimentation conditions. Safe yield supplies were considered for the City of Corpus Christi and their customers (including Wholesale Water Providers).

Since the decision was made in the 1970s to pursue a second reservoir in the Nueces River Basin to enhance the yield of Lake Corpus Christi reservoir, a considerable amount of attention has been given to the potential effects of reduced freshwater inflow to the upper Nueces Bay and Nueces Delta. The following sections provide a brief history of ecological studies in the Nueces Estuary and a management strategy for maximizing the productivity of the Nueces Delta ecosystem while increasing the firm yield of the CCR/LCC System.

4C.9.3 CCR/LCC System Yield Recovery

4C.9.3.1 Summary of Ecological Studies of the Nueces Estuary

Beginning with the USBR's Environmental Impact Statement (EIS) for the Choke Canyon project,[12] the impact of an additional reservoir in the Lower Nueces River Basin on freshwater inflows to the Nueces Estuary has been discussed, studied, and debated. In the late 1970's and 1980's, a series of studies and reports were published regarding the freshwater needs of the Nueces Estuary. Studies by the United States Fish and Wildlife Service (USFWS),[13,14] the Texas Department of Water Resources (predecessor agency to the Texas Water Development Board),[15] Espey, Huston and Associates,[16] and unpublished research by scientists at the

[12] USBR, "Environmental Impact Statement for Choke Canyon Reservoir," December 1975.
[13] United States Fish and Wildlife Service (USFWS), "Supplemental Fish and Wildlife Coordination Act Report, Choke Canyon Dam and Reservoir, Nueces River Project, Texas," 1984.
[14] USFWS, "Phase 4 Report – Studies of Freshwater Needs of Fish and Wildlife Resources in Nueces-Corpus Christi Bay Area, Texas," August 1980.
[15] Texas Department of Water Resources, "Nueces and Mission-Aransas Estuaries: A Study of the Influence of Freshwater Inflows," January 1981.
[16] Espey, Huston and Associates, "Enhancement Potential Determination for the Nueces River/Deltaic Marsh System Study," 1981.

University of Texas Marine Science Institute (UTMSI) regarding effects of freshwater inflows to the Nueces Delta were conducted with a variety of differing goals and objectives. However, each study arrived at a similar set of conclusions: (1) the construction and operation of Choke Canyon Reservoir would reduce the volume of freshwater inflows to the Nueces Estuary; and (2) direct diversions of river flows and/or wastewater effluent return flows to the upper Nueces Delta could provide considerable mitigation for the reduction in freshwater inflows to the Nueces Estuary due to the CCR/LCC System.

In 1990, after the completion of Choke Canyon Reservoir, a Technical Advisory Committee (TAC) was formed by the Texas Water Commission (predecessor to the TCEQ) to assist the Commission in formulating a permanent freshwater inflow operating procedure for the Choke Canyon/Lake Corpus Christi reservoir system in accordance with Special Provision 5.B in the water rights permit for Choke Canyon Reservoir.[17] As the TAC process called attention to the need to formulate a long-term operating plan for freshwater inflows to the Nueces Estuary, it also created new interest in using diversions of both freshwater inflows and wastewater return flows as mechanisms to make optimal use of these limited resources.

In 1991, the City of Corpus Christi and several other local sponsors initiated what became a two-phased study[18,19] of the potential to divert freshwater into the Nueces Delta with the objective of reducing requirements to "release" water from the reservoir system. Findings of these reports included recommendations for one or two demonstration projects to be developed to evaluate the feasibility of both river diversions and wastewater effluent diversions into the Nueces Delta, and additional scientific monitoring to routinely collect pertinent data to improve the scientific understanding of the Nueces Delta and Bay ecosystems. Additionally, detailed results of studies of primary productivity in the Nueces Delta/Bay system reported in the Phase II Study[20] supported the concept that placing freshwater into marsh systems in the delta could provide three to five times the levels of primary productivity that the same amount of freshwater would produce when discharged into the water column of Nueces Bay via the Nueces River tidal segment. These two studies provided the impetus for the eventual development of the two

[17] TCEQ, Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, et al.
[18] HDR, et al., "Nueces Estuary Regional Wastewater Planning Study, Phase 1," City of Corpus Christi, et al., November 1991.
[19] HDR, et al., "Nueces Estuary Regional Wastewater Planning Study, Phase 2," City of Corpus Christi, et al., March 1993.
[20] Ibid.

freshwater diversion demonstration projects that have been implemented to date: the USBR's Rincon Bayou Demonstration Project and the Allison Wastewater Treatment Plant Effluent Diversion Demonstration Project, sponsored by the City of Corpus Christi.

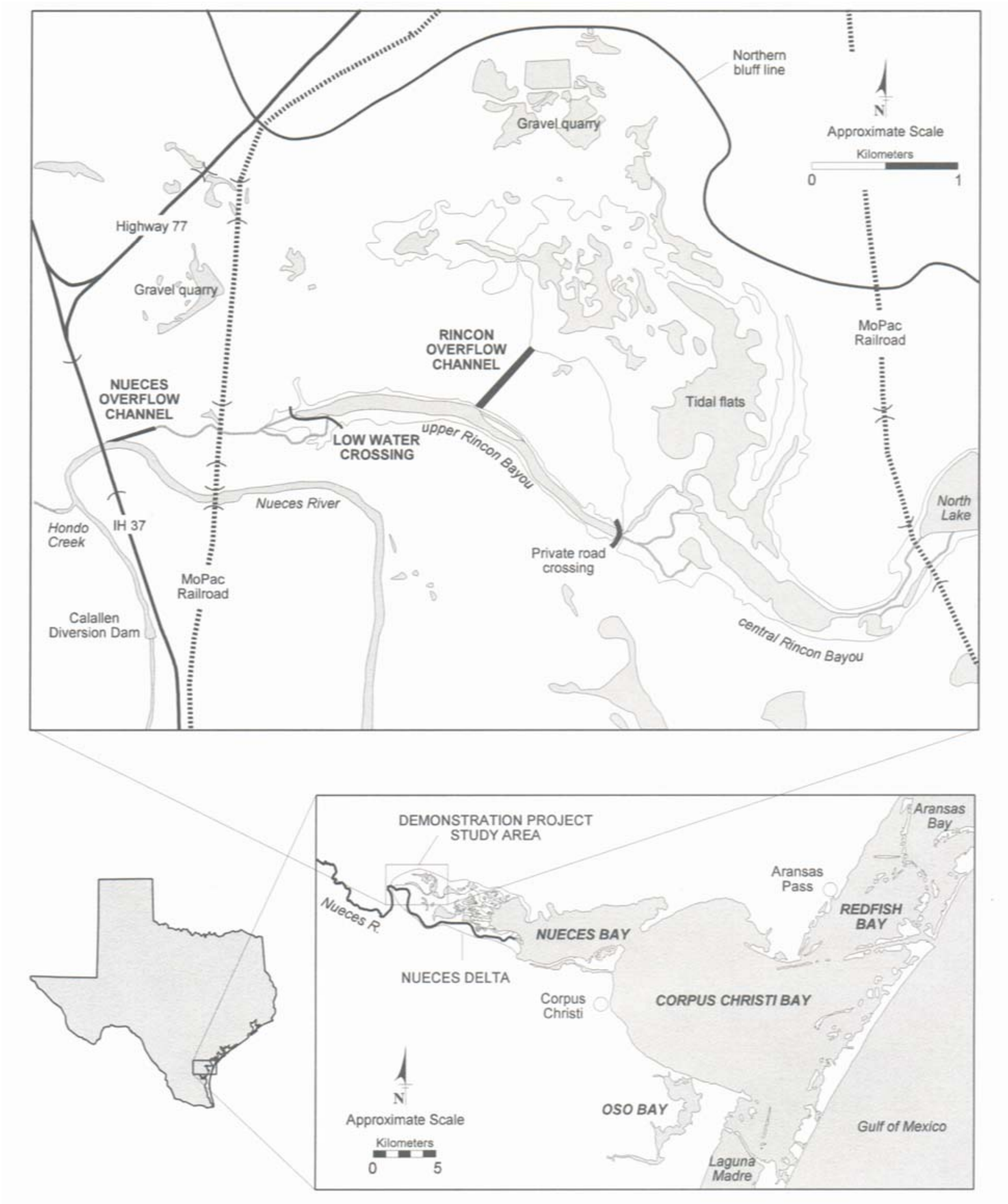
The Rincon Bayou Demonstration Project involved the excavation the Nueces Overflow Channel and the Rincon Overflow Channel in 1995, and subsequent monitoring activities through December 1999 (Figure 4C.9-2). While the demonstration project term expired in September 2000, and the Nueces Overflow Channel was subsequently filled in, the project's Concluding Report[21] describes the successes achieved during this relatively short period of time in restoring much of the ecological function of the Rincon Bayou portion of the Nueces Delta. Based on the benefits demonstrated by the Rincon Bayou Demonstration Project and the 2001 Agreed Order, the City reopened the channels and conducts an on-going monitoring program to facilitate an adaptive management program for freshwater inflows to the Nueces Estuary.[22.]

The Allison Wastewater Diversion Project completed a 5-year data collection program in September 2003 (see Figure 4C.9-3). The data collection program (1999 to 2003) was conducted by Texas A&M University at Corpus Christi and University of Texas Marine Science Institute. A reduced monitoring program is anticipated for 2005. The City of Corpus Christi is maintaining an extensive monitoring program designed to assess the benefits of the 2 MGD of effluent being discharged into the wetlands of the South Lake area of the Nueces Delta. The location of treated effluent discharges is important to consider when evaluating the benefits to the Nueces Delta and Estuary. Effluent discharges returned to the upper portions of the Nueces Bay and Estuary will have greater potential benefits.

4C.9.3.2 Potential Effluent Diversion Projects and Associated Firm Yield Impacts

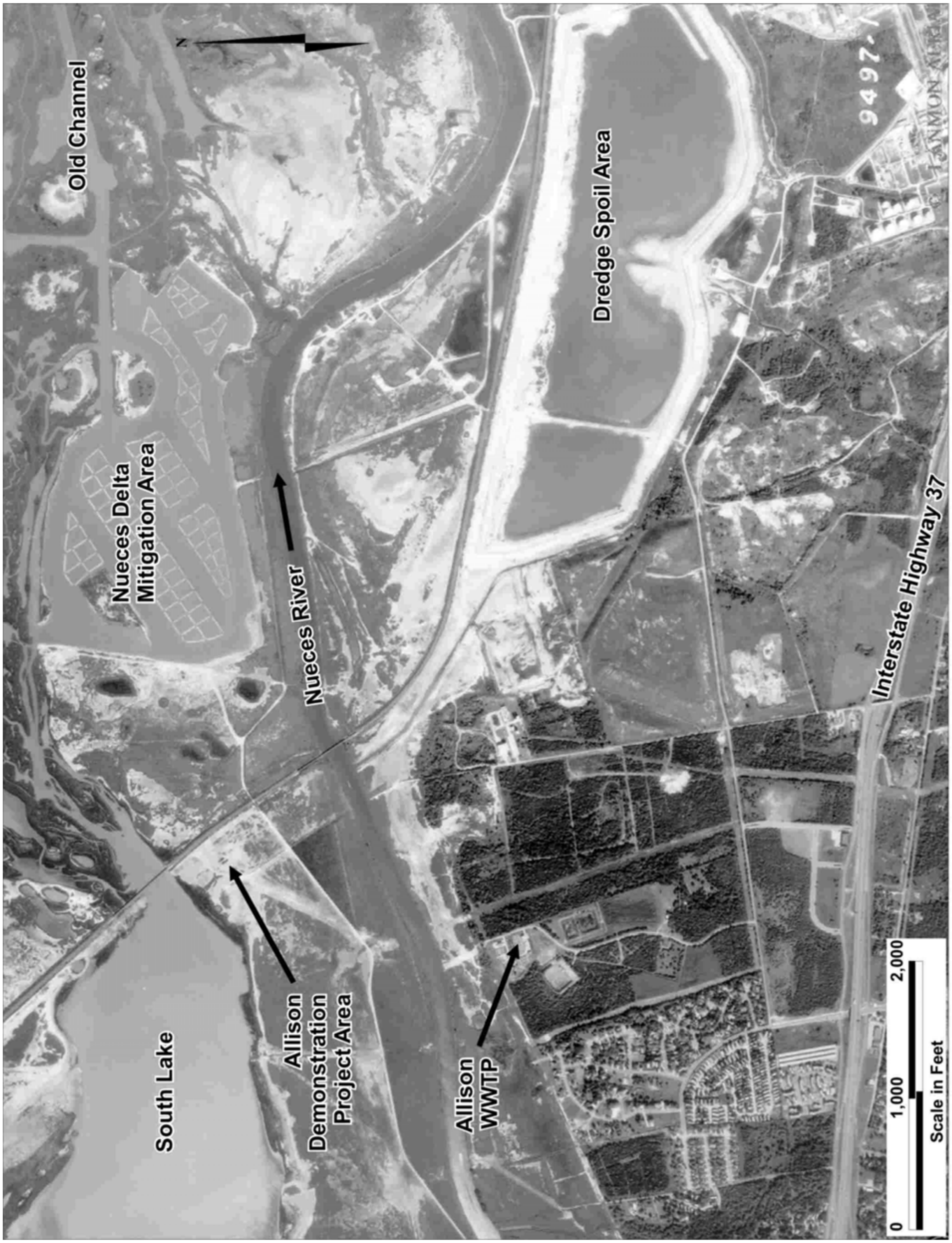
As shown in the previous studies detailed above, the location of freshwater inflows to the Nueces Estuary can be as important as the volume of flow. In this water management strategy, the Lower Nueces River Basin and Estuary Model (NUBAY) was used to evaluate the increase in CCR/LCC System firm yield due to alternative reservoir operating policies regarding freshwater inflows to upper Nueces Bay and Estuary. In the analysis, it was assumed that effluent from the City of Corpus Christi's wastewater treatment plants (WWTP) would be

[21] USBR, "Rincon Bayou Demonstration Project, Concluding Report," Volumes I and II, U.S. Dept. of the Interior, et al., September 2000.
[22] City of Corpus Christi, Integrated Monitoring Plan Fiscal Year 2005, January 2005.



Source: Rincon Bayou Demonstration Project, Concluding Report, Volume I, Executive Summary, USBR, September 2000.

Figure 4C.9-2. Location of the Nueces Delta (below) and of the Rincon Bayou Demonstration Project Features (above)



Source: Naismith Engineering, Inc.

Figure 4C.9-3. Diversion of Corpus Christi WWTP Effluent to the Nueces Delta

diverted to the Rincon Delta in exchange for freshwater pass-throughs from the CCR/LCC System. The three scenarios for the additional effluent diversions analyzed are summarized in Table 4C.9-4.

Table 4C.9-4.
Summary of Effluent Diversion Volumes and Sources

Scenario Number	***Additional Diversion Volume***	***Effluent Source(s)***
1	4 MGD	Allison WWTP
2	9 MGD	Allison and Broadway WWTPs
3	20 MGD	Allison, Broadway, and Greenwood WWTPs
Note: Diversion volumes include future expected wastewater effluent volumes and do not include existing 3 MGD at Allison that is currently discharged to Nueces Bay and the Allison Effluent Diversion Demonstration Project or 4 MGD of existing discharge to the Greenwood WWTP receiving stream.		

Under Scenario 1, future effluent discharges from the City of Corpus Christi's Allison WWTP (up to 4 MGD by 2020) would be discharged into the Nueces Delta. Similarly, under Scenario 2, the City's existing Broadway WWTP would be retired and up to 5 MGD of wastewater would be sent to the Allison WWTP. Under this scenario, the Allison WWTP would be expanded to treat the additional effluent from Broadway and the total additional effluent available for diversion to the bay or delta would be 9 MGD. In the last scenario, the Broadway WWTP would be retired and up to 5 MGD of wastewater sent to the City's Greenwood WWTP. Expansions at Greenwood would provide for an additional combined 16 MGD of effluent under future conditions for diversion to Nueces Bay or Delta. This effluent would be piped to the Allison WWTP and combined with the additional effluent from Allison (4 MGD) and discharged into the bay or delta. Figures 4C.9-4 and 4C.9-5 show the location of the WWTPs and the proposed pipelines to divert water to the bay or delta for Scenarios 2 and 3. No additional transmission facilities would be necessary for implementation of Scenario 1.

Under this water management strategy, in return for the additional effluent diversions to the Nueces Bay or Delta the CCR/LCC System would be allowed to suspend freshwater pass-throughs to Nueces Bay when CCR/LCC System storage drops below the selected threshold. While the reservoirs are operating above these system storage threshold triggers, the additional

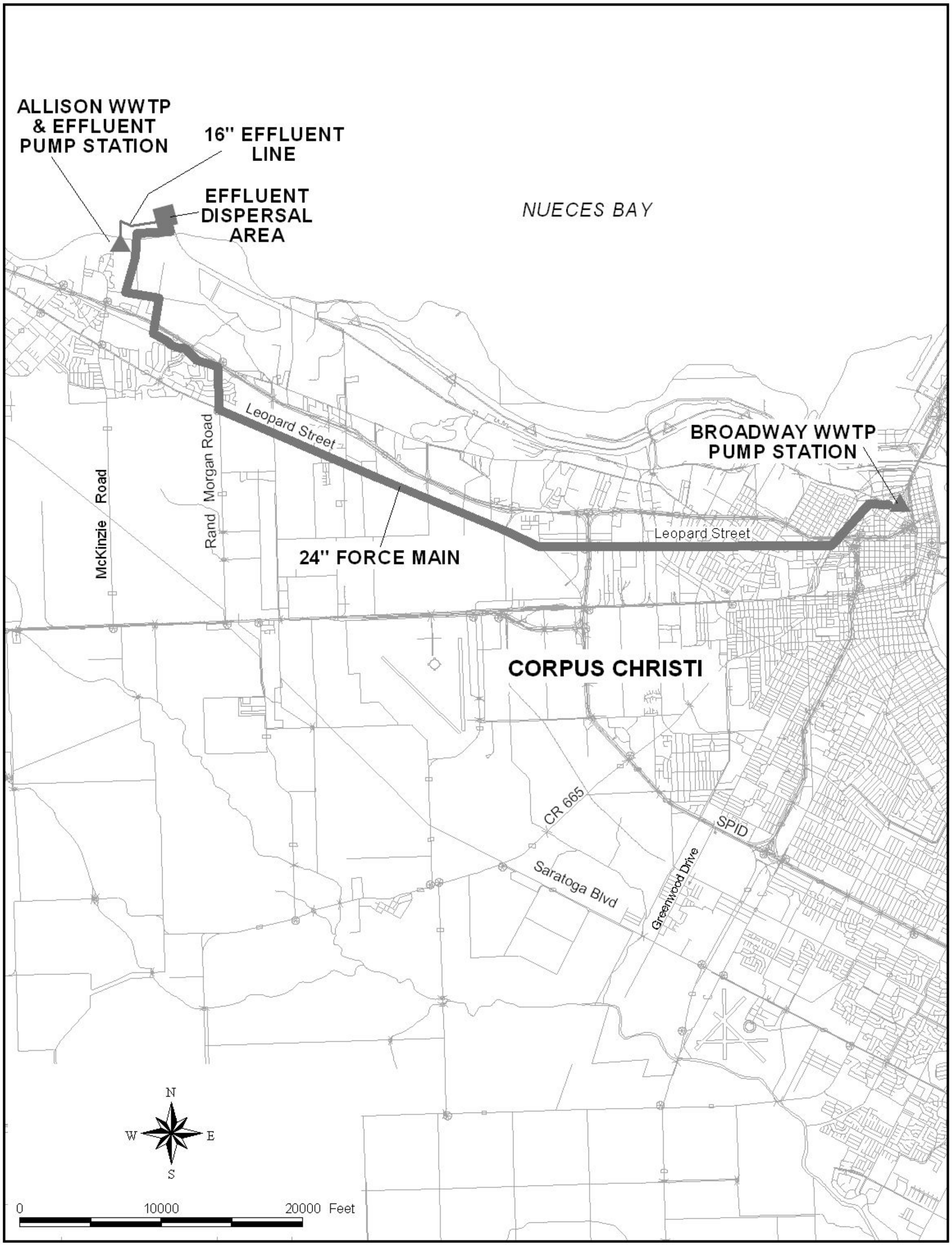


Figure 4C.9-4. Effluent Diversion Scenario 2

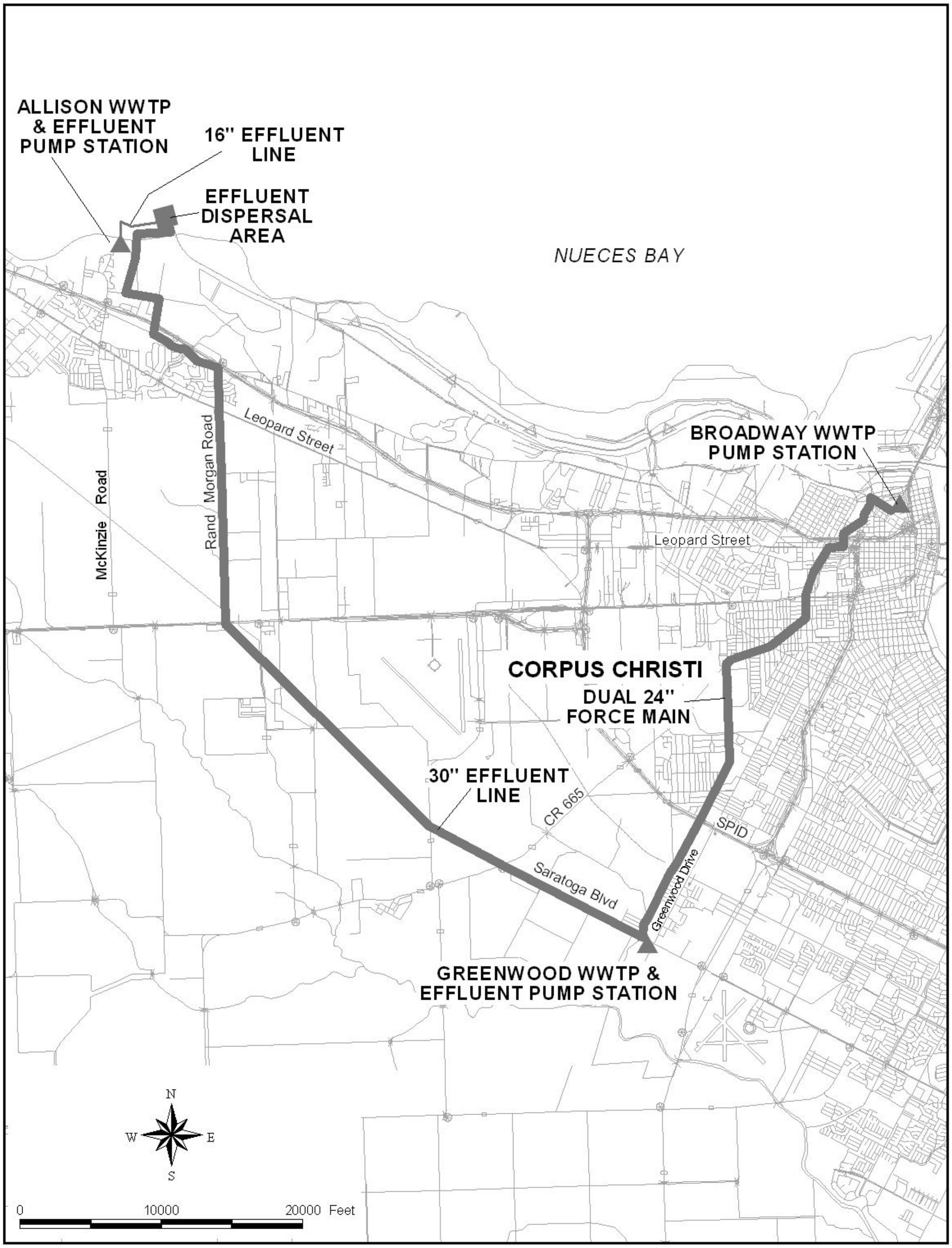


Figure 4C.9-5. Effluent Diversion Scenario 3

effluent diverted to the delta could satisfy a significant part of the Agreed Order pass-through requirements leaving additional freshwater in storage and thereby enhancing the CCR/LCC System firm yield. For purposes of these analyses, the following thresholds were used: 60, 50 and 40 percent of system storage. A series of NUBAY Model runs were performed for the above combinations. The incremental increases in CCR/LCC System firm yield range from a low of 7,100 acft/yr (Scenario 1 with a 40 percent system storage trigger) to a high of 13,100 acft/yr (Scenario 3 with a 60 percent system storage trigger). As shown in Table 4C.9-5 and Figure 4C.9-6, in general, as one increases the volume of effluent to the delta and/or increases the percent of system storage at which pass-throughs are suspended, the firm yield of the CCR/LCC System increases.

Table 4C.9-5.
Incremental Firm Yield Increases for
Alternative CCR/LCC Operating Scenarios (acft/yr)

	System Storage Trigger below which Freshwater Pass-Throughs are Suspended		
Scenario	40%	50%	60%
1	7,100	9,100	10,700
2	7,100	10,200	11,400
3	9,100	12,100	13,100

1. 2010 Reservoir Sediment Conditions.
2. Phase IV Reservoir Operating Policy
3. Baseline CCR/LCC System Demand = 180,000 acft/yr

4C.9.4 Environmental Issues

Fifty-two percent of the water diverted and used by the City is returned to various points in the estuary as treated wastewater. Presently, the largest portion of these discharges is made into the Nueces River, the Ship Channel, Oso Creek, and Oso Bay. This alternative involves reusing a portion of this treated wastewater by moving treated wastewater discharges from their present discharge points to the Nueces Delta (e.g., Rincon Bayou and Upper Nueces Delta.) The discharge of treated wastewater to the Nueces Delta offers potential for benefits in terms of increasing freshwater availability to meet municipal and industrial requirements in Corpus Christi, while at the same time potentially enhancing the productivity of Nueces Delta.

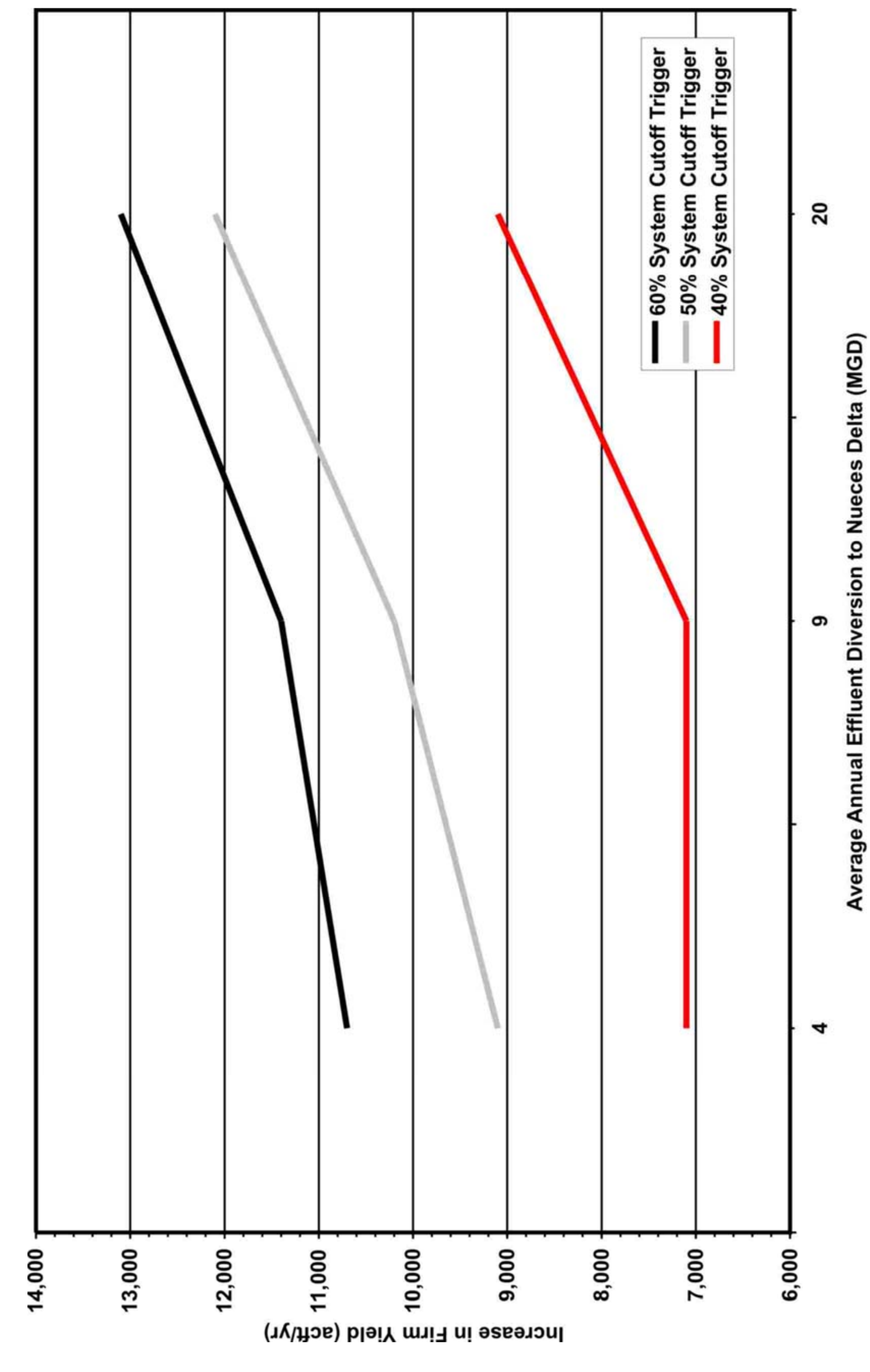


Figure 4C.9-6. Increase in Firm Yield versus Effluent Diversion to Nueces Delta

The Nueces-Corpus Christi Bay system supports several endangered species and the resources critical to their continued existence, migratory bird use areas, wetlands, and marine fish and invertebrate nursery areas. Because phytoplankton and emergent plants provide food and habitat for animals, especially during early developmental stages, and these in turn provide food for larger animals, changes in primary productivity and plant diversity can be expected to influence the assemblage of animals resident in the estuary. Previous studies indicate that the Nueces Delta and Nueces Bay are critically important as the site of much of the planktonic primary production that drives biological processes throughout the Nueces Estuary, and that nutrients are utilized relatively inefficiently by primary producers in Corpus Christi Bay because of its turbidity and depth. These studies indicate that treated wastewater could have as much as a fivefold stimulatory effect on primary productivity if discharged into the Nueces Delta rather than being discharged into the Nueces River.[23,24] Therefore, it has been recommended that wastewater be diverted and discharged into the delta to help meet the freshwater inflow requirement, as specified in the 2001 Agreed Order, under which the CCR/LCC System now operates. This proposed wastewater discharge to the Nueces Delta would increase water availability from the CCR/LCC System by obtaining potential relief from freshwater pass-throughs designed to meet Nueces Bay inflow requirements.

Studies designed to assess the effects of diverting wastewater to the Nueces Delta have been conducted by researchers from the UTMSI.[25,26] These studies involved determinations of monthly salinity, temperature, dissolved oxygen, dissolved inorganic nitrogen (that is available to support plant growth), phosphate, silicate, and water transparency at 25 sampling stations. Additionally, primary production was measured at five sites. Primary production and phytoplankton pigment biomass, and the biomass, species diversity and species abundance of emergent vegetation were measured at four sites in each of 1991 and 1992. Additionally, the City's ongoing studies of the Nueces Delta monitor water quality parameters as part of the 2001 Agreed Order.

[23] HDR et al., Op. Cit., November 1991.
[24] HDR et al., Op. Cit., March 1993.
[25] Whitledge, T.E. and D.A. Stockwell, "The Effects of Mandated Freshwater Releases on the Nutrient and Pigment Environment in Nueces Bay and Rincon Delta: 1990-1994." In: Water for Texas, Research Leads the Way (Jensen, R. ed.). Proceedings of the 24th Water for Texas Conference, 1995.
[26] Dunton, K.H., B. Hardegree, and T.E. Whitledge, "Annual Variations in Biomass and Distribution of Emergent Marsh Vegetation in the Nueces River Delta." In: Water for Texas, Research Leads the Way (Jensen, R. ed). Proceedings of the 24th Water for Texas Conference, 1995.

These studies indicate that primary productivity is positively correlated with the concentration of nutrients in the water. Increased flow and nutrient concentrations appeared to increase the relative abundance and species diversity of emergent vegetation.[27] The effects of wastewater on relative abundance and species diversity varied among study sites indicating that other factors, in addition to freshwater flows and nutrient concentrations (e.g. initial species composition and abundance, duration of flooding, and frequency of flooding), may affect the relative abundance and diversity of species. More comprehensive, long-term studies would be needed to assess the potential effects of wastewater on the relative abundance and diversity of species in the Nueces Estuary.

Pipelines necessary to route discharges to the Nueces Delta would be constructed primarily in existing right-of-ways which are located in urban areas. Less than 30 acres of delta wetlands and brushy uplands would be affected.

Use of these pipelines to transport effluent from Broadway and Greenwood WWTPs will reduce discharges at each of the facilities. Current plans by the City of Corpus Christi are to retire the Broadway WWTP and expand either Greenwood or Allison WWTP to handle the wastewater currently being treated at Broadway. Therefore, this management strategy will not additionally impact effluent discharges at Broadway as they are planned to be discontinued whether this project is implemented or not. In addition, scenarios presented herein assume that a minimum effluent discharge of 4 MGD will be maintained at the Greenwood WWTP in order to maintain the ecology of the receiving stream downstream of the WWTP outfall. Lastly, the additional flows at Allison WWTP that are proposed to be diverted to the Nueces Delta are future return flows above and beyond existing discharges.

Figure 4C.9-7 shows the potential changes in flow to the entire Nueces Estuary (including Nueces Delta, Nueces Bay, Corpus Christi Bay, Oso Bay and other adjacent receiving estuaries) based on 2001 Plan. Figure 4C.9-8 shows the potential changes in flow to the Upper Nueces Delta and Bay in particular. Although not evaluated separately during the 2006 planning process, since the reservoir systems are operating with safe yield supply, these inflows may be greater than presented since the reservoir system would be operating with safe storage. The evaluations were made using 1995 Agreed Order freshwater inflows targets, which are essentially the same for the 2001 Agreed Order. Each of the graphs in these two figures shows

[27] Ibid.

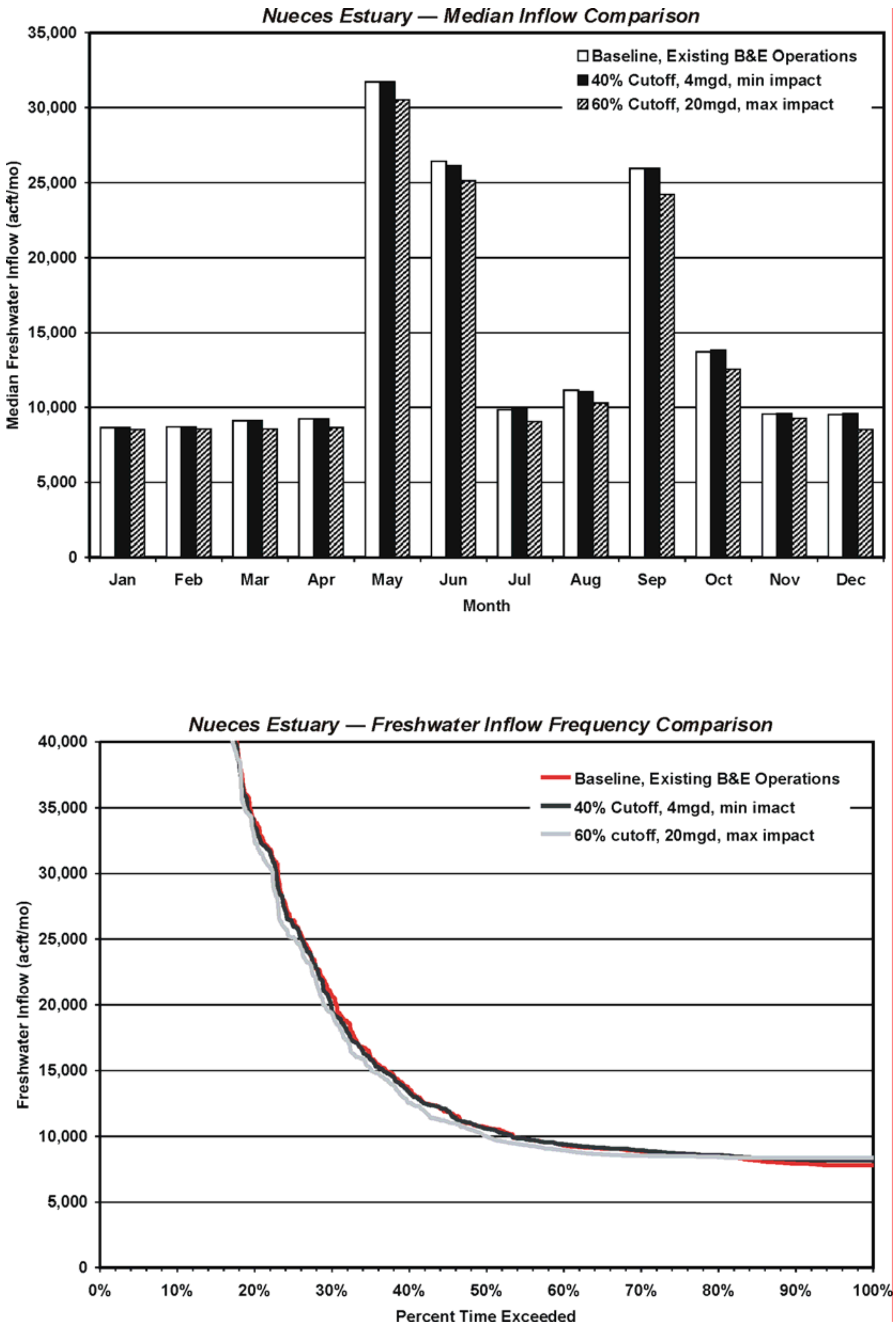


Figure 4C.9-7. Impacts to Freshwater Inflows to Nueces Estuary

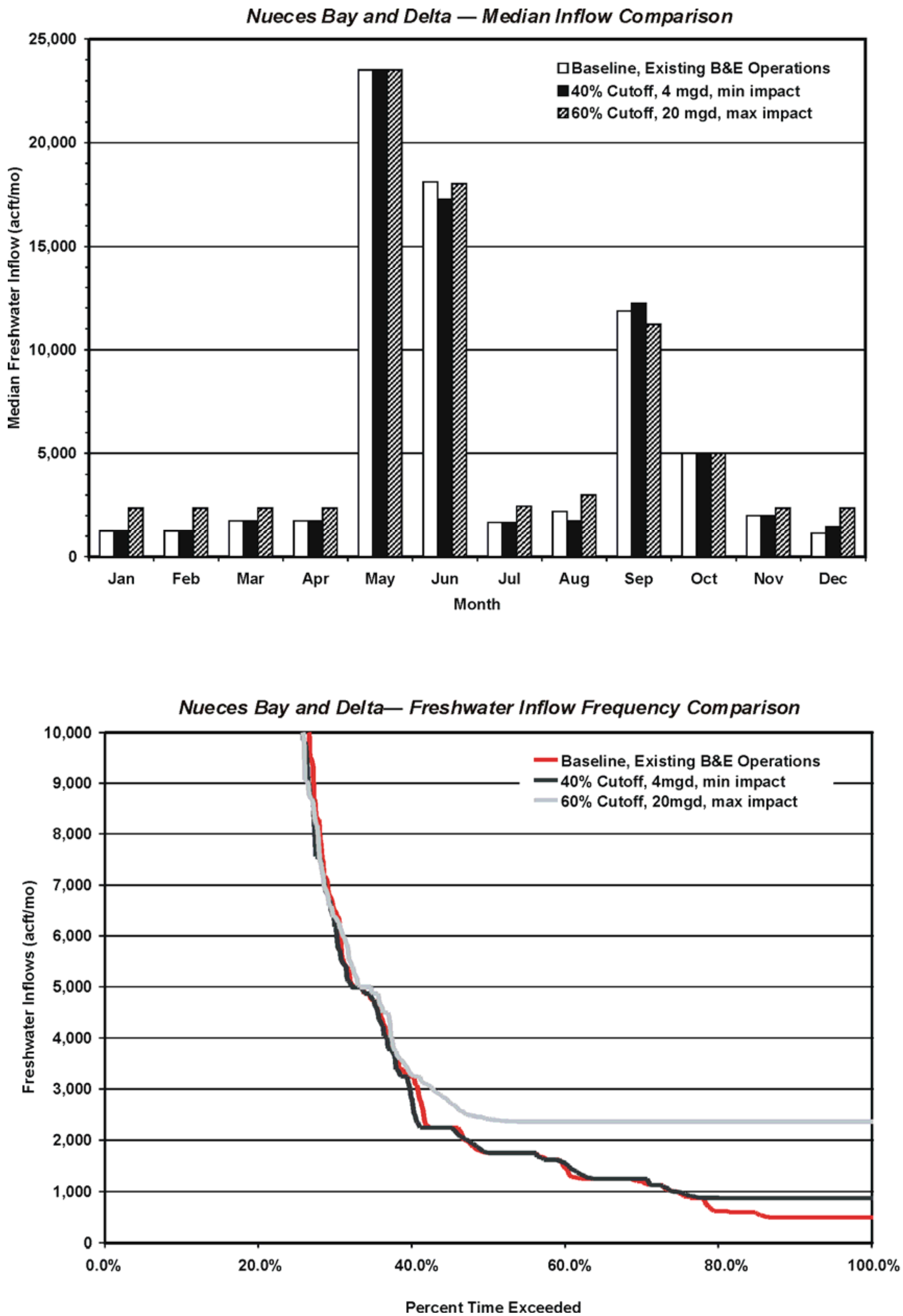


Figure 4C.9-8. Impacts to Freshwater Inflows to Nueces Bay and Delta

three scenarios: the baseline (existing 2001 Agreed Order), a minimum impact scenario (Scenario 1 with a system storage pass-through suspension target of 40 percent) and a maximum impact scenario (Scenario 3 with a system storage pass-through suspension target of 60 percent). Maximum and minimum impact was determined for this analysis as the maximum and minimum decrease in average annual estuarine inflow compared to the baseline condition.

As shown in these two sets of figures, the trade-off in freshwater inflows are an increase in freshwater inflow to the Upper Nueces bay and delta in exchange for an overall decrease in freshwater inflows to the estuary. As shown in each of the plots, the difference in monthly median freshwater inflows to the estuary and/or bay are relatively unaffected by the operations under the minimum impact scenario. In addition, as shown in the frequency curve on Figure 4C.9-8, for the lowest 20 percent of freshwater inflows to Nueces Bay and Delta (i.e., 80- to 100-percent exceeded on the bottom plot), flows are almost doubled under the minimum impact scenario as compared to existing operations. A review of the maximum impact scenario as compared to the baseline condition reveals that the in the summer (June through August) and winter and spring (November through April) median monthly streamflows to the estuary are slightly decreased while inflows to the upper delta and bay are significantly increased. In addition, in the lower 60 percent of the flows to the upper delta and bay (i.e., 40- to 100-percent exceeded on the bottom plot of Figure 4C.9-8), more water is delivered to the bay and delta under the maximum impact scenario (over four times as much in the lowest 20 percent of the flows). However, a review of the frequency plot for flows to the estuary (Figure 4C.9-7) reveals that changes to total flow to the estuary during low flow conditions are minor.

Some caution is warranted when analyzing the median monthly flow plots for Nueces Bay. The changes in flow in this plot should be compared to the existing 2001 Agreed Order flows (shown in the white bars). It is notable that these medians may or may not meet the monthly inflow targets established in the 2001 Agreed Order (for freshwater inflows to Nueces Bay), but reflect simulated, reservoir inflow-limited, freshwater pass-throughs which are dominated in the low flow months by wastewater return flows. As a result, during these low flow months, freshwater inflow to Nueces Bay and Delta is enhanced by effluent diversions to the upper Nueces Bay and Delta.

In addition to effluent diversions to the Rincon Delta, the USBR Rincon Bayou Demonstration Project[28] (see Section 4C.9.3.1) showed favorable enhancements to the ecology of the delta through cutting a diversion notch in the bank of the Nueces River and allowing freshwater pass-throughs from Lake Corpus Christi, as well as tidal fluctuations in the river, to frequently wet the bayou. The City of Corpus Christi has re-opened the Nueces and Rincon overflow channels as a part of the overall plan to enhance the Nueces Estuary ecosystem.

4C.9.5 Engineering and Costing

Three scenarios were costed for delivery of additional wastewater effluent from the City's WWTPs to the Rincon Delta. Scenario 1 (4 MGD of additional effluent to delta) requires no construction of new facilities, only increased pumping and O&M costs for the increased diversion. These costs were updated to reflect 2002 Second Quarter Prices. Table 4C.9-6 provides a cost breakdown for Scenario 1.

Scenario 2 (9 MGD of additional wastewater to the delta) requires the following facilities and improvements:

- Wastewater pump station at the Broadway WWTP;
- Transmission pipeline and intermediate pump station from Broadway WWTP to Allison WWTP; and
- Upgraded effluent pump station, pipeline, and dispersion capacity at Allison WWTP.

Table 4C.9-7 summarizes the costs for Scenario 2.

The total capital cost for building the transmission facilities for Scenario 2 is $16,474,000. After land acquisition costs and cost for engineering, legal, environmental mitigation, and interest during construction, the total project cost comes to $22,606,000. The debt service at 6 percent over 30 years and the annual operations and maintenance costs including energy results in a total annual cost of $1,957,000.

Scenario 3 (20 MGD of additional wastewater to the delta) requires these additional facilities:

- Wastewater pump station at Broadway WWTP;
- Dual transmission pipelines and intermediate pump station from Broadway WWTP to Greenwood WWTP;
- Effluent pump station at Greenwood WWTP;
- Transmission pipeline from Greenwood WWTP to Allison WWTP; and
- Upgraded effluent pump station, pipeline and dispersion capacity at Allison WWTP.

[28] USBR, Op.Cit., September 2000.

Table 4C.9-6.
Cost Estimate Summary for
Effluent Diversion Scenario 1[1]
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Effluent Force Main	$0
Effluent Pump Station	0
Total Capital Costs	**$0**
Engineering, Legal Costs and Contingencies	0
Environmental & Archaeology Studies and Mitigation	0
Land Acquisition and Surveying	0
Interest During Construction (1 year)	0
Total Project Cost	**$ (See Note 2)**
Annual Costs	
Debt Service (6 percent for 30 years)	$ (See Note 2)
Operation and Maintenance:	
Effluent Force Main and Pump Station	14,060
Pumping Energy Costs	14,060
Total Annual Cost	**$28,120**
Available Project Yield (acft/yr)	7,100 to 10,700[3]
Annual Cost of Water ($ per acft)	$3.96 to $2.63[3]
Annual Cost of Water ($ per 1,000 gallons)	$0.01

1 Diversion of 4 MGD effluent from Allison WWTP to Nueces Delta.
2 No new facilities are required for this scenario. Existing effluent facilities constructed for demonstration project will handle this diversion.
3 Range in yield due to varying system storage cutoff trigger from 40 to 60 percent

Table 4C.9-7.
Cost Estimate Summary for
Effluent Diversion Scenario 2[1]
(Second Quarter 2002 Prices)

Item	***Estimated Costs***
Capital Costs	
Pipelines (14.4 miles)	$15,036,000
Pump Stations	2,779,000
Total Capital Costs	**$17,815,000**
Engineering, Legal Costs and Contingencies	5,344,000
Environmental & Archaeology Studies and Mitigation	351,000
Land Acquisition and Surveying	224,000
Interest During Construction (3 years)	712,000
Total Project Cost	**$24,446,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$1,776,000
Operation and Maintenance:	
Pipelines and Pump Stations	220,000
Pumping Energy Costs	121,000
Total Annual Cost	**$2,117,000**
Available Project Yield (acft/yr)	**7,100 to 11,400**
Annual Cost of Water ($ per acft)	**$298 to $186 3**
Annual Cost of Water ($ per 1,000 gallons)	**$0.91 to $0.57 3**

[1] Diversion of all raw wastewater from Broadway WWTP to Allison WWTP, then diversion of 9 MGD effluent from Allison WWTP to Nueces Delta.

[2] New facilities required for this scenario include: (1) new pump station at Broadway WWTP, (2) 20" force main to diversion pump station near I-37 and Crosstown Expressway, (3) new diversion pump station, (4) dual 24" force main from diversion pump station to Allison WWTP, (5) parallel 16" effluent force main from Allison WWTP to Nueces Delta, and (6) additional pumping capacity at existing demonstration project pump station.

[3] Range in yield due to varying system storage cutoff trigger from 40% to 60%.

Table 4C.9-8 provides a cost breakdown for Scenario 3.

Table 4C.9-8.
Cost Estimate Summary for
Effluent Diversion Scenario 3[1]
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Pipelines (20.6 miles)	$16,550,000
Pump Stations	6,240,000
Total Capital Costs	**$22,790,000**
Engineering, Legal Costs and Contingencies	6,837,000
Environmental & Archaeology Studies and Mitigation	548,000
Land Acquisition and Surveying	353,000
Interest During Construction (4 years)	1,221,000
Total Project Cost	**$31,749,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$2,307,000
Operation and Maintenance**:**	
Pipelines and Pump Stations	321,000
Pumping Energy Costs	393,000
Total Annual Cost	**$3,021,000**
Available Project Yield (acft/yr)	9,100 to 13,100
Annual Cost of Water ($ per acft)	$332 to $231[3]
Annual Cost of Water ($ per 1,000 gallons)	$1.02 to $0.71[3]

[1] Diversion of all raw wastewater from Broadway WWTP to Greenwood WWTP, then diversion of 16 MGD effluent from Greenwood WWTP to Nueces Delta and 4 MGD effluent from Allison WWTP to Nueces Delta.

[2] No new facilities are required at Allison WWTP. Existing effluent facilities constructed for demonstration project will handle this diversion. New facilities required for this scenario include: (1) new pump station at Broadway WWTP, (2) 20" force main to diversion pump station near I37 and Crosstown Expressway, (3) new diversion pump station, (4) dual 24" force main from diversion pump station to Greenwood WWTP, (5) 30" effluent force main from Greenwood WWTP to Nueces Delta, and (6) effluent pump station at Greenwood WWTP.

[3] Range in yield due to varying system storage cutoff trigger from 40 to 60 percent.

The estimated capital cost associated with Scenario 3 is $21,074,000. The additional costs associated with land acquisition, engineering, legal, environmental mitigation, and interest during construction bring the total project cost to $29,358,000. The annual debt service, operations and maintenance, and energy costs result in an annual cost of $2,793,000.

4C.9.6 Implementation Issues

This option requires the construction of new facilities as well as the upgrade and use of the pumping facilities owned and operated by the City of Corpus Christi at the Allison Wastewater Treatment Plant.

Since the TCEQ 1995 Agreed Order regarding freshwater pass-throughs, as currently written, does not allow operations like those presented herein, the potential amendment of the TCEQ permit would have to be considered before implementing such a project.

In addition to providing a cost effective water supply source to the City, additional benefits of such a project could be reduced WWTP upgrade costs. The cost of upgrading facilities to higher levels of effluent treatment could be saved since the higher treated water would not be as effective in promoting biological activity in the delta. Therefore, increased effluent treatment at the WWTPs could be counter-productive when the water is diverted to the delta.

Requirements Specific to Transfer of Water

1. It will be necessary to obtain these permits:
   a. Permit amendment from TCEQ to existing 1995 Agreed Order;
   b. Nueces Estuary Advisory Committee review;
   c. TPWD Sand, Gravel, and Marl permit;
   d. GLO Sand and Gravel Removal permits; and
   e. Wastewater permit amendments from TCEQ.
2. Permitting, at a minimum, will require these studies:
   a. Evaluation of biological impacts in the Nueces Delta;
   b. Habitat mitigation plan;
   c. Environmental studies; and
   d. Cultural resource studies.
3. Land and easements will need to be acquired by negotiations or condemnation.

Requirements Specific to Pipelines

1. Necessary permits:
   a. U.S. Army Corps of Engineers Sections 10 and 404 dredge and fill permits for stream crossings;
   b. GLO Sand and Gravel Removal permits;
   c. Coastal Coordinating Council review; and
   d. TPWD Sand, Gravel, and Marl permit for river crossings.
2. Approval from various agencies for these crossings:
   a. Highways and railroads;
   b. Creeks and rivers;
   c. Other utilities.

4C.9.7 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 4C.9-9.

Table 4C.9-9.
Evaluation Summary of Modifications to Existing Reservoir Operating Policy

Impact Category	***Comment(s)***
a. Water supply: 1. Quantity 2. Reliability 3. Cost of treated water	 1. Firm yield: 7,100 to 13,100 acft/yr (in 2010) 2. Good reliability. 3. Generally low cost; between $3 to $332 per acft
b. Environmental factors: 1. Instream flows 2. Bay and estuary inflows 3. Wildlife habitat 4. Wetlands 5. Threatened and endangered species 6. Cultural resources 7. Water quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. Increases in freshwater inflow to Upper Nueces Bay. Potential environmental impact due to reduced freshwater inflow to Estuary. 2. Positive impacts to biological activity in the Nueces Estuary & Upper Nueces Delta by increasing returned flows. Potential environmental impact due to reduced freshwater inflow to Estuary. 3. None or low impact. 4. None or low impact. 5. Positive impacts to biological activity in the Nueces Estuary & Upper Nueces Delta by increasing returned flows. Potential environmental impact due to reduced freshwater inflow to Estuary. 6. Cultural Resource Survey will be needed to avoid any significant sites 7. The City's Integrated Plan provides on-going studies of water quality issues of the Nueces Delta. 7a. Dissolved solids are a concern to be addressed with further studies. 7b. Salinity is a concern to be addressed with further studies. 7c. Bacteria is a concern to be addressed with further studies. 7d. Chlorides are a concern to be addressed. 7e-h. None or low impact. 7i. Alkalinity a concern and will need to be addressed.
c. State water resources	• No negative impacts on other water resources • Potential benefit to Nueces Estuary from increase freshwater return flows
d. Threats to agriculture and natural resources in region	• None
e. Recreational	• None
f. Equitable comparison of strategies	• Standard analyses and methods used
g. Interbasin transfers	• Potentially could require the transfer of water from the Nueces River Basin to the San Antonio-Nueces Coastal Basin
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Provides enhanced recreational opportunities (birding in Upper Nueces Delta)
j. Effect on navigation	• None

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4C.10 Pipeline between Choke Canyon Reservoir and Lake Corpus Christi (N-10)

4C.10.1 Description of Strategy

Channel losses in streams that deliver water from Choke Canyon Reservoir (CCR) to Lake Corpus Christi (LCC) are often large. Previous studies[1] indicate that channel losses in the 63-mile reach of the Frio and Nueces Rivers downstream of CCR to LCC, which include seepage losses within LCC, can be significant. Recent analysis has shown that since the completion of CCR, these losses have averaged 37.8 percent for this reach.[2]

Since the majority of the surface water supply from the CCR/LCC System for the City of Corpus Christi and its customers is stored in CCR and delivered to LCC using the natural stream channel, the yield of the system is affected by these losses. However, if water could be delivered by a pipeline that bypasses the stream channels, it would not be subjected to these losses and would result in more water in storage and enhance the system yield. Past studies[3] have shown that a pipeline between CCR and LCC could provide a significant increase to the CCR/LCC System at a relatively low cost. In addition to the pipeline between CCR and LCC, several past studies[4,5,6] have evaluated the possibility of enhancing the CCR/LCC System yield by taking advantage of CCR's proximity to the Nueces River and diverting water from the Nueces River near Simmons or Three Rivers and storing it in CCR. The results of these studies have shown that enhancements to the CCR/LCC System are small and result in high unit costs. Analyses of streamflow records show that the main reason those yield increases are small is due to the fact that in drought conditions, flows in the Nueces River are limited and would be captured by available storage in LCC. Therefore, analysis of the pump-back from the Nueces River to CCR is not included in this evaluation.

The pipeline route between CCR and LCC is shown in Figure 4C.10-1. Going from CCR to LCC, the route follows a southeasterly direction from CCR, crosses the Nueces River, and terminates on the upper west side of LCC. The pipeline operation will require an intake at CCR and an outlet structure at LCC. In the 2001 Plan, the pipeline route extended an additional

[1] HDR Engineering, Inc. (HDR), "Regional Water Supply Planning Study, Phase I, Nueces River Basin," Vols. 1, 2, and 3, Nueces River Authority, et al., May 1991.
[2] CCR/LCC updates, 2005.
[3] HDR, Op. Cit., May 1991.
[4] HDR, "Diversion from Nueces River to Choke Canyon Reservoir," Memo to James Dodson, September 8, 1997.
[5] HDR, Op. Cit., May 1991.
[6] Raushchuder, D.G., "Potential for Development of Additional Water Supply from the Nueces River between Simmons and Calallen Diversion Dam," 1985.

12 miles to the lower west side of LCC (Figure 4C.10-1) to allow operation of a two-way pipeline with a deep-water pump station at LCC. The two-way option showed small additional yield and resulted in high unit costs attributable to additional costs for the extra pipeline length and pump station at LCC. Therefore, the two-way pipeline was removed from consideration for the 2006 Plan.

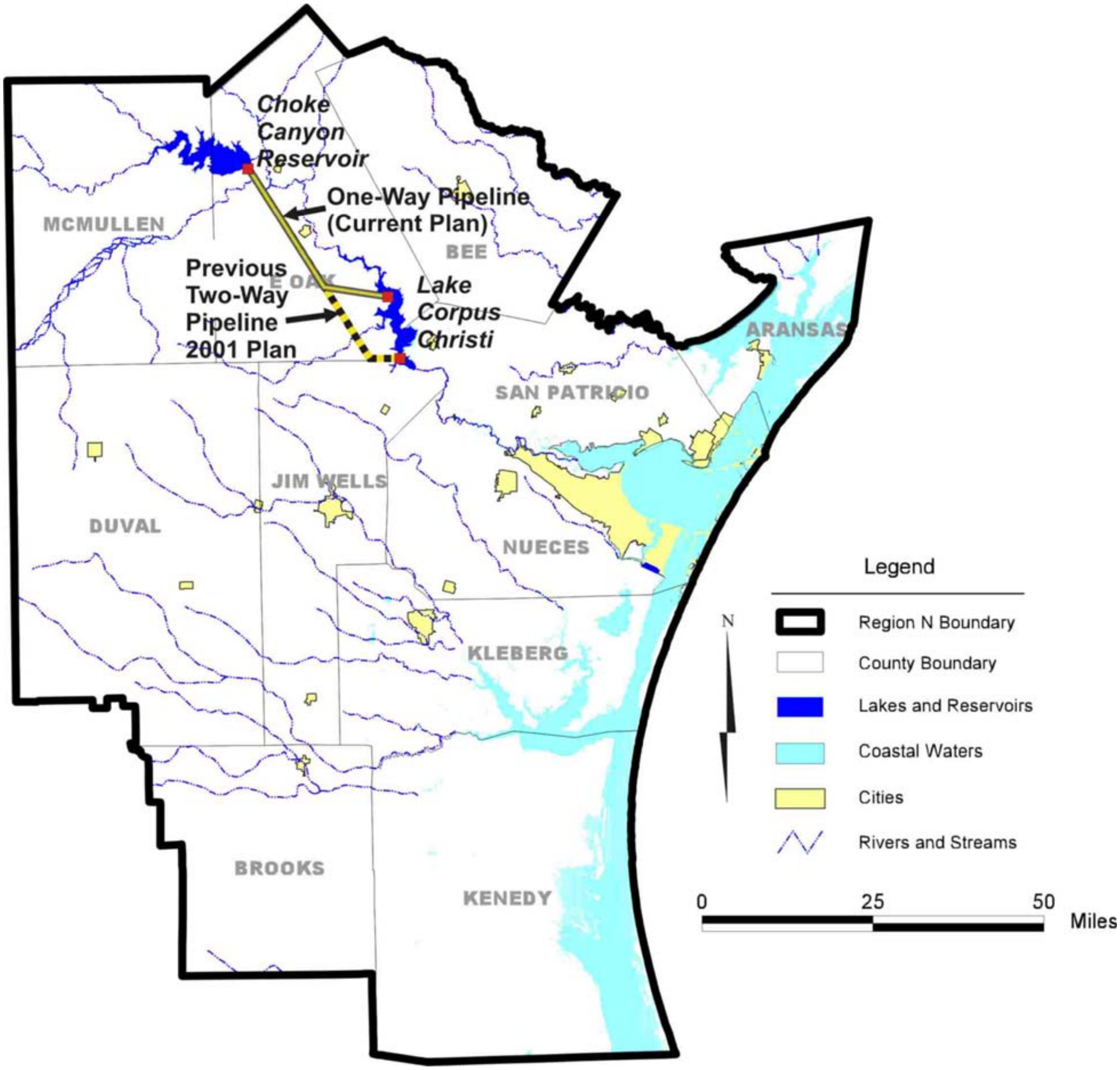


Figure 4C.10-1. Pipeline between Choke Canyon Reservoir and Lake Corpus Christi

CCR is required to continue its release of 33 cfs for senior water rights and environmental considerations even with the pipeline in operation to deliver water supply releases.

The analysis for a pump-back operation at Three Rivers in conjunction with the CCR to LCC pipeline showed that unlike the off-channel reservoir project described in Section 4C.11, which has the benefit of catching storm flows in LCC for later diversion over a long period of time, the pump back option could only divert the storm flows for a period of a few days as it traveled downstream. This resulted in significantly less flow being diverted into CCR, than could be diverted into the off-channel reservoir. The results of the pump-back option analysis indicated that from hydrological and operational standpoints this option was not efficient in producing the desired additional water supply.

4C.10.2 Available Yield

Yield analyses for this alternative were performed to meet the following objectives:

- Establish the optimum reservoir levels for operating the transmission system between the two reservoirs.
- Determine the delivery rate from CCR to LCC that will provide the largest yield increase at reasonable unit costs.

Simulations were made for the historical period from 1934 to 2003 using the City of Corpus Christi's Phase IV Operations Plan, the 2001 TNRCC Agreed Order, and 2010 reservoir sedimentation conditions. After the optimum reservoir levels and delivery rates were obtained for the 2010 sediment conditions, they were analyzed at 2060 reservoir sediment conditions. For modeling purposes, it was assumed that the same channel loss and reservoir seepage functions would apply to any water released into the stream system in excess of the capacity of the pipeline. The operating guidelines for both reservoirs and the pipeline are detailed below. CCR and the pipeline were operated in the following manner:

1) A minimum 2,000 acft/month (33 cfs) was released from CCR to the Frio River, as specified in the existing permit;
2) When required, water supply releases from CCR larger than 2,000 acft in any month and less than pipeline capacity are delivered through the pipeline between the two reservoirs up to the capacity of the pipeline; and
3) When monthly releases at CCR exceed the capacity of the pipeline, the remaining portion of the release is delivered via the Frio and Nueces Rivers.

This release policy assumes that the instream flow requirements downstream of CCR are met by the 2,000 acft/month (33 cfs) minimum release requirement in the existing permit, and that this instream flow volume together with flows in excess of the pipeline capacity would satisfy instream flow requirements and senior water rights in the reach between the two reservoirs.

Table 4C.10-1 shows yields and costs for the pipeline delivery rates used in this analysis. The 300-cfs delivery rate results in the preferred delivery rate when cost and additional yield provided are taken into consideration. A detailed cost analyses for the one-way pipeline for the 300-cfs delivery rate is presented in Section 4C.10.4.

Table 4C.10-1.
Summary of Yield and Costs for
One-Way Pipeline from Choke Canyon Reservoir to
Lake Corpus Christi for 2010 Sediment Conditions

Delivery Rate (cfs)	*Pipe Diameter[1] (inches)*	*Firm Yield[2] (acft/yr)*	*2010 Yield Increase (acft/yr)*	*Annual Cost ($ Million)*	*Approximate 2010 Unit Cost ($/acft/yr)*	*Incremental Unit Costs[3] ($/acft/yr)*
200	84	204,400	30,200	$7.03	$232	—
250	90	209,700	35,500	$7.61	$214	$110
300	96	213,200	39,000	$8.78	$225	$336
350	108	215,700	41,500	$10.72	$258	$774

[1] Pipeline sized to maintain average velocity near 5 fps.

[2] Baseline yield without pipeline under phase IV operations policy, 2010 sediment conditions, and the 2001 Agreed Order equals 174,200 acft/yr.

[3] Incremental costs were calculated as the difference in Annual Cost ($ Million) between options divided by the difference in yield between options. Incremental unit costs were used to determine the optimal pipeline delivery rate that would provide additional water supply at a reasonable cost.

Table 4C.10-2 shows the yields for both 2010 and 2060 reservoir sediment conditions for each delivery rate, as well as the unit cost of water for 2060 conditions for the pipeline.

The increase in yield due to the pipeline in 2060 is greater than experienced in 2010. The benefit of the pipeline increases as the reservoirs fill with sediment. Comparison of unit cost for 2060 sediment conditions shows that the delivery rate of 300 cfs produces the preferred unit cost of water for the one-way pipeline.

Table 4C.10-2.
Summary of Yield Increases for both 2010 and 2060 Sediment Conditions and 2060 Unit Costs for One-Way Pipeline

Delivery Rate (cfs)	2010		2060		Approximate 2060 One-Way Pipeline Unit Cost ($ per acft/yr)	Approximate 2060 Incremental Unit Costs[2] ($ per acft/yr)
	Firm Yield[1] (acft/yr)	Increase in Firm Yield Due to Pipeline	Firm Yield[1] (acft/yr)	Increase in Firm Yield Due to Pipeline		
0	174,200	—	168,500	—	—	—
200	204,400	30,200	200,000	31,600	$222	—
250	209,700	35,500	204,700	36,200	$210	$127
300	213,200	39,000	208,000	39,500	$222	$356
350	215,700	41,500	210,700	42,200	$254	$717

[1] Yield calculated under phase IV operations policy and the 2001 Agreed Order.
[2] Incremental costs were calculated as the difference in Annual Cost ($ Million) between options divided by the difference in yield between options. Incremental unit costs were used to determine the optimal pipeline delivery rate that would provide additional water supply at a reasonable cost.

4C.10.3 Environmental Issues

Environmental issues related to transferring water by pipelines from CCR to LCC can be categorized as follows:

- Effects related to pipeline construction and maintenance;[7] and
- Effects resulting from changes in Nueces River flows, including inflows to the Nueces Estuary.

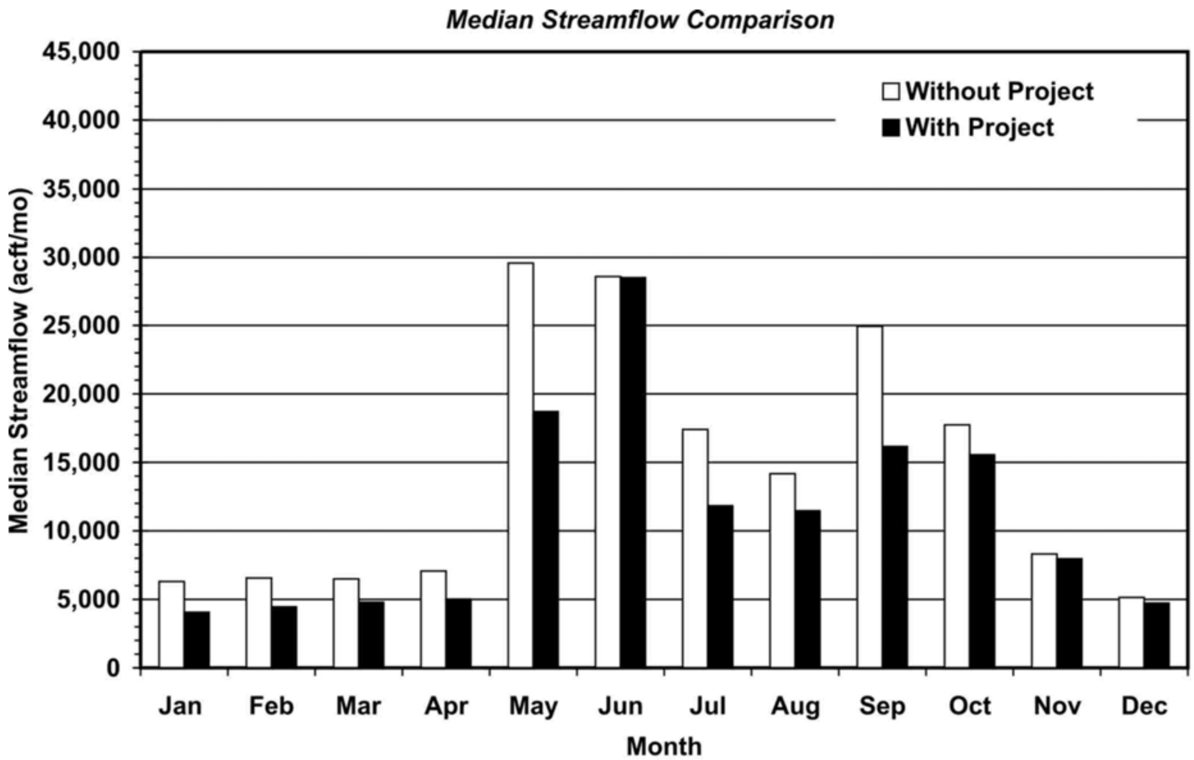
The proposed pipeline corridor would be within Live Oak County. The construction of a pipeline from CCR to LCC would result in soil and vegetation disturbance within the approximately 226-acre pipeline construction corridor. Longer-term terrestrial impacts would be confined to the 115-acre maintained right-of-way. In Like Oak County, the jaguarundi (*Felis yagouaroundi*), listed as endangered, has been reported to habitat within the proposed pipeline corridor and several state-protected species may be present in the area. The ocelot (*Felis pardalis*), listed as endangered, has been reported in Live Oak County and studies of cats have been done along Highway 281.[8] Temporarily wet areas or drainages in uplands and in wetland portions of the pipeline corridor may provide habitat for several state-protected amphibians. The

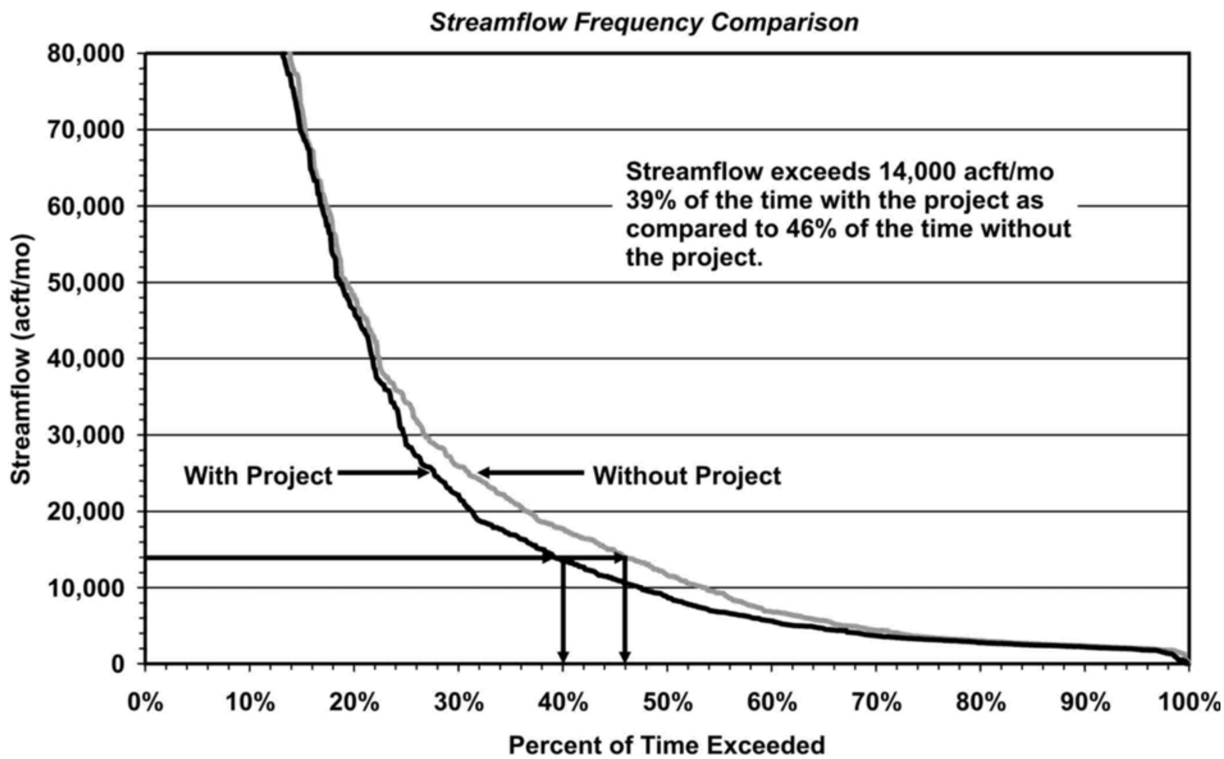
[7] "HDR, et al., "Trans-Texas Water Program – Corpus Christi Study Area – Phase II Report," City of Corpus Christi, et al., September 1995.
[8] French, J., RWPG meeting, February 2005.

black-spotted newt (*Notophthalmus meridionalis*) and Rio Grande lesser siren (*Siren intermedia texana*) are found in wet or temporally wet arroyos, canals, ditches, or shall depressions. During dry periods, they aestivate underground. The sheep frog (*Hypopachus variolosus*) inhabits wet areas and freshwater marshes in the Rio Grande Valley, lower South Texas Plains, and Southern Coastal Prairie. The Mathis spiderling (*Boerhavia mathisiana*) was a possibly extinct plant that has been proposed for protection to USFWS. It inhabits open thorn shrublands with shallow sandy to gravely soils over limestone or on bare limestone or caliche outcrops. The Mathis spiderling was once found in the vicinity of LCC in San Patricio County.

Several sites on or eligible for inclusion on the National Register of Historic Places are known from the vicinity of the pipeline corridor, and other types of cultural resource sites may be present, although none are known to be located within the corridor.

Use of pipeline transport will periodically reduce river flows between CCR and LCC. The presently required maintenance releases of 2,000 acft/month would be continued. However, historical monthly median flows will be reduced by up to 37 percent in some months, as shown in the top plot of Figure 4C.10-2 for the 300-cfs delivery option. The bottom plot of Figure 4C.10-2 shows the streamflow frequency at Three Rivers with and without the project. As shown by the arrows on the plot, the monthly median flow for the period of record of 14,000 acft is exceeded 46 percent of the time without the project and 39 percent with the project. River flows below LCC at Mathis and estuarine inflows would be increased. Considering return flows, the annual inflows to the Nueces Estuary are increased on average, 14,800 acft/yr, for years with annual flows less than 190,000 acft/yr. Both increases in flow result from the additional yield in the CCR/LCC System being delivered to Corpus Christi. Figures 4C.10-3 and 4C.10-4 display the monthly median streamflows and streamflow frequency plots for river flows at Mathis and estuarine inflows. Implementation of the project will also impact reservoir levels in both CCR and LCC. Figure 4C.10-5 displays plots of water surface elevation versus time for each reservoir and a system storage frequency comparison. Figure 4C.10-6 shows the amount of water, on an annual basis, that is delivered through the pipeline to LCC from CCR.





Results based on Phase IV operating policy, 2060 sediment conditions, the 2001 Agreed Order, 300 cfs pipeline delivery rate, and a demand of 168,500 acft/yr without project and 208,000 acft/yr with CCR/LCC Pipeline.

Figure 4C.10-2. Project Impacts on Streamflow, Nueces River at Three Rivers

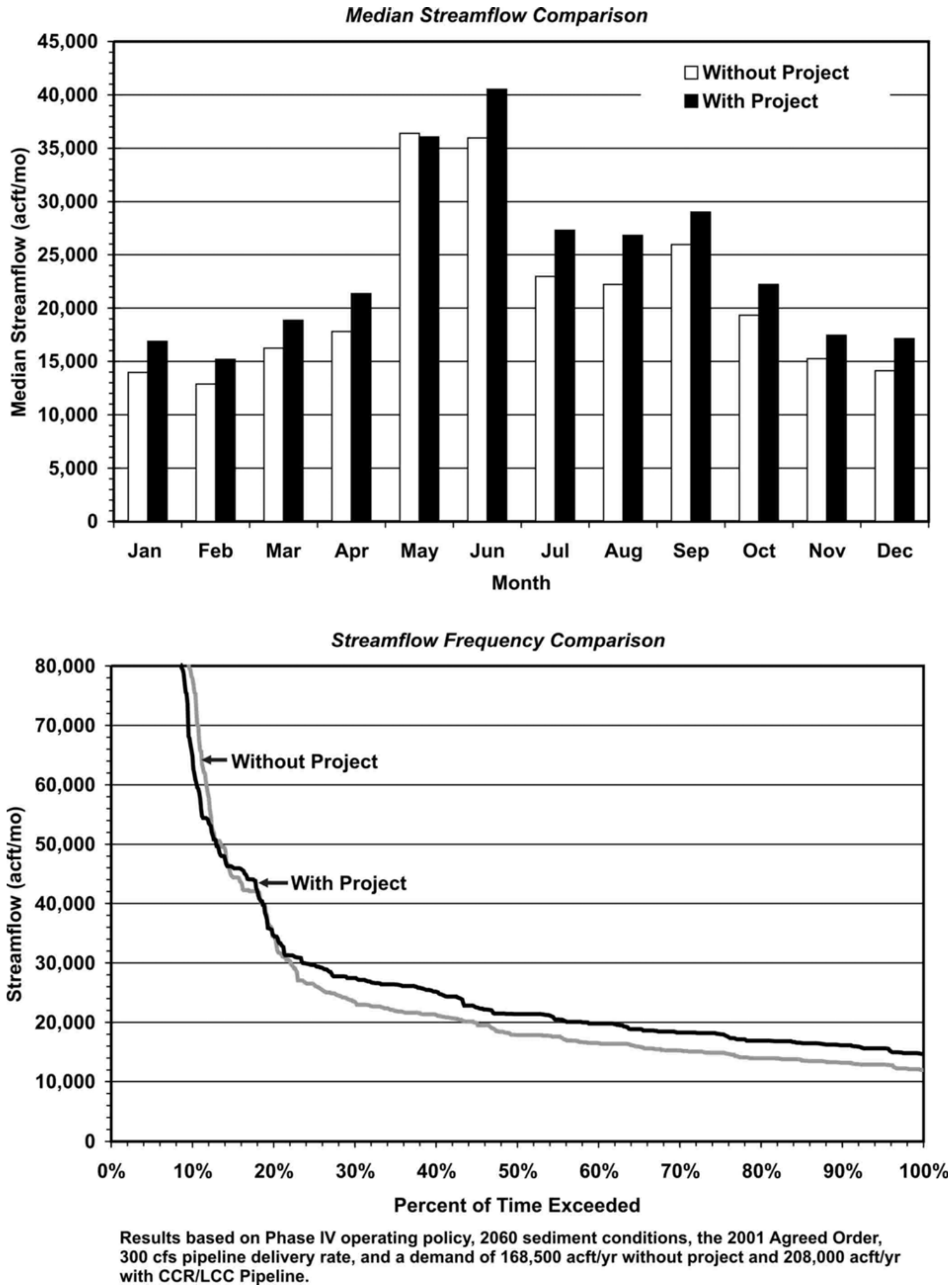
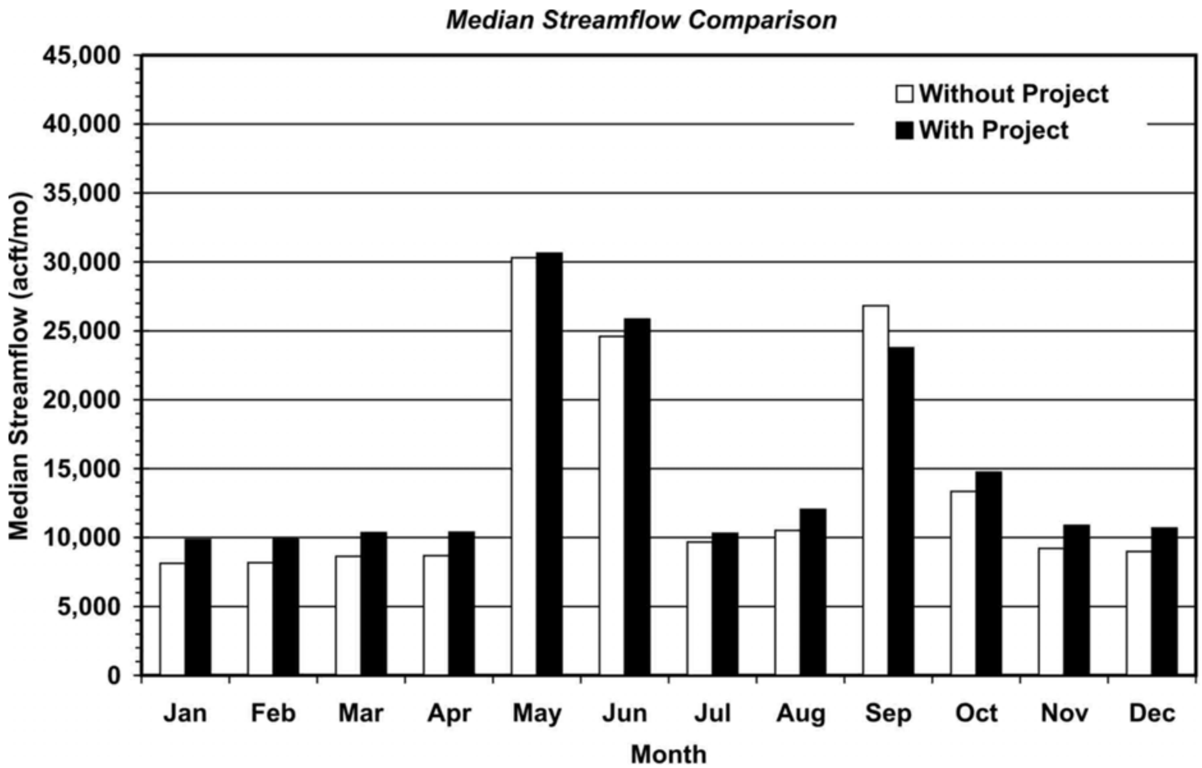
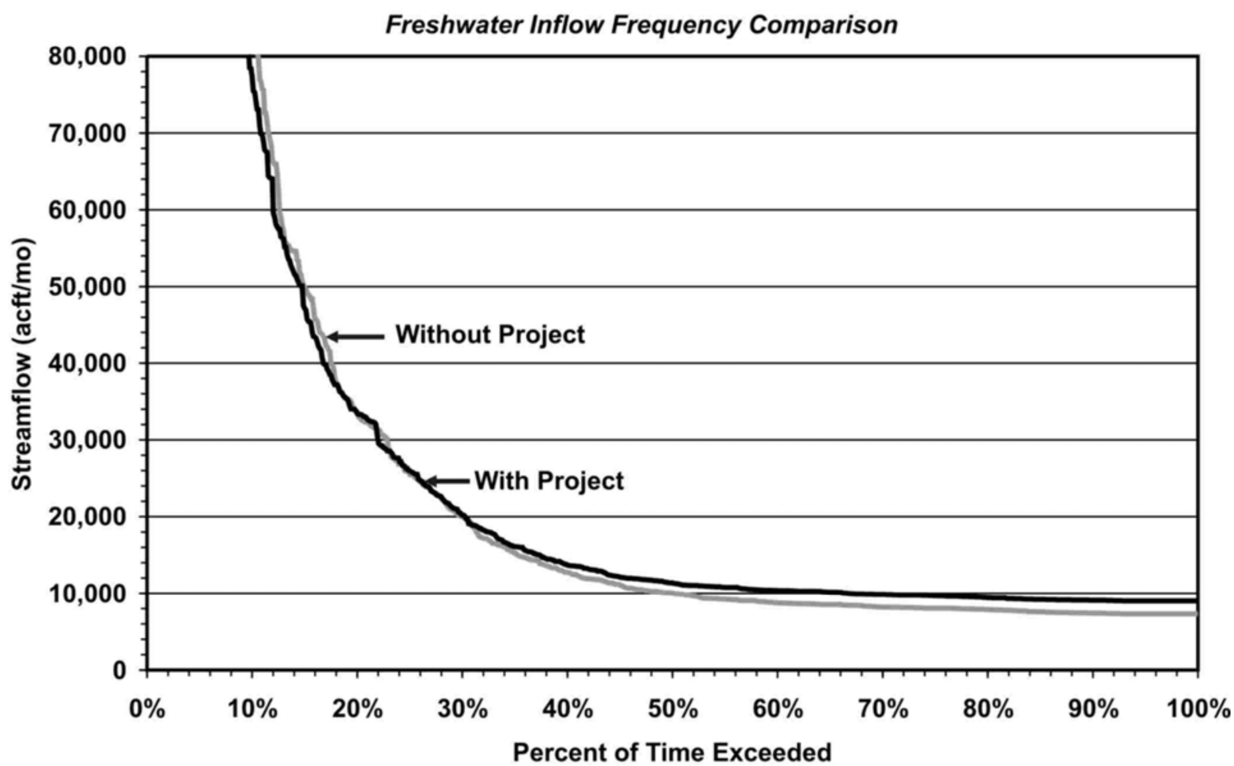


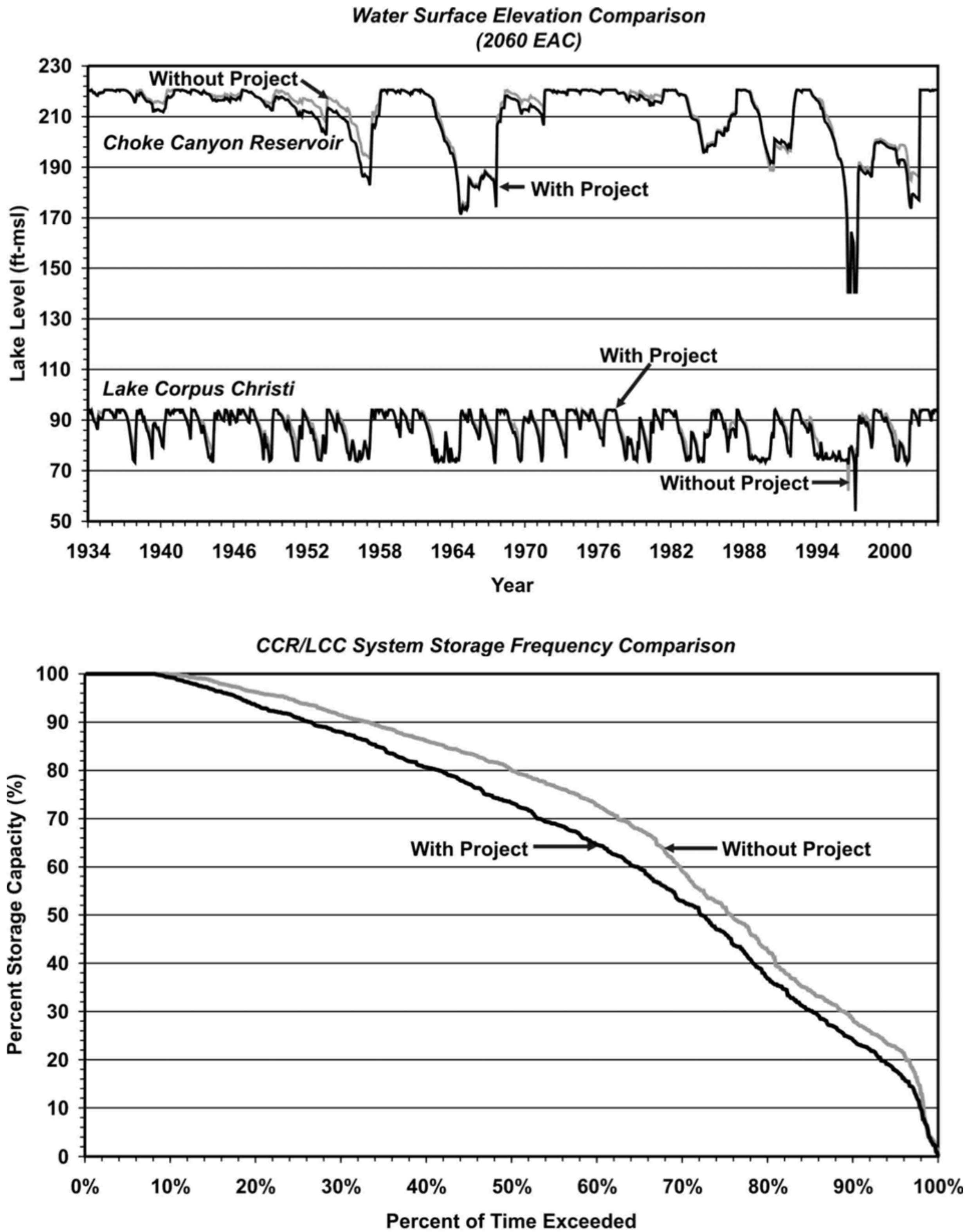
Figure 4C.10-3. Project Impacts on Streamflow, Nueces River at Mathis





Results based on Phase IV operating policy, 2060 sediment conditions, the 2001 Agreed Order, 300 cfs pipeline delivery rate, and a demand of 168,500 acft/yr without project and 208,000 acft/yr with CCR/LCC Pipeline.

Figure 4C.10-4. Project Impacts on Freshwater Inflows into Nueces Estuary



Results based on Phase IV operating policy, 2060 sediment conditions, the 2001 Agreed Order, 300 cfs pipeline delivery rate, and a demand of 168,500 acft/yr without project and 208,000 acft/yr with CCR/LCC Pipeline.

Figure 4C.10-5. Project Impacts on Choke Canyon Reservoir and Lake Corpus Christi

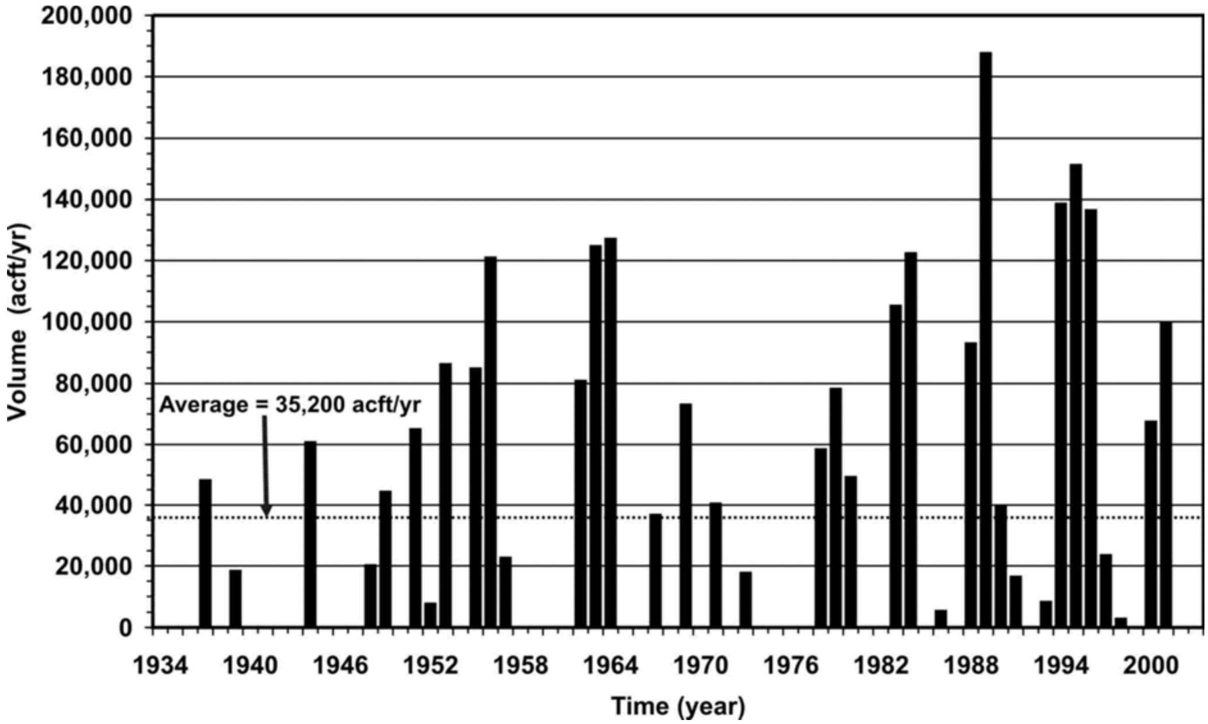


Figure 4C.10-6. Volume Pumped through LCC-CCR Pipeline (acft/yr) for 300 cfs Pipeline

4C.10.4 Engineering and Costing

Table 4C.10-3 provides a summary of the estimated costs to implement a one-way pipeline from CCR to LCC. The pipeline operation is most cost effective at the 300 cfs delivery rate, with annual costs equal to $222 per acft. This annual cost includes a reserve fund for additional pumping energy costs based on a 3-year maximum, which occurred in the model simulations from 1994 to 1996. Cost could potentially be reduced through Federal participation as may be available through the USCOE Nueces River Basin Feasibility Study.

4C.10.5 Implementation Issues

The primary implementation issue that would need to be addressed with this pipeline alternative would be the impact of the reduced flows in the Nueces River downstream of CCR. An evaluation of the impacts of reduced flows on the river habitat should be undertaken to fully investigate the consequences of implementing this alternative. In addition, the TCEQ permits may need to be amended depending on changes in locations of diversions. Additionally, before a

Table 4C.10-3.
Cost Estimate Summary for
Pipeline Linking CCR and LCC (300 cfs)
(Second Quarter 2002 Prices)

Item	***Estimated Costs for Facilities***
Capital Costs	
Intake and Pump Station (194 MGD)	$13,811,000
Transmission Pipeline (96 in dia., 23 miles)	58,023,000
Relocations & Other	174,000
Total Capital Cost	**$72,008,000**
Engineering, Legal Costs and Contingencies	$22,302,000
Environmental & Archaeology Studies and Mitigation	585,000
Land Acquisition and Surveying (115 acres)	1,086,000
Interest During Construction (1.5 years)	5,759,000
Reserve Fund (additional pumping energy costs for maximum 3 years)	3,688,000
Total Project Cost	**$105,428,000**
Annual Costs	
Debt Service (6 percent, 30 years)	$7,659,000
Operation and Maintenance	
Intake, Pipeline, Pump Station	926,000
Pumping Energy Costs (3320165.66471607 kWh @ 0.06 $/kWh)	199,000
Total Annual Cost	**$8,784,000**
Available 2060 Project Yield (acft/yr)	**39,500**
Annual Cost of Water ($ per acft)	**$222**
Annual Cost of Water ($ per 1,000 gallons)	**$0.68**

significant expenditure of funds would be considered for either of these alternatives, detailed long-term investigations of channel losses should be undertaken to fully understand the seasonality and variability of channel losses that occur, particularly between Three Rivers and LCC. In order to better quantify the channel losses in this reach, the City is currently working with the U.S. Geological Survey (USGS) and has installed a new gage just upstream of LCC.

Requirements Specific to Pipelines:

1. Necessary Permits:
   - USCOE Sections 10 and 404 dredge and fill permits for stream crossings.
   - GLO Sand and Gravel Removal permits.
   - Coastal Coordinating Council review.
   - TPWD Sand, Gravel, and Marl permit for river crossings.
   - Cultural Resource Survey as required by Texas Antiquities Commission.
2. Right-of-way and easement acquisition.
3. Crossings:
   - Highways and railroads.
   - Creeks and rivers.
   - Other utilities.

4C.10.6 Evaluation Summary

An evaluation summary of this regional water management option is provided in Table 4C.10-4.

Table 4C.10-4.
Evaluation Summary for Pipeline between
Choke Canyon Reservoir and Lake Corpus Christi

Impact Category	*Comment(s)*
a. Water supply: 1. Quantity 2. Reliability 3. Cost of treated water	 1. Firm Yield: 30,200 to 42,200 acft/yr 2. Good reliability. 3. Generally low cost; between $210 to $258 per acft
b. Environmental factors: 1. Instream flows 2. Bay and estuary inflows 3. Wildlife habitat 4. Wetlands 5. Threatened and endangered species 6. Cultural resources 7. Water quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. Reduction in streamflows between Choke Canyon Reservoir and Lake Corpus Christi 2. Increase in streamflows below Lake Corpus Christi and freshwater inflows to Nueces Estuary. 3. Low impact to wildlife habitat. 4. Low impact to wetlands. 5. Low impact to threatened and endangered species. 6. Cultural Resource Survey needed to avoid impacts. 7. Low impact to water quality. 7a-b. Will improve dissolved solids and salinity levels at CCR by reducing evaporation from reservoir.
c. State water resources	• No negative impacts on other water resources
d. Threats to agriculture and natural resources in region	• None
e. Recreational	• None
f. Equitable comparison of strategies	• Standard analyses and methods used
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Reduces losses in the CCR/LCC System
j. Effect on navigation	• None

4C.11 Off-Channel Reservoir near Lake Corpus Christi (N-11)

4C.11.1 Description of Strategy

Choke Canyon Reservoir (CCR) has a storage capacity of approximately 695,000 acft and a contributing drainage of approximately 5,500 square miles. Lake Corpus Christi (LCC) has a storage capacity of approximately 257,000 acft and a contributing drainage of approximately 16,500 square miles. This configuration creates a situation where the smallest reservoir has the largest potential for capturing storm events because of the larger contributing drainage area.

The yield of the system is affected by the limited storage capacity of LCC and its limited ability to capture a majority of the storm events that travel down the Nueces River. Since LCC has the smaller capacity, many times it fills and spills flow to the bay when there is available storage in CCR. However, if water could be pumped into an off-channel reservoir (OCR), it would result in more water in storage and enhance the system yield.

The modeling analysis that was utilized in evaluating this option, and all other water management strategies of the Lower Nueces River Basin, has embedded logic that applies strict application of the prior appropriation doctrine to ensure that senior water rights are protected in all scenarios.

The OCR site and pipeline route between LCC and the OCR is shown in Figure 4C.11-1. The reservoir is located near the upper western section of LCC. The OCR will require an intake and pump station at LCC to pump available water from LCC. The off-channel reservoir operating conjunctively with CCR/LCC pipeline was also evaluated.

4C.11.2 Available Yield

Yield analyses for this alternative were performed to meet the following objectives:

- Establish reasonable reservoir levels for operating the pump station to fill the OCR and also to then release water from the OCR back to LCC;
- Determine the pumping rate to the OCR that will provide the greatest yield increase at reasonable unit costs; and
- Determine the size of the OCR that will provide the greatest yield increase at reasonable unit costs.

Simulations were made for the historical period from 1934 to 2003 using the City of Corpus Christi's Phase IV Operations Plan, the 2001 TCEQ Agreed Order, and 2010 reservoir sedimentation conditions. These simulations were performed using an updated version of the

City of Corpus Christi's Lower Nueces River Basin and Estuary (NUBAY) Model that includes the capability to simulate the OCR. After the optimum reservoir levels and delivery rates were obtained for the 2010 sediment conditions, they were analyzed at 2060 reservoir sediment conditions. The operating guidelines for both reservoirs and the pipeline are detailed below.

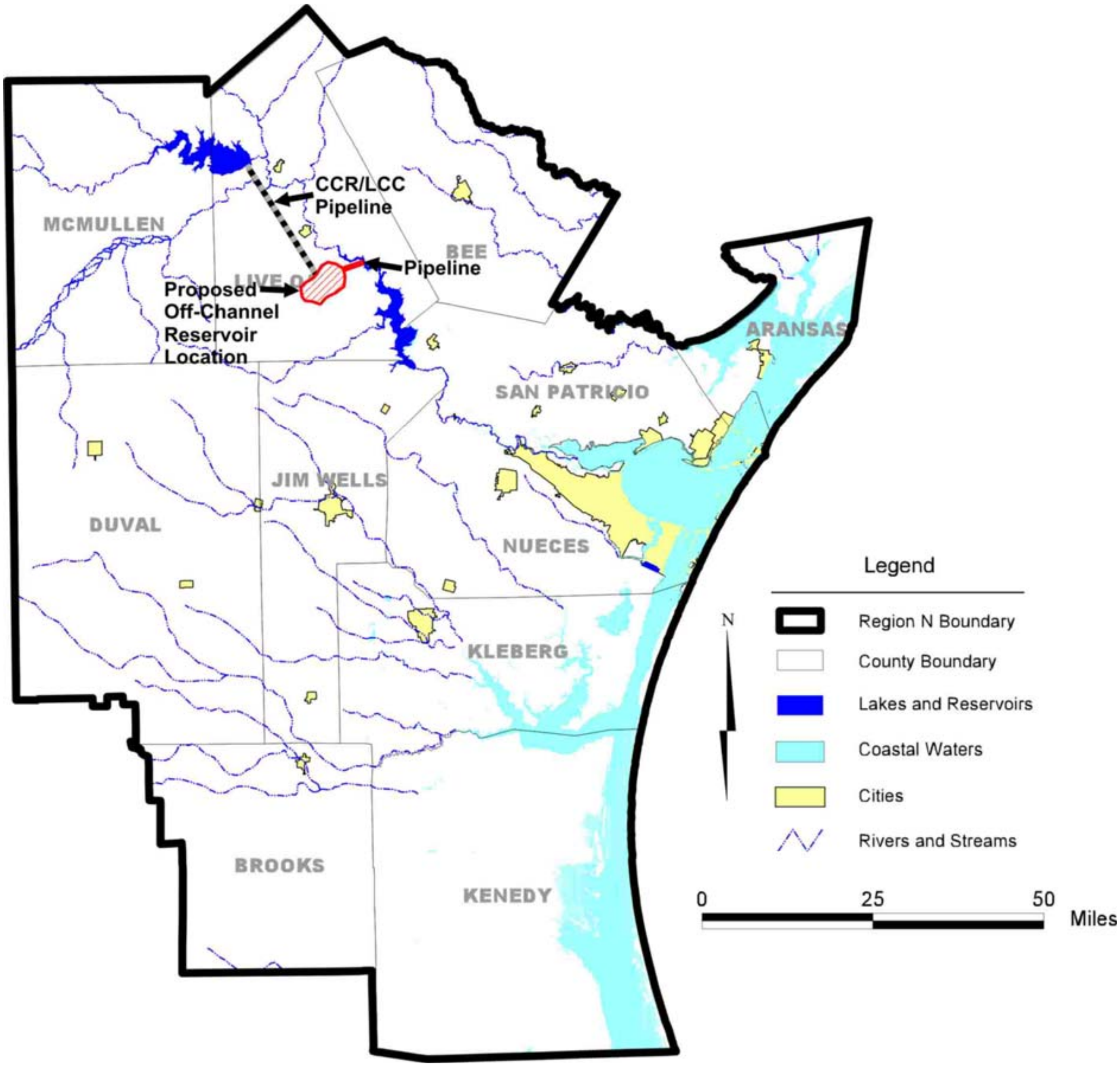


Figure 4C.11-1 Off-Channel Reservoir and Pipeline to Lake Corpus Christi

Operational parameters for the reservoir and pipeline operations at the OCR were developed to identify the optimum set of LCC elevation triggers, pipeline capacity and OCR storage capacity. After several combinations were evaluated, the OCR, CCR and LCC were operated in the following manner:

1. LCC would attempt to fill the OCR, up to the capacity of the pump station and pipeline, anytime the elevation in LCC was 93 ft-msl or greater and storage was available in the OCR.
2. The OCR would release to LCC anytime the elevation in LCC was less than or equal to 80 ft-msl.
3. Releases from CCR were triggered when LCC elevation level was less than or equal to 74 ft-msl.

The optimization analysis included looking at four different storage capacities for the OCR, and four different pump station and pipeline capacities. This analysis also included looking at four different LCC target levels for diverting water into the OCR, and four different target levels for releasing water from the OCR to LCC.

The four different storage capacities ranged from 100,000 acft to 400,000 acft. The most favorable capacity with respect to yield and cost for this analysis was the 200,000 acft capacity.

Table 4C.11-1 shows yields and costs for the potential OCR capacities and pipeline delivery rates for 2010 reservoir sedimentation conditions. The 750-cfs delivery rate in conjunction with a 200,000 acft reservoir results in the preferred option when unit cost and additional yield are taken into consideration.

Table 4C.11-1.
Summary of Yield and Costs for
Off-Channel Reservoir and Pipeline Linking Off-Channel Reservoir and
Lake Corpus Christi for 2010 Sediment Conditions

Pipeline Delivery Rate (cfs)	*Off-Channel Capacity (acft)*	*2010 Firm Yield[1] (acft/yr)*	*2010 Yield Increase (acft/yr)*	*Annual Cost ($ Million)*	*Cost per acft ($/acft/yr)*	*Incremental Unit Costs[2] ($/acft/yr)*
500	100,000	193,000	18,800	$7.86	$418	—
750	200,000	206,000	31,800	$12.65	$398	$369
1,500	300,000	222,400	48,200	$20.86	$433	$500
2,000	400,000	230,400	56,200	$28.32	$504	$933

[1] Baseline yield without project under phase IV operations policy, 2010 sediment conditions, and the 2001 Agreed Order equals 174,200 acft/yr.

[2] Incremental costs were calculated as the difference in Annual Cost ($ Million) between options divided by the difference in yield between options. Incremental unit costs were used to determine the optimal pipeline delivery rate that would provide additional water supply at a reasonable cost.

Table 4C.11-2 shows the yields for both 2010 and 2060 reservoir sediment conditions. Comparison of unit cost for 2060 sediment conditions shows that the delivery rate of 750 cfs and

OCR capacity of 200,000 acft produces the optimum unit cost of water for the project for the sizes and rates studied. A detailed cost analysis for the 200,000 acft with a 750-cfs delivery rate is presented in Section 4C.11.4. Further analysis could indicate that the true optimum capacity is somewhere between 200,000 and 300,000 acft.

Table 4C.11-2.
Summary of Yield Increases for both 2010 and 2060 Sediment Conditions and 2060 Unit Costs for Off-Channel Reservoir Project

Pipeline Delivery Rate (cfs)	Off-Channel Capacity	2010		2060		Approximate 2060 Unit Cost ($ per acft/yr)	Approximate 2060 Incremental Unit Costs[2] ($ per acft/yr)
		Firm Yield[1] (acft/yr)	Increase in Firm Yield Due to Pipeline	Firm Yield[1] (acft/yr)	Increase in Firm Yield Due to Pipeline		
0	—	174,200	—	168,500	—		
500	100,000	193,000	18,800	187,400	18,900	$416	—
750	200,000	206,000	31,800	202,900	34,400	$368	$309
1,500	300,000	222,400	48,200	218,300	49,800	$419	$533
2,000	400,000	230,400	56,200	225,600	57,100	$496	$1,022

1 Baseline firm yield of CCR/LCC System (without Texana water) calculated under phase IV operations policy, the 2001 Agreed Order, and 2010 or 2060 sedimentation conditions.

2 Incremental costs were calculated as the difference in Annual Cost ($ Million) between options divided by the difference in yield between options. Incremental unit costs were used to determine the optimal pipeline delivery rate that would provide additional water supply at a reasonable cost.

4C.11.2.1 Available Yield when Combined with CCR/LCC Pipeline

An additional analysis was completed that looked at operating the optimum OCR project with the optimum CCR/LCC pipeline project. The CCR/LCC pipeline would increase system yield by alleviating some of the channel losses incurred below CCR and above LCC. The OCR would create additional storage that would allow the system to take advantage of the large watershed of LCC. When combined and simulated in the updated NUBAY Model, the yield of the system is increased by 67,700 acft/yr (or 92 percent of the combined individual yields), at an average unit cost of $316/acft.

4C.11.3 Environmental Issues

Environmental issues related to transferring water by pipeline from OCR to LCC and construction of an off-channel reservoir can be categorized as follows:

- Effects related to pipeline construction and maintenance;[1]
- Effects related to off-channel reservoir construction and maintenance, and
- Effects resulting from changes in Nueces River flows, including inflows to the Nueces Estuary.
- Effects related to inundating approximately 5,000 acres for the OCR.

The proposed pipeline corridor would be within Live Oak County. The construction of a pipeline from the OCR to LCC would result in soil and vegetation disturbance within the approximately 60-acre pipeline construction corridor. Longer-term terrestrial impacts would be confined to the 20-acre maintained right-of-way, and the approximately 5,000 acres that would be inundated by construction of the OCR. In Live Oak County, the jaguarundi (*Felis yagouaroundi*), listed as endangered, has been reported to occur within the proposed project site and habitat for several state-protected species may be present. The ocelot (*Felis pardalis*), listed as endangered, has been reported in Live Oak County and studies of cats have been done along Highway 281.[2] Temporarily wet areas or drainages in uplands and in wetland portions of the project may provide habitat for several state-protected amphibians. The black-spotted newt (*Notophthalmus meridionalis*) and Rio Grande lesser siren (*Siren intermedia texana*) are found in wet or temporally wet arroyos, canals, ditches, or shall depressions. During dry periods, they aestivate underground. The sheep frog (*Hypopachus variolosus*) inhabits wet areas and freshwater marshes in the Rio Grande Valley, lower South Texas Plains, and Southern Coastal Prairie. The Mathis spiderling (*Boerhavia mathisiana*) was a possibly extinct plant that has been proposed for protection to USFWS. It inhabits open thorn shrublands with shallow sandy to gravely soils over limestone or on bare limestone or caliche outcrops. The Mathis spiderling was once found in the vicinity of LCC in San Patricio County.

Several sites on or eligible for inclusion on the National Register of Historic Places are known from the vicinity of the project, and other types of cultural resource sites may be present, although none are known to be located within the project vicinity.

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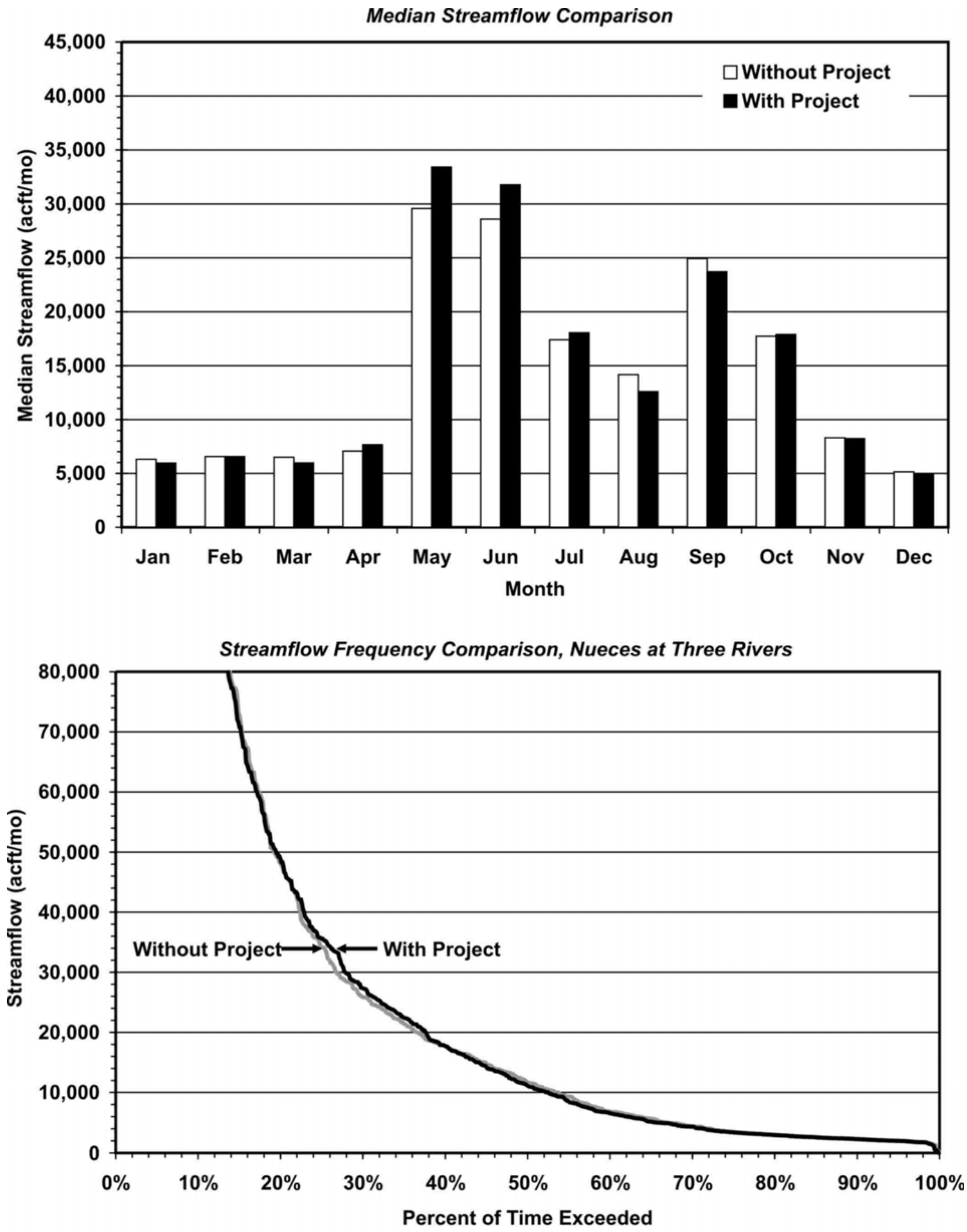
[1] Ibid.
[2] French, J., RWPG meeting, February 2005.

The presently required maintenance releases of 2,000 acft/month from CCR are continued in the simulation with OCR. Use of the OCR project does not significantly change river flows between CCR and LCC, as shown in the top plot of Figure 4C.11-2 for the 750-cfs delivery with 200,000 acft OCR option. The bottom plot of Figure 4C.11-2 shows the streamflow frequency at Three Rivers with and without the project. More noticeable flow changes occur below LCC at Mathis, where during typical flow conditions river flows are increased with the OCR, as shown in Figure 4C.11-3. The increases in flow result from the additional yield in the CCR/LCC System being delivered through the Nueces River. During high flow events, river flows are reduced and the OCR stores water which helps to mitigate flood events. Figure 4C.11-4 displays the monthly median streamflows and the streamflow frequency for Nueces Estuary inflows. The annual inflows to the Nueces Estuary, which include returned flows, are increased on average by 10,300 acft/yr, for years with annual flows less than 190,000 acft/yr.

The updated model uses the 2001 TCEQ Agreed Order guidelines for setting the monthly targets for the bay and estuary inflows. Implementation of the project will impact reservoir levels in both CCR and LCC. Figure 4C.11-5 displays plots of water surface elevation versus time for each reservoir and a system storage frequency comparison. Figure 4C.11-6 shows the amount of water, on an annual basis, that was pumped from LCC to off-channel storage and the annual amount of water delivered from off-channel to LCC. The average annual difference of 5,800 acft/yr is due to evaporation losses.

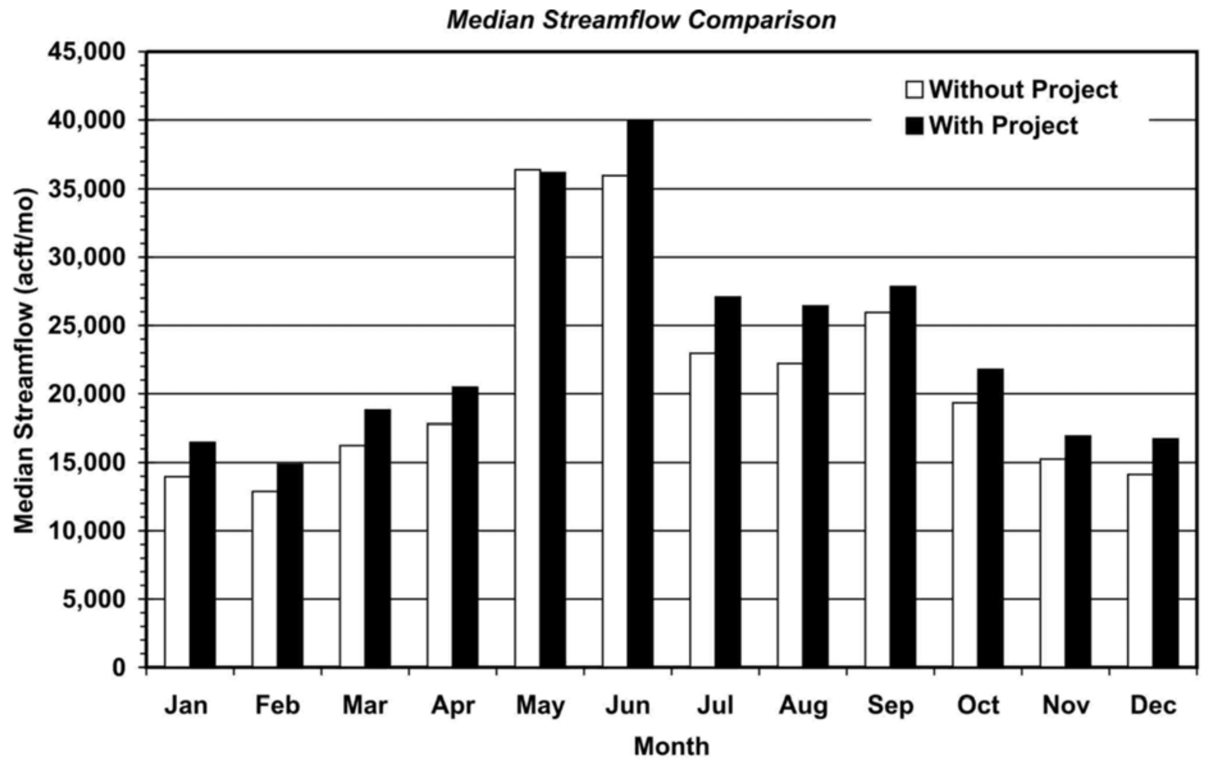
4C.11.4 Engineering and Costing

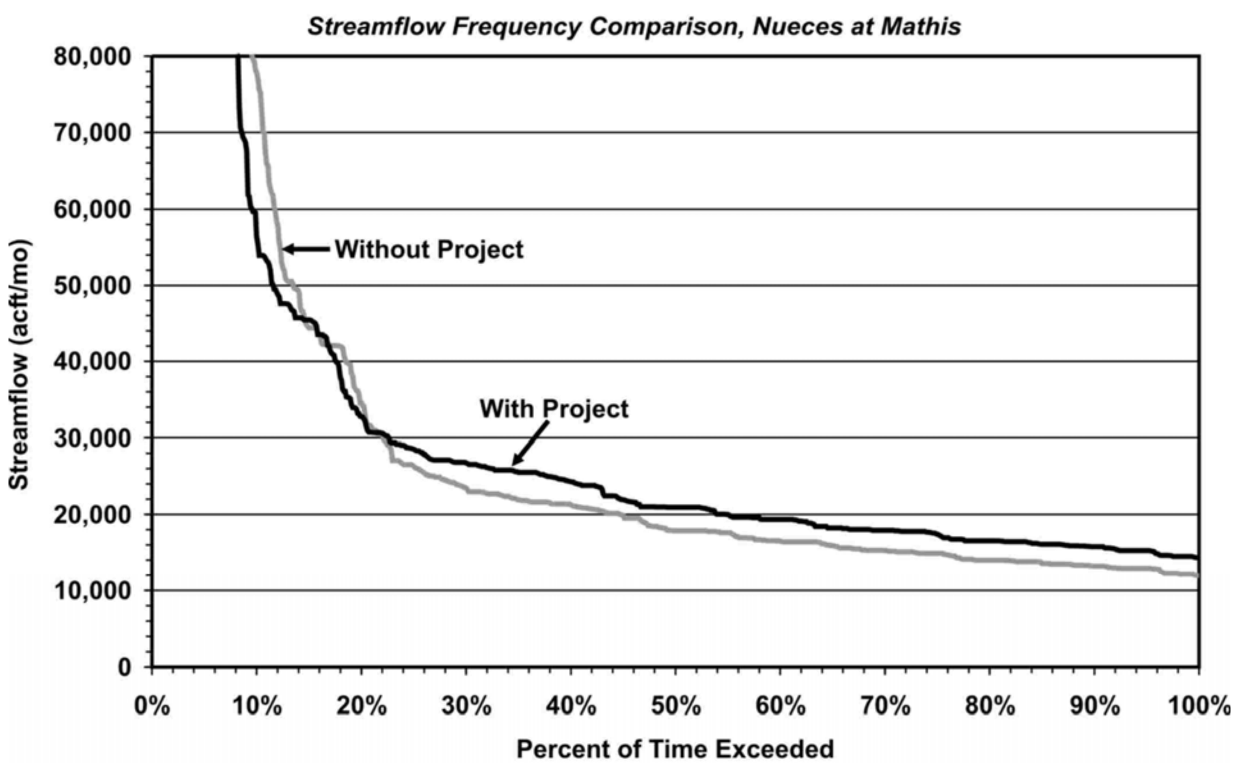
Table 4C.11-3 provides detailed summaries of the estimated costs to implement the OCR project and pipeline between the OCR and LCC. The project operation is most cost effective at the 750 cfs delivery rate, 200,000 acft capacity for the OCR with annual costs equal to $372 per acft. This annual cost includes a fund for pumping energy costs that would be required to initially fill the OCR. This project requires a transmission pipeline and an intake and an outfall in the OCR and in LCC. Cost could potentially be reduced through Federal participation, as may be available through the USCOE Nueces River Basin Feasibility Study.



Results based on Phase IV operating policy, 2060 sediment conditions, the 2001 Agreed Order, 750 cfs pipeline delivery rate, 200,000 acft reservoir, and demand of 168,500 acft/yr without project and 202,500 acft/yr with off-channel reservoir.

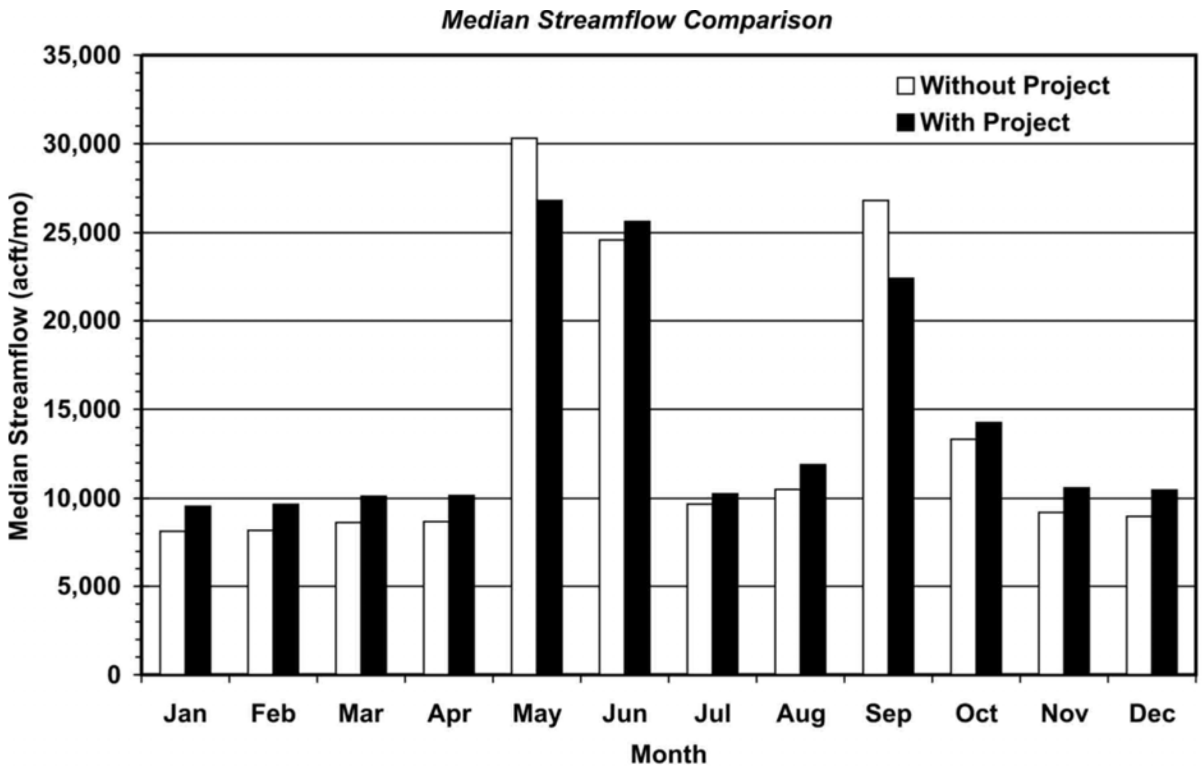
Figure 4C.11-2. Project Impacts on Streamflow, Nueces River at Three Rivers

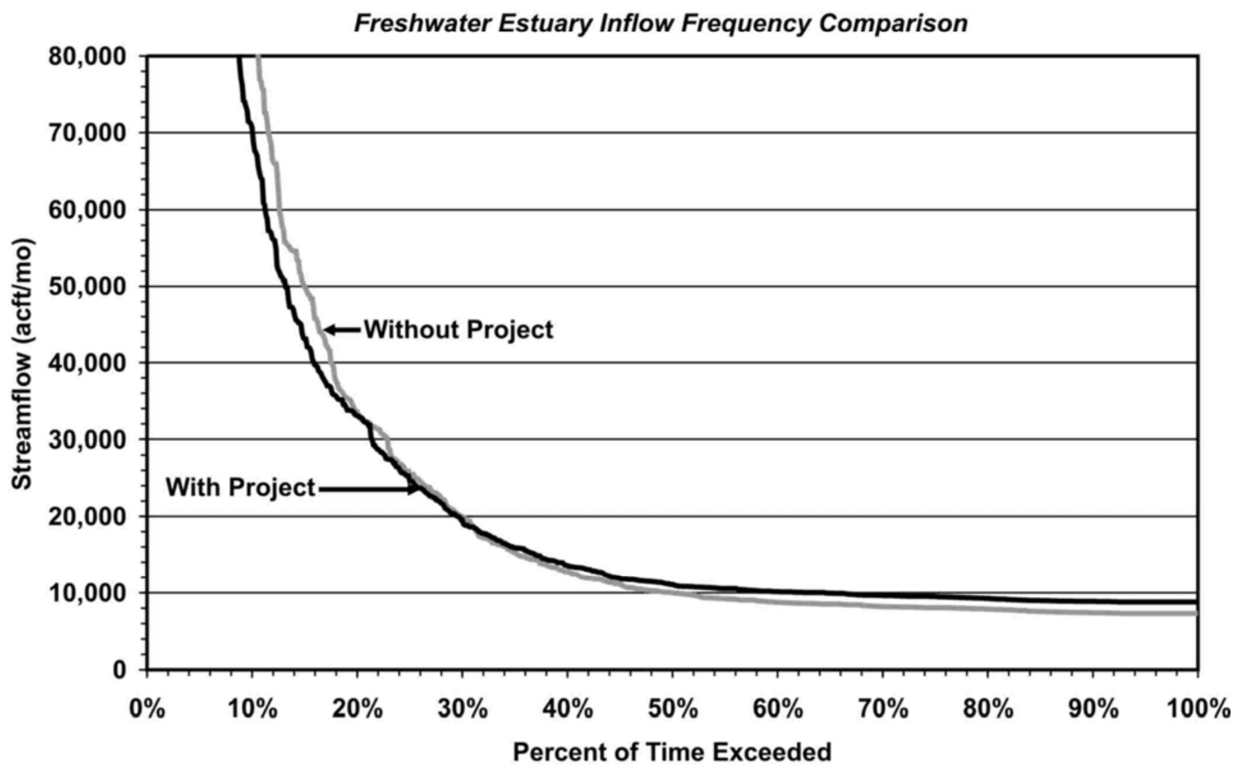




Results based on Phase IV operating policy, 2060 sediment conditions, the 2001 Agreed Order, 750 cfs pipeline delivery rate, 200,000 acft reservoir, and demand of 168,500 acft/yr without project and 202,500 acft/yr with off-channel reservoir.

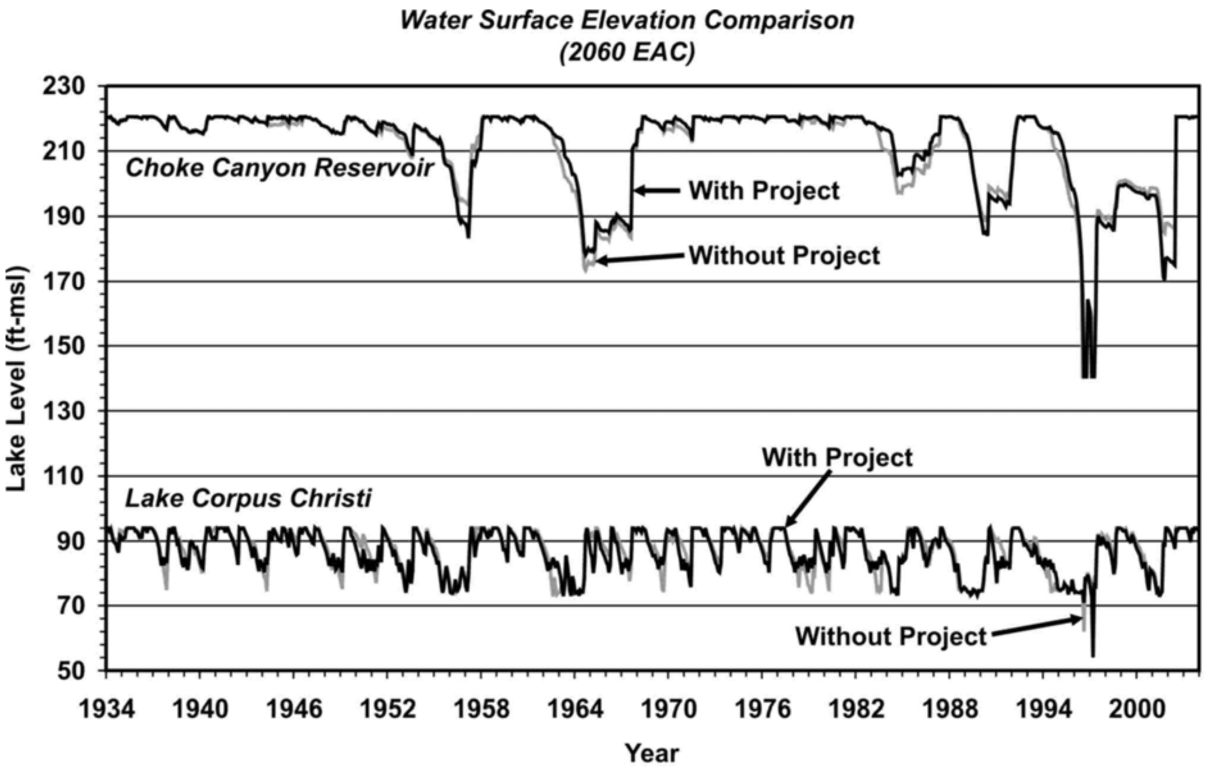
Figure 4C.11-3. Project Impacts on Streamflow, Nueces River at Mathis

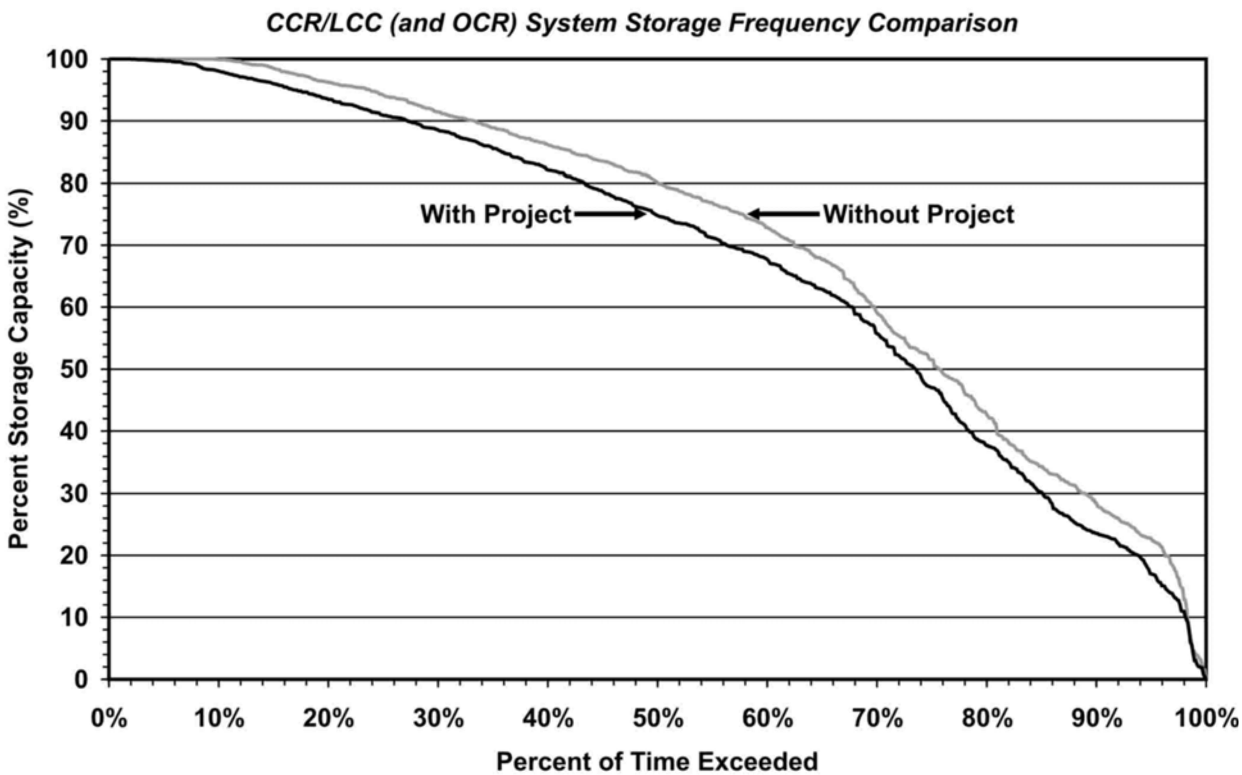




Results based on Phase IV operating policy, 2060 sediment conditions, the 2001 Agreed Order, 750 cfs pipeline delivery rate, 200,000 acft reservoir, and demand of 168,500 acft/yr without project and 202,500 acft/yr with off-channel reservoir.

Figure 4C.11-4. Project Impacts on Freshwater Inflows into Nueces Estuary





Results based on Phase IV operating policy, 2060 sediment conditions, the 2001 Agreed Order, 750 cfs pipeline delivery rate, 200,000 acft reservoir, and demand of 168,500 acft/yr without project and 202,500 acft/yr with off-channel reservoir.

Figure 4C.11-5. Project Impacts on Choke Canyon Reservoir and Lake Corpus Christi

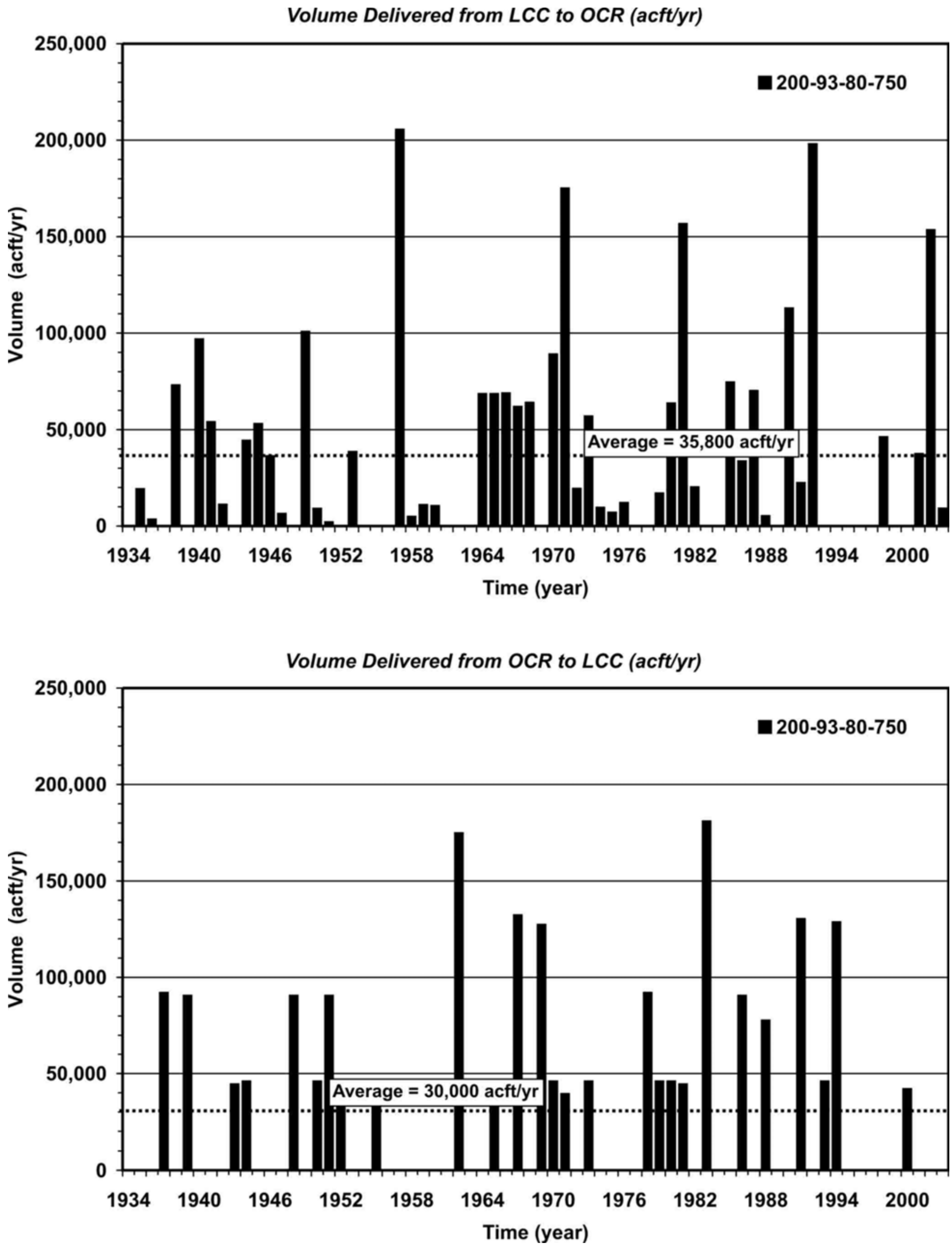


Figure 4C.11-6. Summary of Water Pumped

Table 4C.11-3.
Cost Estimate Summary for
Off-Channel Reservoir (200,000 acft) and Pipeline (750 cfs)
(Second Quarter 2002 Prices)

Item	***Estimated Costs for Facilities***
Capital Costs	
Dam and Reservoir (Conservation Pool 200,000 acft, 4,688 acres, 265 ft-msl)	$56,495,000
Intake and Pump Station (484 MGD)	23,407,000
Transmission Pipeline (108-inch dia., 3 miles)	12,160,000
Total Capital Cost	**$92,062,000**
Engineering, Legal Costs and Contingencies	$31,614,000
Environmental & Archaeology Studies and Mitigation	5,281,000
Land Acquisition and Surveying (4704 acres)	5,575,000
Interest During Construction (4 years)	17,898,000
Initial Filling of Reservoir	2,598,000
Total Project Cost	**$155,028,000**
Annual Costs	
Debt Service (6 percent, 30 years)	$3,924,000
Reservoir Debt Service (6 percent, 40 years)	6,713,000
Operation and Maintenance	
Intake, Pipeline, Pump Station	707,000
Dam and Reservoir	847,000
Pumping Energy Costs (7663925.05502069 kWh @ 0.06 $/kWh)	460,000
Total Annual Cost	**$12,651,000**
Available Project Yield (acft/yr)	**34,000**
Annual Cost of Water ($ per acft)	**$372**
Annual Cost of Water ($ per 1,000 gallons)	**$1.14**

4C.11.5 Implementation Issues

The primary implementation issue that would need to be addressed with this project alternative would be the impact of the inundated area of the OCR. A detailed evaluation of the impacts of this inundated area and its habitat would have to be undertaken to fully investigate the consequences of implementing this alternative. In addition, the TCEQ permits will need to be amended to obtain the right to impound additional water in the OCR. Additionally, before a significant expenditure of funds would be considered for either of these alternatives, detailed investigations of the possibility of seepage from the off-channel reservoir into the surrounding Gulf Coast Aquifer should be undertaken to fully understand the impact on the project.

Requirements Specific to Pipelines:

1. Necessary Permits:
   - U.S. Army Corps of Engineers Sections 10 and 404 dredge and fill permits for stream crossings.
   - General Land Office Sand and Gravel Removal permits.
   - Coastal Coordinating Council review.
   - Texas Parks and Wildlife Department Sand, Gravel, and Marl permit for river crossings.
   - Cultural Resource Survey as required by Texas Antiquities Commission.
2. Right-of-way and easement acquisition.
3. Crossings:
   - Highways and railroads.
   - Creeks and rivers.
   - Other utilities.

4C.11.6 Evaluation Summary

An evaluation summary of this regional water management option is provided in Table 4C.11-4.

Table 4C.11-4.
Evaluation Summary for Pipeline between
Choke Canyon Reservoir and Lake Corpus Christi

Impact Category	***Comment(s)***
a. Water supply:	
1. Quantity	1. Firm Yield: 19,000 to 57,000 acft/yr
2. Reliability	2. Good reliability.
3. Cost of treated water	3. Generally low cost; between $372 to $497 per acft
b. Environmental factors:	
1. Instream flows	1. Generally increases streamflows below Lake Corpus Christi.
2. Bay and estuary inflows	2. Increase freshwater inflows to Nueces Estuary.
3. Wildlife habitat	3. Some impact to wildlife habitat. Inundated land area for off-channel reservoir.
4. Wetlands	4. Low impact to wetlands.
5. Threatened and endangered species	5. Low impact to threatened and endangered species.
6. Cultural resources	6. Cultural Resource Survey needed to avoid impacts.
7. Water quality	7. Low impact to water quality.
a. dissolved solids	
b. salinity	
c. bacteria	
d. chlorides	
e. bromide	
f. sulfate	
g. uranium	
h. arsenic	
i. other water quality constituents	
c. State water resources	• No negative impacts on other water resources
d. Threats to agriculture and natural resources in region	• None
e. Recreational	• None
f. Equitable comparison of strategies	• Standard analyses and methods used
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Maximizes opportunities to capture water from a large drainage area.
j. Effect on navigation	• None

4C.12 Voluntary Redistribution of Available Supplies and U.S. Army Corps of Engineers Nueces Feasibility Studies (N-12)

4C.12.1 Description of Strategy

In order to increase available supply, this option evaluates opportunities to reallocate surface water through utilization of unused supply and sales of existing water rights; and the potential trading/transfer of surface water with the South Central Texas Regional Water Planning Area including consideration of the Corps of Engineers Nueces River Basin Feasibility studies.

4C.12.2 Available Yield

4C.12.2.1 Utilization of Unused City of Three Rivers' Supply

Of the 215,843 acft of surface water in 2060 available in the region, the City of Corpus Christi directly or indirectly supplies 93 percent of the total. The City has a contract with the City of Three Rivers to supply up to 3,363 acft/yr. This water is provided out of CCR/LCC System and constitutes Three Rivers' 2-percent stake in the CCR/LCC System. Three Rivers has the ability to purchase an additional 2,240 acft/yr without a renegotiation of the existing contract. The City of Three Rivers also holds run-of-river rights in the Nueces Basin for municipal uses at 700 acft, which is available for delivery on a firm yield basis. The supply listed in Section 4 (Table 4-16) reflects the 4,063 acft, including the 3,363-acft contract amount and 700 acft from Nueces Basin permit. Three Rivers municipal demands range from 425 acft in 2000 to 399 acft in 2060. In January 2004, the City of Three Rivers acquired Choke Canyon Water Supply Corporation (WSC). Choke Canyon WSC has a maximum water demand of 477 acft (in 2030) distributed between Live Oak and McMullen Counties. They receive between 40 and 50 percent of their water supplies from groundwater, with the remaining amount supplied by the City of Three Rivers.

There is also a significant projected manufacturing demand in the City of Three Rivers, which increases each decade to a maximum of 2,194 acft in 2060. Three Rivers has a run-of-river water permit in the Nueces Basin amounting to 800 acft for industrial uses, which is available for firm yield delivery. Based on 2010 water demand projections for the City of Three Rivers, 3,353 acft of Three Rivers' contract could be made available to other entities, including local industries. In 2060, up to 3,463 acft could be made available to other entities, including local industries. An evaluation summary of the utilization of unused surface water is presented in Table 4C.12-1.

Table 4C.12-1.
Evaluation Summary of
the Utilization of Unused Surface Water

Impact Category	*Comment(s)*
a. Water Supply	
1. Quantity	1. Firm yield: Reallocation of up to 3,463 acft CCR/LCC System firm yield
2. Reliability	2. Good reliability
3. Cost of treated water	3. Cost: Not applicable
b. Environmental factors:	
1. Instream flows	1. Negligible. Utilization of surface water supplies that would not otherwise be used may have a minimal to low impact on downstream flows.
2. Bay and estuary inflows	2. No impacts.
3. Wildlife habitat	3. No impacts.
4. Wetlands	4. No impacts.
5. Threatened and endangered species	5. No impacts.
6. Cultural resources	6. No impacts.
7. Water quality	7. No change to water quality.
a. dissolved solids	
b. salinity	
c. bacteria	
d. chlorides	
e. bromide	
f. sulfate	
g. uranium	
h. arsenic	
i. other water quality constituents	
c. State water resources	• No impacts
d. Threats to agriculture and natural resources in region	• No impacts
e. Recreational	• No impacts
f. Equitable comparison of strategies	• Standard analyses and methods used
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• None
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None

4C.12.2.2 Use or Purchase of Underutilized Nueces County WCID #3 Water Right

Nueces County WCID #3 (the District) has two municipal water rights and two irrigation water rights which authorize a total diversion of 11,546 acft/yr. For the purposes of the following analysis, it is assumed that the irrigation permits can be amended for any use. Two of the diversions (one municipal, one irrigation) have a priority date of February 7, 1909 (senior to Corpus Christi), the other two (one municipal, one irrigation) have a priority date of January 28, 1925 (junior to Corpus Christi). The Nueces River Basin water availability model (TCEQ's WRAP model), shows a minimum annual firm yield diversion of 7,103 acft/yr for the District.

The irrigation demands for Nueces County total 1,449 acft in 2010 and decrease to 692 acft by 2060. Surface water supplies for Nueces County irrigation are provided by Nueces County WCID #3, Nueces-Rio Grande Coastal Basin, and a City of Corpus Christi irrigation water permit. The irrigation demand placed on the District is 109 acft in 2060.[1]

The municipal demands placed on the District by their customers—City of North San Pedro, City of Robstown, and River Acres WSC— total 2,399 acft in 2060. This results in a total 2060 surplus of 4,595 acft. Assuming the same proportion to total water right diversion, a purchase of 7,469 acft water right would have an approximate firm yield of 4,595 acft.

For this surplus to be fully utilized, three options are available. One is for the District to increase its water contract with River Acres WSC to meet their current and projected needs, which shows a shortage of 590 acft in 2060. Another option is for the District to expand its existing distribution system to serve the County-Other population, provided County-Other users fall within service area boundaries of the District. The last option is for the City of Corpus Christi or other wholesale water providers to purchase the unutilized 4,595 acft/yr of firm water and make it available to meet manufacturing or mining needs of the region. At $505/acft,[2] the one-time purchase price of 7,469 acft is $3,771,845. Annual cost for 30 years is $274,000. With 4,595 acft in availability, cost per acft per year is $60. An evaluation summary for this option is presented in Table 4C.12-2.

[1] Assumes full utilization of Nueces Rio Grande Coastal Basin and City of Corpus Christi firm yields.
[2] Purchase price is based on estimated cost of Garwood project, with $225 for treatment (see Table ES-3).

Table 4C.12-2.
Evaluation Summary of
Use/Purchase of Nueces County WCID #3 Water Right

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost of treated water	 1. Firm yield: 4,704 acft 2. Good reliability 3. Costs: • Nueces County WCID #3: costs of additional distribution system • If purchased by others, $58 acft/yr for purchase of water right plus costs of distribution
b. Environmental factors: 1. Instream flows 2. Bay and estuary inflows 3. Wildlife habitat 4. Wetlands 5. Threatened and endangered species 6. Cultural resources 7. Water quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. Negligible. Utilization of surface water supplies that would not otherwise be used may have a minimal to low impact on downstream flows. 2. No impacts. 3. No impacts. 4. No impacts. 5. No impacts. 6. No impacts. 7. No change to water quality.
c. Impacts to State water resources	• No impacts
d. Threats to agriculture and natural resources in region	• No impacts
e. Recreational impacts	• No impacts
f. Equitable Comparison of Strategies	• Standard analyses and methods used
g. Interbasin transfers	• Not significant
h. Third party social and economic impacts from voluntary redistribution of water	• Willingness of Nueces County WCID #3 to serve County-Other population • Willingness of Nueces County WCID #3 to sell rights.
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None

4C.12.2.3 Trades/Transfers with South Central Texas Region

The Nueces River Basin covers three Regional Water Planning Areas: Coastal Bend, South Central Texas, and Rio Grande. Options have been developed for the South Central Texas Region (Region L) that would trade/transfer water between the South Central Texas and Coastal Bend Regions. Below is a summary of those options. (The options discussed below are those that have not been discussed as one of the 17 options in Section 5).

4C.12.2.3.1 Recharge Enhancement in Exchange for Other Water

This option involves the decrease of firm yield to the CCR/LCC System by building recharge enhancement projects over the Edwards Aquifer in the upper reaches of the Nueces River Basin. These recharge enhancement projects would result in additional supply for the South Central Texas Region. Three separate enhancement project programs have been developed by Region L, one of which would be built if the option is determined to be a management supply solution. The South Central Texas Regional Water Planning Group has recommended a program that includes recharge enhancement of five tributaries in the Nueces River Basin (Indian Creek, Lower Frio, Lower Sabinal, Lower Hondo, and Lower Verde). This program would impound combined maximum recharge pool storage of 94,000 acft and periodically inundate 5,776 acres in the Nueces Basin. By capturing water before it arrives at the CCR/LCC System, the firm yield of the system is decreased from anywhere between 1,355 acft/yr to 4,308 acft/yr, depending on which program is built.[3] Available yield to the South Central Texas Region would range from 13,451 acft/yr to 21,577 acft/yr. The maximum impact on average inflow to the Nueces Estuary is a reduction of about 14,590 acft/yr, or 6 percent.[4]

Numerous options exist to replace the decrease in firm yield to the CCR/LCC System resulting from the recharge enhancement projects. The first option involves diversion and transmission of water from sources located along the Mary Rhodes Pipeline, including the Guadalupe River, groundwater from the Gulf Coast Aquifer, Colorado River water, or additional Lake Texana water. This water would be delivered to the City's O.N. Stevens Water Treatment Plant. Additional options involve potential enhancements to streamflow associated with brush management and/or weather modification programs on the Upper Nueces River. If studies are

[3] Based on period from 1934- 1989, does not reflect drought of the 1990's.
[4] For further details please consult South Central Texas Initially Prepared Plan, June 2005.

pursued and results are favorable, this additional supply could be used to benefit the Coastal Bend Region and partially mitigate effects of recharge enhancement projects.

Although not fully analyzed, the alternative exists for the City of Corpus Christi to trade their 35,000-acft/yr Garwood water right to the South Central Texas Regional Water Planning Area in exchange for 35,000 acft/yr of Guadalupe River water. Under this option, Guadalupe River water would need to be pumped via a new pipeline approximately 7 miles in length to the Mary Rhodes Pipeline. The cost of the 7-mile pipeline would be significantly less than either the 42-mile or 17-mile pipelines necessary to transport Garwood water to the existing Mary Rhodes Pipeline.

As can be seen in Table 4C.12-3, the mixing of Guadalupe River water, Colorado River, or Lake Texana water with Nueces River Water at the O.N. Stevens Water Treatment Plant poses minimal water quality issues.

Table 4C.12-3.
General Statistics on
Water Quality at Potential Water Sources

Location		***Chloride***	***Hardness***	***Sulfate***
Nueces River @ Stevens	Max	338	312	—
	Med	162	219	—
	Min	67	138	—
Guadalupe River @ Victoria	Max	72	297	56
	Med	36	221	29
	Min	9	75	8
Lake Texana	Max	96	216	27
	Med	21	75	10
	Min	1	37	6
Colorado River @ Wharton	Max	140	280	110
	Med	48	210	38
	Min	11	75	12

4C.12.2.3.2 U.S. Army Corps of Engineers Nueces Feasibility Studies

The U.S. Army Corps of Engineers (USCOE) is currently studying six projects as part of the Nueces River Basin Feasibility Study to evaluate opportunities for flood damage reduction, ecosystem restoration, and/or benefit water supplies in South Texas. The six projects selected by the USCOE and participating sponsors for feasibility studies are:

- Desalination Facilities
- Wastewater Diversion to Nueces Delta
- Cotulla Diversion Project
- CCR/LCC Pipeline with Off Channel Storage
- Recharge Enhancement Projects
- Brush Control Opportunities

Four of the six projects were considered as separate water management strategies for this plan (desalination, wastewater diversion to Nueces Delta, CCR/LCC Pipeline and Off-Channel Storage, and Brush Control). Five of these projects could potentially serve to mitigate the effects of the recharge enhancement projects. Costs to implement these projects could potentially be reduced through Federal participation as may be available through the USCOE Nueces River Basin Feasibility Study. For example, the total project cost of a 25-MGD desalination facility in Corpus Christi is estimated at $200,005,000. This results in an annual cost of $33,324,000. For an available project yield of 28,000 acft/yr, the unit cost would be approximately $1,190 per acft (Table 4C.17-6). Assuming federal funding participation of 65 percent, the total project cost could be reduced to $70,000,000. The annual cost (including operation and maintenance costs and reduced debt service) would be $19,302,000, which results in a unit cost of around $689 per acft, or about 58 percent of the unit cost without Federal participation. For federal participation of multiple projects the savings potential for the Coastal Bend Region could be significant.

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4C.13 Stage II of Lake Texana (Lavaca-Navidad River Basin)(N-13)

4C.13.1 Description of Strategy

The TWDB and the LNRA hold a TNRCC Certificate of Adjudication, #16-2096B, for the completion of Palmetto Bend Stage II Dam and Reservoir (Stage II of Lake Texana) on the Lavaca River. Stage I, now known as Lake Texana, was completed in 1981 and is located on the Navidad River. Stage I is operated by LNRA primarily for water supply purposes and has a firm yield of 79,000 acft/yr. In 1998, the Mary Rhodes Memorial Pipeline was completed to deliver 41,840 acft/yr from Lake Texana to the City of Corpus Christi.

The LNRA has expressed a renewed interest in the potential development of Stage II. In the 2001 Coastal Bend Regional Water Plan, water supply from the development of Stage II was evaluated as part of an interregional water supply by both the Coastal Bend Regional Water Planning Group (Region N) and the South Central Texas Regional Water Planning Group (Region L). Previously, the South Central Texas Region Water Planning Group considered two Stage II water delivery options: to coastal irrigation areas near the Colorado River at Bay City and to the Guadalupe River near the Saltwater Barrier. However, the South Central Texas Regional Water Planning Group is no longer actively pursing these options. Stage II could be developed by Region N on its own or could contribute to a cooperative water supply between the two regions in the following way:

- Exchanging Stage II water for coastal area surface water rights and/or options owned by Corpus Christi for Colorado River streamflow that might be diverted at an upstream point near Columbus and delivered to the South Central Region. The Stage II water would be delivered to the City of Corpus Christi's water treatment plant via the Mary Rhodes Memorial Pipeline.

Originally, the U.S. Bureau of Reclamation proposed that Stage II would be located on the Lavaca River and share a common pool with Stage I (Lake Texana). However, previous studies have shown that Stage II could be constructed more economically if operated separately from Lake Texana and located further upstream at an alternative site on the Lavaca River.[1] As proposed, at the original site, the Certificate of Adjudication states:

> "Upon completion of the Stage 2 dam and reservoir on the Lavaca River, owner Texas Water Development Board is authorized to use an additional amount of

[1] HDR Engineering, Inc., "Regional Water Planning Study Cost Update for Palmetto Bend Stage 2 and Yield Enhancement Alternative for Lake Texana and Palmetto Bend Stage 2," Lavaca-Navidad River Authority, et al., May 1991.

> 18,122 acft/yr, for a total of 48,122 acft/yr, of which up to 7,150 acft/yr shall be for municipal purposes, up to 22,850 acft/yr shall be for industrial purposes, and at least 18,122 acft/yr shall be for the maintenance of the Lavaca-Matagorda Bay and Estuary System. The entire Stage 2 appropriation remains subject to release of water for the maintenance of the bay and estuary system until a release schedule is developed pursuant to the provisions of Section 4.B of this certificate of adjudication."[2]

For the purposes of this study, Stage II is assumed to be constructed at the alternative site located approximately 1.4 miles upstream of the original site. Since this site results in a different yield than stated in the certificate, the conditions in the certificate will need to be revised to account for the change in yield of Stage II. The revisions to the certificate should also reflect the impacts that joint operations of Lake Texana and Palmetto Bend Stage II could have on the releases necessary to maintain the bay and estuary system downstream of the projects. In 1997, a study[3] was conducted by the LCRA to estimate target and critical freshwater inflow needs for the Matagorda Bay System from the Colorado River. Target inflow is defined based on criteria established for salinity and nutrient inflow, in addition to necessary long-term inflow to produce 98% of maximum population for nine key estuarine species. Critical freshwater inflow is the minimum inflow, based on salinity levels, necessary to provide for fish habitat during drought conditions. Recent studies of Matagorda Bay and Lavaca-Colorado Estuary[4] indicate that releases to the bay and estuary (from 1941-1987), on average, exceed target inflow by over 50% with an average inflow of 3,080,301 acft as compared to a target inflow of 2,000,100 acft.[5] These inflows, which include releases from Lake Texana, exceed mitigation requirements and may enhance the productivity of certain species in the bay and estuary. These results indicate that releases from Stage II for maintaining the bay and estuaries may be less restrictive than those called for in the Environmental Water Needs Criteria of the Consensus Planning Process.[6] However, in addition to the bay and estuary requirements, releases from Stage II might be required for the 3.5-mile reach of the Lavaca River downstream of the dam site to the confluence with the Navidad River.[7] Therefore, it is assumed that releases from Stage II will be in

[2] Texas Natural Resource Conservation Commission Certificate of Adjudication No. 16-2096B, 1994.
[3] LCRA, "Freshwater Inflow Needs of the Matagorda Bay System," December 1997.
[4] TWDB, "Texas Bay and Estuary Program- Matagorda Bay and Lavaca-Colorado Estuary", 1998.
[5] The monthly average inflow exceeds target monthly inflow for all months, except April which is slightly less than target levels.
[6] Texas Water Development Board (TWDB), "Environmental Water Needs Criteria of the Consensus Planning Process," January 1996.
[7] Personal communications with Gary Powell, TWDB, July 1999.

accordance with the Consensus Criteria for maintenance of the river reach just below the dam. The Freshwater Inflow Needs for the Matagorda Bay System is currently undergoing a revision which should be considered in future water planning efforts.

Figure 4C.13-1 shows the location of Stage II and route of the Mary Rhodes Memorial Pipeline. This option will require an intake station at the Stage II reservoir site, a transmission line, and an outlet structure.

4C.13.2 Available Yield

At the alternative Stage II site, the reservoir has a drainage area of 830 square miles. Based on the topography of the site, the top of dam was selected at elevation 55 ft-msl and the conservation pool was set at elevation 44 ft-msl. The initial conservation storage capacity of the reservoir would be 57,676 acft, and the reservoir area at elevation 44 ft-msl would be 4,679 acres. The reservoir area at the top of the dam would be approximately 8,200 acres. Data from the 2001 Coastal Bend Regional Plan for 2050 conditions was extrapolated to estimate 2060 sedimentation conditions. After 60 years of sediment accumulation, the conservation storage capacity is reduced to 45,687 acft. Table 4C.13-1 shows the elevation, area, and capacity data for the site for initial conditions and after 60 years of accumulated sediment.

Table 4C.13-1.
Palmetto Bend Stage II
Elevation, Area and Capacity Table

Elevation (ft-msl)	*Initial Conditions*		*2060 Conditions[1,2]*	
	Area (acres)	*Capacity (acft)*	*Area (acres)*	*Capacity (acft)*
44.0 (Top of Pool)	4,679	57,676	4,679	45,687
40.0	3,888	40,543	3,270	29,406
35.0	2,940	23,475	2,317	15,446
30.0	1,774	11,695	1,253	6,523
25.0	914	4,980	529	2,064
20.0	352	1,819	105	465
15.0	138	596	13	150
10.0	40	152	3	72
4.7	0	0	0	0

[1] Estimated based on a sedimentation rate of 0.243 acft per square mile per year or 10,090 acft of sediment after 50 years.

[2] 2060 Conditions extrapolated based on area and capacity relationship of Palmetto Bend Stage II and Lake Texana for 2000 to 2050 conditions and applying annual sedimentation ratio for 60 years based on 2060 sedimentation data for Lake Texana.

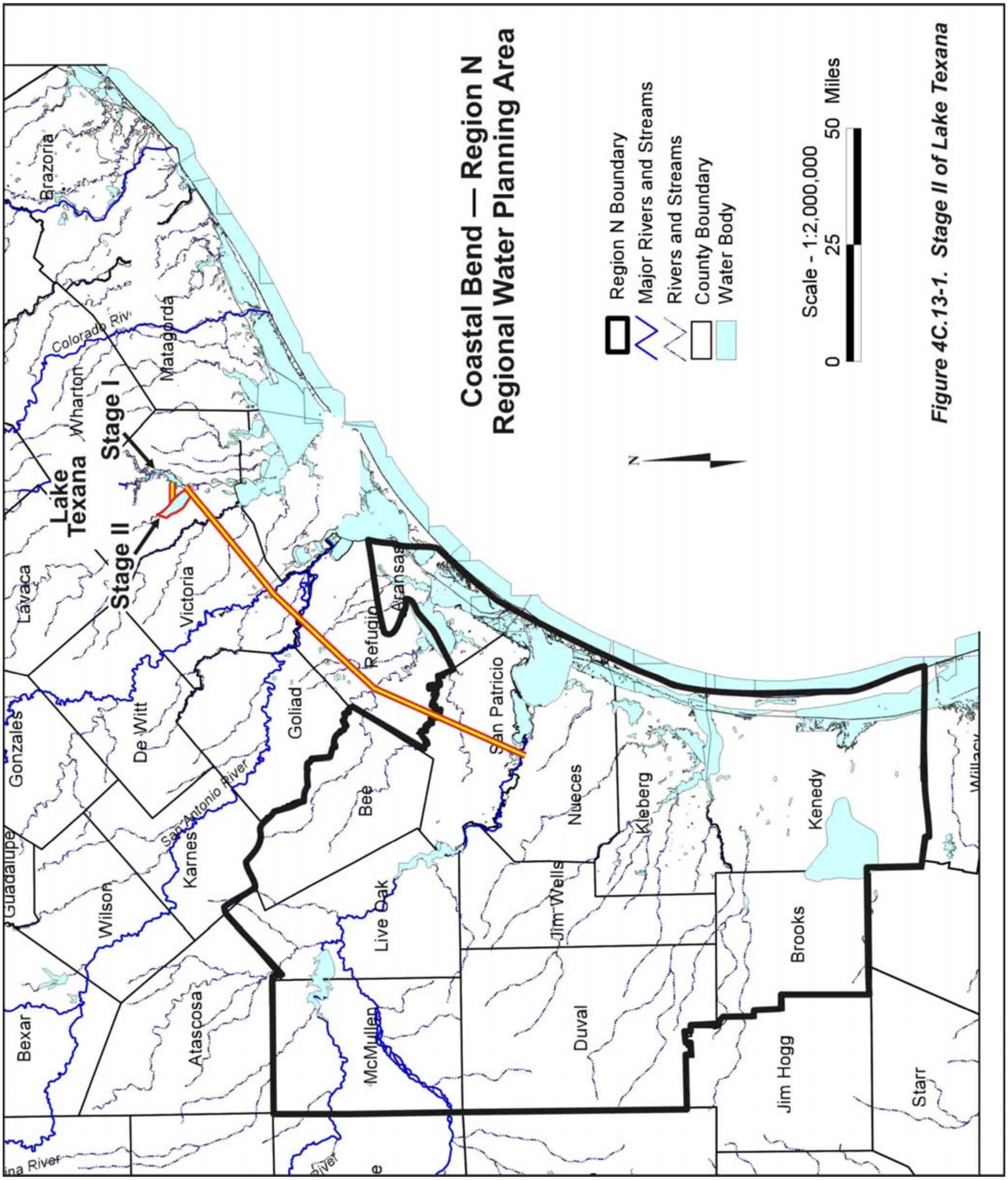


Figure 4C.13-1. Stage II of Lake Texana

For the 2001 Plan, the firm yield of Stage II operated separately from Lake Texana was calculated based on seasonal demand patterns for City of Corpus Christi and estimated 2050 sediment conditions. A second seasonal demand pattern used by TWDB in determining the yield at the original Stage II site was also evaluated. Assuming reservoir capacity loss associated with 10 additional years of sedimentation (from Year 2050 through Year 2060) are minor, the firm yield for Year 2060 is equal to Year 2050 presented in the 2001 Plan (i.e., 28,000 acft/yr). The yield calculations required development of hydrologic data at the dam site, determination of release requirements in accordance with the Consensus Criteria, determination of seasonal demand factors for delivery to Lake Texana, and simulation of the Stage II reservoir operations.

A historical daily flow set for the Lavaca River was developed using naturalized monthly flows adjusted for senior upstream water rights. This monthly flow set was computed by the Texas Commission on Environmental Quality (TCEQ) using the Lavaca-Navidad River Basin Model and includes the period from 1940 through 1979. The monthly flows were adjusted using a drainage area ratio method to account for the location of the dam site in relation to the output points in the Lavaca-Navidad River Basin Model. The monthly flows were distributed to a daily time step using the flow pattern recorded at a nearby USGS gage on the Lavaca River near Edna, Texas. Evaporation was calculated utilizing the average of published[8] and supplemental monthly net evaporation rates developed by the TWDB.

The monthly median flows (Zone 1) and 25th percentile flows (Zone 2) used to define the Consensus Criteria release requirements were computed from the monthly naturalized flows from the Lavaca-Navidad River Basin Model distributed to a daily time step. The Zone 3 requirement (7Q2) was taken from TCEQ's published water quality standards.[9] Table 4C.13-2 shows the daily release (inflow passage) requirements from Stage II. Table 4C.13-3 displays the monthly demand factors used to send Stage II water to Lake Texana for delivery to the Mary Rhodes Pipeline. The first demand pattern in the table reflects the City of Corpus Christi's municipal demand pattern and the second demand pattern is a generic seasonal pattern used by the TWDB in their determination of Stage II firm yield.

[8] TWDB, "Monthly Reservoir Evaporation Rates for Texas, 1940 through 1965," Report 64, October 1967.
[9] Texas Administrative Code, Chapter 307, Texas Surface Water Quality Standards.

Table 4C.13-2.
Consensus Criteria Release Requirements (cfs)
for Palmetto Bend Stage II

Month	Consensus Criteria Zone		
	1	2	3
	>80% Capacity	<80% to >50% Capacity	<50% Capacity
January	63.0	26.1	21.6
February	92.8	39.0	21.6
March	76.9	37.6	21.6
April	78.9	36.8	21.6
May	92.2	35.	21.6
June	47.5	22.6	21.6
August	37.3	21.6	21.6
September	41.2	21.6	21.6
October	39.2	21.6	21.6
November	48.3	21.6	21.6
December	55.1	24.3	21.6
Note: Consensus Criteria published in 2001 Coastal Bend Regional Water Plan.			

Table 4C.13-3.
Firm Yield Estimates for Palmetto Bend Stage II [1]

Month	4.5-Mile Pipeline to Lake Texana Yield = 28,000 acft/yr		TWDB Yield = 27,900 acft/yr	
	Municipal Demand Pattern[2]	Quantity (acft/month)	TWDB Demand Pattern[3]	Quantity (acft/month)
January	0.072	2,030	0.068	1,897
February	0.066	1,861	0.062	1,730
March	0.081	2,284	0.074	2,065
April	0.084	2,269	0.079	2,204
May	0.087	2,453	0.083	2,316
June	0.091	2,566	0.090	2,511
July	0.103	2,905	0.113	3,153
August	0.102	2,876	0.116	3,236
September	0.084	2,369	0.091	2,539
October	0.081	2,284	0.084	2,344
November	0.075	2,115	0.070	1,953
December	0.074	2,088	0.070	1,953
—	Pipe Size: 54-inch		—	

[1] Dam at the alternative site for Stage II with conservation pool at 44 ft-msl.
[2] Municipal Demand Pattern for the City of Corpus Christi.
[3] Generic Demand Pattern used by TWDB to calculate Stage II firm yield.

For the 2001 Coastal Bend Regional Plan, reservoir operations were simulated on a daily basis using the SIMDLY model developed by the TWDB. The yields calculated for each option under initial conditions and the pipeline sizes necessary to deliver the different quantities of water are shown in Table 4C.13-3. Under initial conditions, the yield using the TWDB seasonal demand pattern is 27,900 acft/yr. The delivery of Stage II water based on the City of Corpus Christi's demand pattern results in a yield of 28,000 acft/yr. After 60 years of sedimentation, the yield using the TWDB seasonal demand pattern is 22,800 acft/yr, compared to a yield of 23,000 acft/yr with delivery of Stage II water based on the City of Corpus Christi's demand pattern results. Table 4C.13-4 compares initial condition yields to those calculated after 60 years of sedimentation.

Table 4C.13-4.
Palmetto Bend Stage II Firm Yields
Consensus Criteria vs. No Releases

	Firm Yield (acft/yr)			
	Initial Conditions		2060 Conditions	
Option	Consensus Criteria	No Releases	Consensus Criteria	No Release
Delivery to Lake Texana	28,000	32,300	23,000	27,000
TWDB Analysis	27,900	32,000	22,800	26,800
Note: 2060 Conditions equal to 2050 Conditions from 2001 Coastal Bend Regional Water Plan.				

Table 4C.13-4 also shows the Stage II yields if no inflows were passed. Under initial conditions, the releases made in accordance to the Consensus Criteria reduce the firm yield by an average of 4,100 acft/yr for the two cases analyzed. After 60 years of sedimentation, the releases reduce the yield by 4,000 acft/yr.

Figure 4C.13-2 displays the firm yield storage traces for Stage II under initial conditions operating under both Consensus Criteria with releases and with no releases. Both traces use the TWDB demand pattern and have a critical drawdown occurring from May 1953 to January 1957. The Consensus Criteria operations result in less water being stored in Stage II throughout the period. The firm yield storage traces for the other simulation are not plotted but exhibit similar behavior to that shown in Figure 4C.13-2. Storage frequency plots for the above two conditions are shown in Figure 4C.13-3. Each plot shows the storage frequency at the firm yield of Stage II

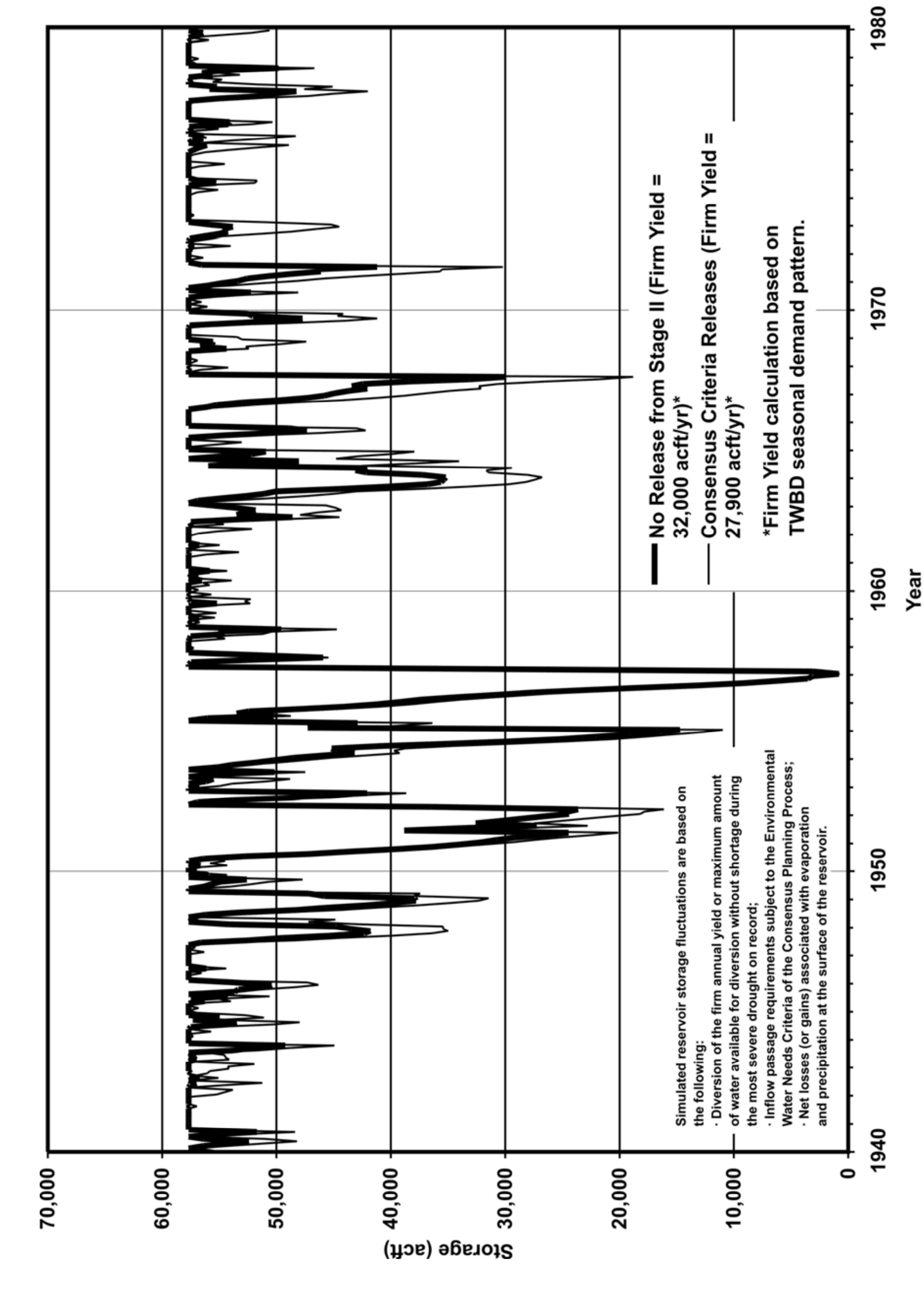
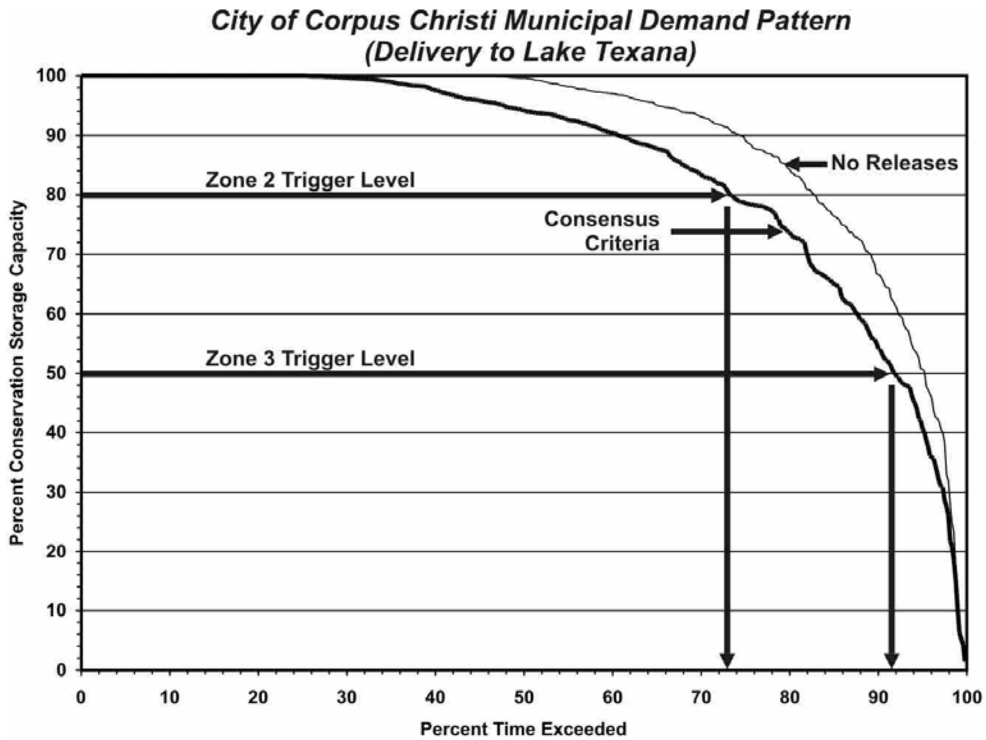


Figure 4C.13-2. Stage II of Lake Texana Firm Yield Storage Trace



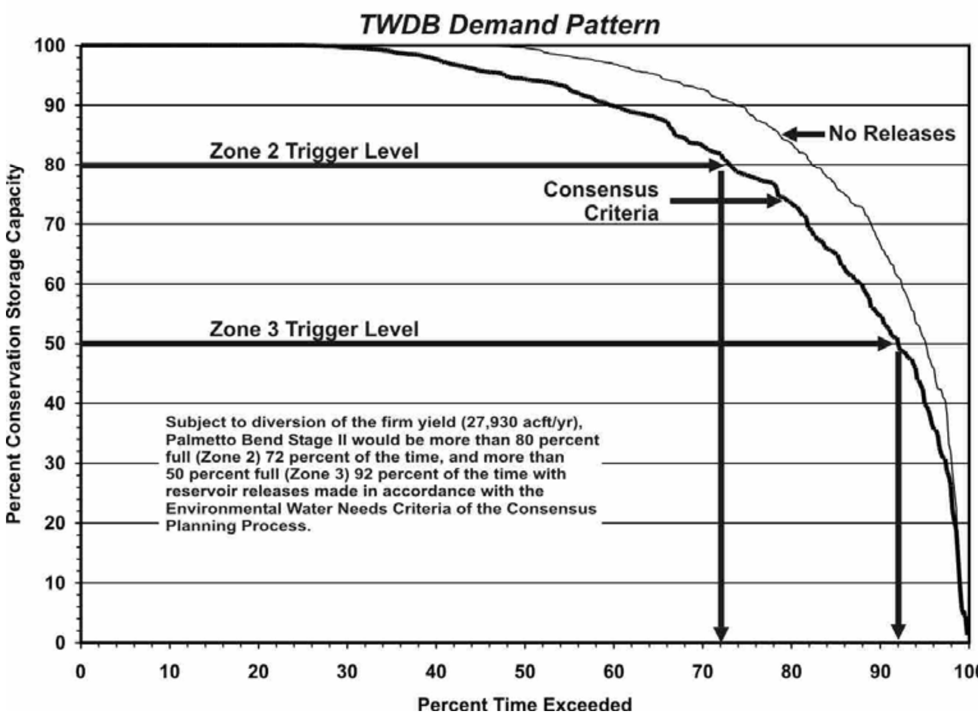


Figure 4C.13-3 Stage II of Lake Texana Storage Frequency at Firm Yield

under Consensus Criteria operations and storage frequency at the firm yield if no releases are made. The Zone 2 and Zone 3 trigger levels dictated by the Consensus Criteria are shown for reference in each plot. For the simulation using the TWDB demand pattern, Stage II would be more than 80 percent full (Zone 2) about 72 percent of the time and more than 50 percent full (Zone 3) about 92 percent of the time when operated in accordance with the Consensus Criteria. When no releases are made under the same demands, Stage II would be more than 80 percent full about 82 percent of the time and more than 50 percent full about 95 percent of the time.

4C.13.3 Environmental Issues

Environmental issues associated with the construction of Stage II can be categorized as follows:

- Effects of the construction and operation of the reservoir;
- Effects on the Lavaca River downstream from the dam; and
- Effects on Lavaca Bay.

The proposed dam would create a 4,679-acre conservation pool area at 44 ft-msl, inundating about 22 miles of the Lavaca River channel. Although no federal or state protected species are known to be present within the reservoir area, important species may be present in the surrounding areas and are listed in Table 4C.13-5. Suitable habitat for protected species may be present at the reservoir site. Several species of migratory birds, marine turtles, and mammals considered by the USFWS and National Marine Fisheries Service to be endangered or threatened are believed to utilize the Lavaca Estuary.

The importance of the flow reductions to the bay and estuary system is a complex function of bay physiography (estuarine volume, area/depth ratio, substrate composition, constrictions or compartmentalization), regional climate, and the flushing energy provided by tidal action, the effects of multiple freshwater inflows, and the estuarine population examined. The operating regime for Stage II meets the Consensus Criteria for both streamflow and estuary requirements, based on the results of “Freshwater Inflow Needs of the Matagorda Bay System.”[10] The changes in streamflow in the Lavaca River and the inflows into Lavaca Bay

[10] LCRA, Op. Cit., December 1997.

Table 4C.13-5. Important Species Having Habitat or Known to Occur in Counties Potentially Affected by Option Palmetto Bend Stage II Reservoir*

Common Name	*Scientific Name*	*Summary of Habitat Preference*	*Listing Agency*			*Potential Occurrence in County*
			USFWS[1]	*TPWD*[1]	*TOES*[2,3,4]	
American Peregrine Falcon	*Falco peregrinus anatum*	Open country; cliffs	E	E	E	Nesting/Migrant
Arctic Peregrine Falcon	*Falco peregrinus tundrius*	Open country; cliffs	T/SA	T	T	Nesting/Migrant
Atlantic Hawksbill Sea Turtle	*Eretmochelys imbricata*	Coastal waters	E	E	E	Resident
Attwater's Prairie-Chicken	*Tympanuchus cupido attwateri*	Gulf coastal prairies	E	E	E	Resident
Bald Eagle	*Haliaeetus leucocephalus*	Large bodies of water with nearby resting sites	T	T	E	Nesting/Migrant
Black Bear	*Ursus americanus*	Mountains, broken country, woods, brushlands, forests	T/SA	T	T	Resident
Black-spotted Newt	*Notophthalmus meridionalis*	Wet or temporally wet arroyos, canals, ditches, shallow depressions; aestivates underground during dry periods	E	T		Resident
Brown Pelican	*Pelecanus Occidentalis*	Coastal islands; shallow Gulf and bays	E	E	E	Resident
Coastal Gay-feather	*Liatris bracteata*	Black clay soils of midgrass grasslands on coastal prairie remnants			WL	Resident
Eskimo Curlew	*Numenius borealis*	Coastal prairies	E	E	E	Migrant
Green Sea Turtle	*Chelonia mydas*	Gulf Coast	T	T	T	Resident
Guadalupe Bass	*Micropterus treculi*	Streams of eastern Edwards Plateau			WL	Resident
Gulf Saltmarsh Snake	*Nerodia clarkii*	Coastal waters		T	NL	Resident
Henslow's Sparrow	*Ammodramus henslowii*	Weedy fields or cut over areas; bare ground for running and walking			NL	Nesting/Migrant
Interior Least Tern	*Sterna antillarum athalassos*	Inland river sandbars for nesting and shallow waters for foraging	E	E	E	Nesting/Migrant
Jaguarundi	*Felis yagouaroundi*	South Texas thick brushlands, favors areas near water	E	E	E	Resident
Keeled Earless Lizard	*Holbrookia propinqua*	Coastal dunes, Barrier islands and sandy areas			NL	Resident
Kemp's Ridley Sea Turtle	*Lepidochelys kempii*	Coastal waters; bays	E	E	E	Resident
Leatherback Sea Turtle	*Dermochelys coriacea*	Coastal and offshore waters	E	E	E	Resident
Loggerhead Sea Turtle	*Caretta caretta*	Coastal waters; bays	T	T	T	Resident
Mulenbrock's Umbrella Sedge	*Cyperus grayioides*	Prairie grasslands, moist meadows	C2	NL	NL	Resident
Ocelot	*Felis pardalis*	Dense chaparral thickets; mesquite-thorn scrubland and live oak mottes; avoids open areas; primarily extreme south Texas	E	E	E	Resident
Peregrine Falcon	*Falco peregrinus*	Open country, cliffs, occasionally cities[5]	E/SA	NL	NL	Nesting/Migrant
Piping Plover	*Charadrius melodus*	Beaches, flats	T	T	T	Resident
Red Wolf (extirpated)	*Canis rufus*	Woods, prairies, river bottom forests	E	E	E	Resident
Reddish Egret	*Egretta rufescens*	Coastal islands for nesting; shallow areas for foraging		T	NL	Nesting/Migrant
Scarlet Snake	*Cemophora coccinea*	Sandy soils	NL	T	WL	Resident
Smooth Green Snake	*Liochlorophis vernalis*	Coastal grasslands		T	NL	Resident
Snowy Plover	*Charadrius alexandrus*	Beaches, flats, streamsides	NL		NL	Winter resident
Sooty Tern	*Sterna fuscata*	Coastal islands for nesting; deep Gulf for foraging	NL	T	WL	Resident
Texas Asaphomyian Tabanid Fly	*Asaphomyia texanus*	Near slow moving water, wait in shady areas for host			WL	Resident
Texas Diamondback Terrapin	*Malaclemys terrapin litoralis*	Bays and coastal marshes		T	T	Resident

Concluded on next page

Table 4C.13-5 concluded

Common Name	Scientific Name	Summary of Habitat Preference	Listing Agency			Potential Occurrence in County
			USFWS[1]	TPWD[1]	TOES[2,3,4]	
Texas Garter Snake	*Thamnophis sirtalis annectens*	Varied, especially wet areas; bottomlands and pastures			NL	Resident
Texas Horned Lizard	*Phrynosoma cornutum*	Varied, sparsely vegetated uplands		T	T	Resident
Texas Tortoise	*Gopherus berlandieri*	Open brush with grass understory; open grass and bare ground avoided; occupies shallow depressions at base of bush or cactus, underground burrows, under objects; active March to November		T	T	Resident
Threeflower Broomweed	*Thurovia triflora*	Black clay soils of remnant coastal prairie grasslands			WL	Resident
Timber/Canebrake Rattlesnake	*Crotalus horridus*	Bottomland hardwoods		T	T	Resident
Welder Machaeranthera	*Psilactis heterocarpa*	Mesquite-huisache woodlands, shrub-invaded grasslands in clay and silt soils			WL	Resident
West Indian Manatee	*Trichechus manatus*	Warm, vegetated coastal waters	E	E	E	
White-faced Ibis	*Plegadis chihi*	Varied, prefers freshwater marshes, sloughs and irrigated rice fields; Nests in low trees		T	T	Nesting/Migrant
White-tailed Hawk	*Buteo albicaudatus*	Prairies, mesquite and oak savannahs, scrub-live oak, cordgrass flats		T	T	Nesting/Migrant
Whooping Crane	*Grus americana*	Potential migrant	E	E	E	Migrant
Wood Stork	*Buteo americana*	Prairie ponds, flooded pastures or fields; shallow standing water		T	T	Nesting/Migrant

[1] Texas Parks and Wildlife Department. Unpublished 1999. September 1999, Data and map files of the Natural Heritage Program, Resource Protection Division, Austin, Texas.
[2] Texas Organization for Endangered Species (TOES). 1995. Endangered, threatened, and watch list of Texas vertebrates. TOES Publication 10. Austin, Texas. 22 pp.
[3] TOES. 1993. Endangered, threatened, and watch list of Texas plants. TOES Publication 9. Austin, Texas. 32 pp.
[4] TOES. 1988. Invertebrates of Special Concern. TOES Publication 7. Austin, Texas. 17 pp.
[5] Peterson, R.T. 1990. A Field Guide to Western Birds. Houghton Mifflin Company, Boston. pg. 86.

* E = Endangered; T = Threatened; C1 = Candidate Category, Substantial Information; C2 = Candidate Category
C3 = No Longer a Candidate for Protection; PE/PT = Proposed Endangered or Threatened
WL = Potentially endangered or threatened; Blank = Rare, but no regulatory listing status; NL = Not listed

resulting from Stage II operation are shown in Figure 4C.13-4. Both plots display the reduction in flows downstream of Stage II when operating in accordance with Consensus Criteria and simulating the TWDB seasonal demands. The top charts show the monthly median flows in the Lavaca River and Lavaca Bay downstream of Stage II with and without the project, while the bottom plot shows the reduction in combined Lavaca-Navidad River flows into Lavaca Bay, with Lake Texana in full operation, and with or without Stage II.[11]

Freshwater inflows play an important role in determining the distribution and abundance of estuarine populations. Most importantly, inflows interact with the tidal regime to produce a range of salinity gradients that generally exhibit more or less predictable seasonal patterns.

[11] R.J. Brandes Company, "Analysis of Lavaca Bay Salinity Impacts of a Proposed Release Program from Lake Texana," Texas Parks and Wildlife Department, Austin, TX, November 1990.

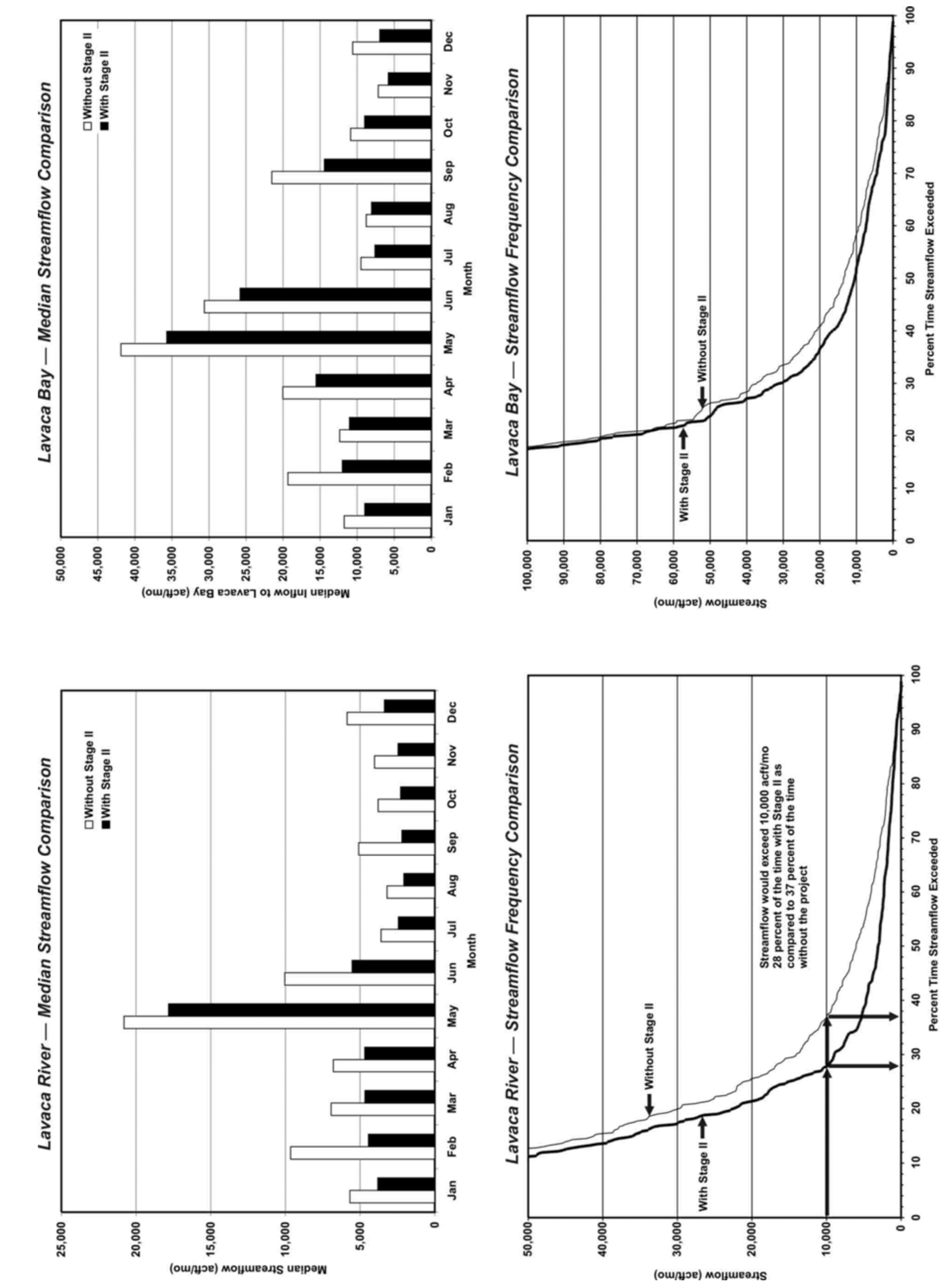


Figure 4C.13-4. Stage II of Lake Texana Streamflow Comparisons

Freshwater inflows may also be important in transporting sediments that play a role in maintaining tidal marsh elevations against subsidence and erosion, and nutrients that may support high levels of planktonic production and respiration.

The Lavaca River is tidally influenced at the proposed dam site; consequently, its biota is variable depending on its recent history of tidal stages and stream discharge, but is typically dominated by a brackish or salt-tolerant fauna. Following completion of the dam for Stage II, a continuous release requirement might prevent the development of adverse salinity and dissolved oxygen conditions below the dam that now accompany episodes of very low flow. Streamflows will tend to be more uniform over time than would be the case without the project, with most of the reduction occurring at flows above the median, while storage is taking place.

The characteristically large runoff events typical of this region have produced sufficient spills and releases from Lake Texana to maintain the Navidad River channel below the dam, and Stage II is expected to operate similarly. Migration will be blocked in the Lavaca River as it is in the Navidad River by Stage I, but strongly migratory species do not have any particular community importance in the present river-estuary system, and none are known that would be eradicated by construction of Stage II.

The slight decrease in estuarine inflows associated with implementation of Stage II (Figure 4C.13-4) would have no net adverse effect on Lavaca Bay or the larger Matagorda Estuarine System. Inflows from the Lavaca-Navidad and Colorado Rivers, together with inflows from Tres Palacios and Garcitas Creeks and numerous, small local drainages are more than sufficient to maintain historic productivity levels with Stage II in place.[12]

In addition to the Palmetto Bend Stage II Reservoir, this option includes diversion of Stage II water by pipeline to Lake Texana. The reservoir and pipeline route are in the gulf Prairies vegetational area, the Western Gulf Coastal Plan ecoregion, and the Texan biotic province. Post oak savannah and tall grass prairies dominated by oaks, mesquites (*Prosopis glandulosa*), acacias and prickly pears (*Opuntia spp.*) characterize the Gulf Prairies vegetational area. This vegetation is supported by acidic clays and clay loams interspersed by sandy loams.

Plant and animal species listed by TPWD, USFWS, and TOES that may be within the vicinity of the pipeline route or the reservoir are listed in Table 4C.13-5. The Texas Natural

[12] LCRA, Op. Cit., December 1997.

Heritage Program (NHP) maps two plants, the Threeflower Broomweed (*Thurovia triflora*) and Welder Machaeranthera (*Psilactis heterocarpa*), in the vicinity of the pipeline route. The Threeflower Broomweed is found in black clay soils of remnant coastal prairie grasslands, while the Welder Machaeranthera thrives in shrub-invaded grasslands in clay and silt soils. This proposed route is located near two rookeries, a wildlife management area, and an area where endangered Attwater's Greater Prairie Chickens have been sighted.

The pipeline route passes through or in the vicinity of Bald Eagle (in 1999, downgraded from endangered to threatened status) habitat. The NHP has mapped Bald Eagle habitat, which extends south from Lake Texana along the Lavaca and Navidad Rivers, and could be affected by the construction of Palmetto Bend Stage II Reservoir or the proposed pipeline to Lake Texana. Bald Eagles usually inhabit areas around large bodies of water with nearby resting sites.

Other protected species that were not mapped in the project area but that could have habitat in the vicinity of the reservoir or proposed pipeline, includes the Black Bear, Jaguarundi, Ocelot, and the Texas Tortoise. The animals depend on brushland and mesquite scrubland habitats in the coastal prairies. The Texas Tortoise occupies shallow depressions at the base of bushes and cacti and underground burrows. Another reptile, the Timber/Canebrake Rattlesnake is usually found in bottomland habitats that support hardwoods.

The White-tailed Hawk (*Buteo albicaudatus*), Interior Least Tern (S*terna antillarum athalassos*), and Eskimo Curlew (*Numensis borealis*) also inhabit the coastal prairies. The White-tailed Hawk can be found in open prairies and mesquite/oak savannah, while the Interior Least Tern inhabits barren to sparsely vegetated sandbars along river, lake, and reservoir shorelines. The Eskimo Curlew has historically migrated through the coastal prairies in March and April.

Implementation of this option is expected to require field surveys for protected species, vegetation, habitats, and cultural resources during right-of-way selection to avoid or minimize impacts. When potential protected species habitat or other significant resources cannot be avoided, additional studies would have to be conducted to evaluate habitat use or eligibility for inclusion in the National Register for Historic Places, respectively. Wetland impacts, primarily pipeline stream crossings, can be minimized by right-of-way selection and appropriate construction methods, including erosion controls and vegetation procedures. Compensation for net losses of wetlands would be required where impacts are unavoidable.

4C.13.4 Engineering and Costing

Costs associated with constructing Palmetto Bend Stage II Dam and Reservoir at the site 1.4 miles upstream of the original site are shown in Table 4C.13-6. In order to deliver Stage II water to Corpus Christi via the existing transmission facilities from Lake Texana to Corpus Christi, an intake pump station at Stage II, a 4.5-mile transmission line, and an outlet structure would be necessary to transfer water from Stage II to Lake Texana. The total project cost with the reservoir is $149,185,000. The annual debt service with the transmission facilities financed over 30 years at 6 percent interest and the reservoir costs financed at 6 percent over 40 years comes to $10,006,000. The annual costs for operations and maintenance and power are estimated at $2,951,000, which includes $1,740,000 of annual power costs incurred at the existing facilities for delivering the additional water. The total annual cost of constructing Stage II and delivering the firm yield to Corpus Christi is $12,957,000. Dividing annual cost by the Year 2060 firm yield of 23,000 equates to an annual cost of $563 per acft (Table 4C.13-6).

The option to deliver the water to Corpus Christi has a low annual cost since there are existing facilities in place at Lake Texana that can be upgraded to deliver the Stage II raw water to Corpus Christi. It should be noted that the costs reported in this option only reflect the costs for Stage II and the delivery of raw water to Corpus Christi. Since the 2001 Plan, the annual cost of water increased by $35 per acft (from $528 to $563 per acft) mainly due to adjusting cost index to Second Quarter 2002 prices.

4C.13.5 Implementation Issues

Implementation of Palmetto Bend Stage II Reservoir with potential delivery of raw water to Corpus Christi (via Lake Texana) could directly affect the feasibility of other water supply options under consideration by the Coastal Bend Region. Since the alternative site of Palmetto Bend involves a different yield than that stated in Certificate of Adjudication #16-2095B, the certificate would need to be amended to reflect the yield at the proposed site and release requirements necessary for the bay and estuary system. An interbasin transfer permit from TCEQ will also be required to deliver of Stage II water (in Region P) to Corpus Christi.

Table 4C.13-6.
Cost Estimate Summary for
Palmetto Bend Stage II Dam and Reservoir to Lake Texana
(Second Quarter 2002 Prices)

Item	***To Lake Texana***
Capital Costs	
Dam and Reservoir (Conservation Pool: 57,676 acft; 4,679 acres; 44 ft-msl)	$73,003,000
Intake and Pump Station (33 MGD; 858 HP)	2,761,000
Outlet Structure	150,000
Transmission Pipeline (54-inch 4.5-mile)	4,658,000
Improvements to Lake Texana System	1,760,000
Total Capital Cost	**$82,332,000**
Engineering, Legal Costs, and Contingencies	$28,583,000
Environmental & Archaeological Studies and Mitigation	8,593,000
Land Acquisition and Surveying (8,224 acres)	9,099,000
Interest During Construction (4 years)	20,578,000
Total Project Cost	**$149,185,000**
Annual Costs	
Debt Service for Transmission Facilities (6 percent for 30 years)	$1,069,000
Reservoir Debt Service (6 percent for 40 years)	8,937,000
Operation and Maintenance	
Intake, Pipeline, Pump Station	116,000
Dam and Reservoir	1,095,000
Pumping Energy Costs (290,000 MWh; 2,983 MWh; 5,834 MWh @ $0.06 per kWh)	1,740,000
Total Annual Cost	**$12,957,000**
Available Project Yield (acft/yr)	**23,000**
Annual Cost of Water ($ per acft) Raw Water Delivered	**$563**
Annual Cost of Water ($ per 1,000 gallons) Raw Water Delivered	**$1.73**

For the Coastal Bend Region, Stage II Lake Texana is recommended as a water management strategy to meet projected Year 2060 shortages for City of Corpus Christi and SPMWD customers. Water supply from Stage II of Lake Texana requires an interbasin transfer from Lavaca Region (Region P) to the Coastal Bend Region. In accordance with Texas Water Code provisions, the projected shortage in the Lavaca Region for year 2000 is 55,755 acft/yr, decreasing to 31,979 acft/yr in Year 2060.[13] The shortages are projected by Region P to be met by groundwater supplies. The CBRWPG recommends a supply of 23,000 acft/yr from Stage II of Lake Texana to meet a portion of the regional need of 53,431 acft/yr in Year 2060.

Requirements Specific to Reservoirs

1. It will be necessary to obtain these permits:
    a. TCEQ Water Right and Storage permits, including interbasin transfer authorization.
    b. U.S. Army Corps of Engineers Sections 10 and 404 dredge and fill permits for the reservoir and pipelines.
    c. General Land Office Sand and Gravel Removal permits.
    d. General Land Office Easement for use of state-owned land.
    e. Coastal Coordination Council review.
    f. Texas Parks and Wildlife Department Sand, Gravel, and Marl permit.
2. Permitting, at a minimum, will require these studies:
    a. Assessment of effects on bays and estuaries.
    b. Habitat mitigation plan.
    c. Environmental studies.
    d. Cultural resource studies.
3. Land will need to be acquired through either negotiations or condemnation.
4. Relocations for the reservoir may include:
    a. Highways and railroads.
    b. Petroleum pipelines.
    c. Other utilities.
    d. Structures of historical significance.
    e. Cemeteries.

[13] Lavaca Regional Planning Group Draft Regional Water Plan, June 2005

Requirements Specific to Pipelines

1. Necessary permits:
   a. U.S. Army Corps of Engineers Sections 10 and 404 dredge and fill permits for stream crossings.
   b. General Land Office Sand and Gravel Removal permits.
   c. Texas Parks and Wildlife Department Sand, Gravel and Marl permit for river crossings.
2. Right-of-way and easement acquisition.
3. Crossings:
   a. Highways and railroads.
   b. Creeks and rivers.
   c. Other utilities.

4C.13.6 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 4C.13-7.

Table 4C.13-7.
Evaluation Summary of Stage II of Lake Texana

Impact Category	Comment(s)
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Firm yield: 23,000 acft/yr. 2. Good reliability. 3. Generally moderate cost at $563 per acft; discounted present value of $891 per acft
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. Reduces instream flows. Stage II releases in accordance with the Consensus Criteria were considered prior to determining yield. 2. Negligible impact to Lavaca Bay. 3. Construction of reservoir may have a negative impact on wildlife habitat. 4. None or low impact. 5. No federal or state protected species are known to be present within the reservoir area. 6. Cultural resources will need to be surveyed and mitigation for significant sites before this project is implemented. 7. Impacts to water quality will need to be evaluated prior to implementing project.
c. Impacts to State water resources	• No apparent negative impacts on other water resources • Potential benefit to river segment before dam due to increased low flows
d. Threats to agriculture and natural resources in region	• Purchase of reservoir land will result in reduced agricultural uses
e. Recreational impacts	• Increase in recreational use opportunities
f. Equitable comparison of strategies	• Standard analyses and methods used.
g. Interbasin transfers	• Requires transfer of water from Lavaca-Navidad River Basin to Nueces River Basin
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• Pipeline from Stage II to Lake Texana may impact wildlife habitat. Field surveys should be conducted to minimize impacts to protected species and vegetation.

4C.14 Garwood Pipeline (Colorado River Basin) and Other Interbasin Transfers (N-14)

4C.14.1 Description of Strategy

Interbasin transfer of water is a part of the Coastal Bend Region's water supply. In 1998, the Mary Rhodes Memorial Pipeline was completed and began to deliver 41,840 acft/yr from Lake Texana in the Lavaca-Navidad River Basin to the City of Corpus Christi in the Nueces River Basin. On July 24, 2001, a contract for an additional 12,000 acft of interruptible water was approved between the City of Corpus Christi and the Lavaca-Navidad River Authority (LNRA). The transmission facilities were designed with the anticipation that additional surface water owned or purchased by the City of Corpus Christi outside the Nueces Basin would be pumped to the Coastal Bend Region via the LNRA's West Water Delivery System and the City of Corpus Christi's Mary Rhodes Memorial Pipeline (hereinafter referred to as the Texana Pipeline).

In September 1992, the City of Corpus Christi entered into an option agreement for the potential purchase of up to 35,000 acft/yr from the Garwood Irrigation Company. The Garwood Irrigation Company (Garwood) held the most significant senior water right in the Lower Colorado River Basin, with a priority date of November 1, 1900. This water right authorized the diversion of 168,000 acft/yr from the Colorado River at a maximum rate of 750 cfs, or 1,488 acft per day. Most of Garwood's service area lies outside the Colorado River Basin, and a large part of its right is used for irrigation of land that is located in the Lavaca-Navidad River Basin. In 1993, TCEQ authorized an amendment to Garwood's water right that allows for the use of 35,000 acft of its right to be used for municipal and industrial purposes. On October 7, 1998, TCEQ approved the City of Corpus Christi's purchase of the 35,000 acft/yr from the Garwood Irrigation Company, herein referred to as the Garwood Purchase.[1] The amendment of the certificate of adjudication authorizes the City of Corpus Christi to divert 35,000 acft/yr from the Colorado River for irrigation, municipal and industrial purpose at a rate not to exceed 150 cfs. The certificate also subordinates the 35,000 acft/yr to the remaining portion of the original Garwood Irrigation water right by giving it a priority of November 2, 1900.

A cooperative water supply between the Coastal Bend Region and the South Central Texas Region would also involve interbasin transfers. The options being evaluated by the South

[1] Texas Natural Resource Conservation Commission, Amended Certificate of Adjudication No. 14-5434B, Garwood Irrigation Company, October 7, 1998.

Central Texas Regional Water Planning Group that involve transfer of water across basin boundaries in the Coastal Bend Region are described below:[2]

- Sharing transmission facilities for the Lower Colorado River Authority (LCRA)-San Antonio Water System (SAWS) Water Project with the City of Corpus Christi's Garwood Project. Assuming integrated concurrent or phased development of these two projects is feasible, shared facilities could include an intake pump station and a 90' inch 37-mile segment of the transmission pipeline from Matagorda County to the pump station at Lake Texana.
- Sharing transmission facilities for the LCRA-SAWS Water Project, Lower Guadalupe Water Supply Project (LGWSP), and City of Corpus Christi's Garwood Project. Assuming integrated concurrent or phased development of these two projects is feasible, shared facilities could include an intake pump station and a 90' inch 37-mile segment of the transmission pipeline from Matagorda County to the pump station at Lake Texana.

The two options involve enhancing the CCR/LCC System yield through imports from the Garwood project, with potential cost savings by sharing capital and operating costs with interests in the South Central Texas Region. Figure 4C.14-1 is a map with the proposed interregional project locations.

The TCEQ permit for use of the Garwood water prevents the water purchased by the City of Corpus Christi from entering Lake Texana. This requirement requires routing the pipeline and transmission facilities around Lake Texana and joining the pipeline from the Colorado River to the Texana Pipeline. The Colorado River diversion site is located at an existing diversion dam near Bay City, and a new pipeline (hereinafter referred to as the Garwood Pipeline) is needed to deliver the water to the Texana Pipeline at a point just downstream of Lake Texana for transmission to Corpus Christi.

In November 2004, the City of Corpus Christi Phase 1 study[3] evaluated delivery options for the Garwood water including: 1) intake pump station locations along the Colorado River or existing irrigation canals; 2) delivery methods of operating including peak pumping from the Colorado River, the use of off-channel storage, or constant pumping from the river; and

[2] HDR Engineering, Inc. (HDR), et al., "South Central Texas Regional Water Planning Area Initially Prepared Regional Water Plan, Volume III – Technical Evaluations of Water Supply Options," San Antonio River Authority, et al., June 2005.

[3] Freese and Nichols, Garwood Water Project – Phase 1 Report: Pipeline Route Screening Report, November 2004.

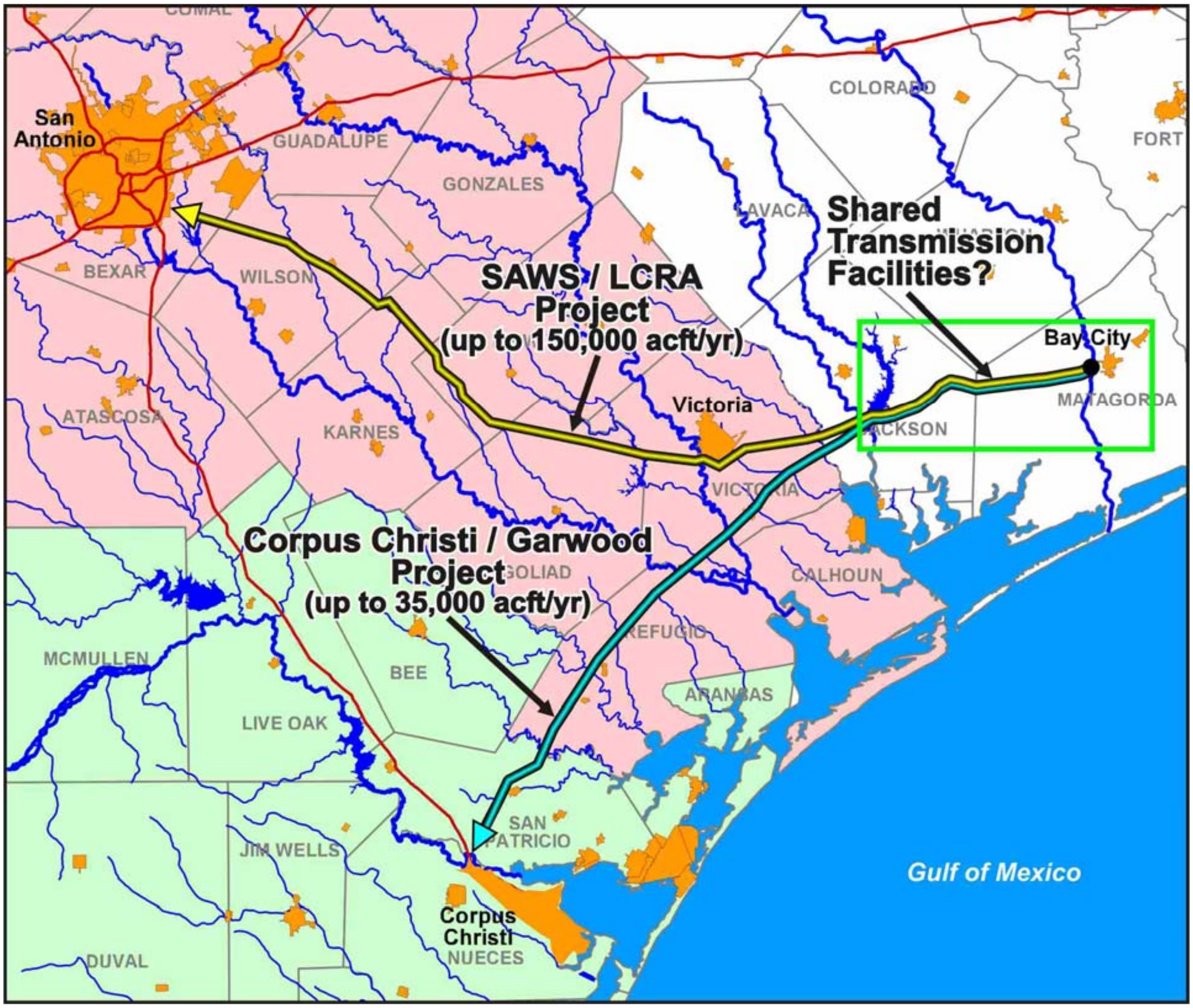


Figure 4C-14.1 Interregional Map of Conceptual Garwood Projects

3) partnership scenarios allowing combined facilities with other water providers. Three options were recommended for a Phase 2 detailed study:

Option 1– Combined Facilities with LCRA/SAWS

Option 5 – Garwood Town Canal to West Mustang Creek

Option 6 – Gulf Coast Furbor Canal to Mary Rhodes Pipeline

These three options are included in this report.

4C.14.1.1 Option 1 – Combined Facilities with LCRA/SAWS[4]

Option 1 involves partnering with LCRA and SAWS to develop combined facilities including pump station, pipeline, and possibly off-channel storage. The delivery of Lower Colorado River water will be from a diversion site located at LCRA's existing channel dam near Bay City to a point near Lake Texana where a connection would be made to the Texana Pipeline for the delivery of water to Corpus Christi, and a separate pipeline would be constructed by SAWS for delivery of water to San Antonio, as shown in Figure 4C.14-2. The joint use of facilities would likely result in capital cost savings, operational cost savings, joint application for permits may facilitate permitting processes, and may also increase reliability of Corpus Christi's Water Right. The LCRA/SAWS facility siting study is on-going and scheduled to be completed within the next five years, with construction of facilities projected to begin within the next 7 to 15 years. During this period, the City of Corpus Christi, LCRA, and SAWS would work together to determine the size and location of pump station and off-channel reservoir facilities as well as the shared portion of the pipeline route, and each member's cost participation for the facilities. If timing is acceptable, the City of Corpus Christi may consider possible partnership with LCRA and SAWS for joint facilities.

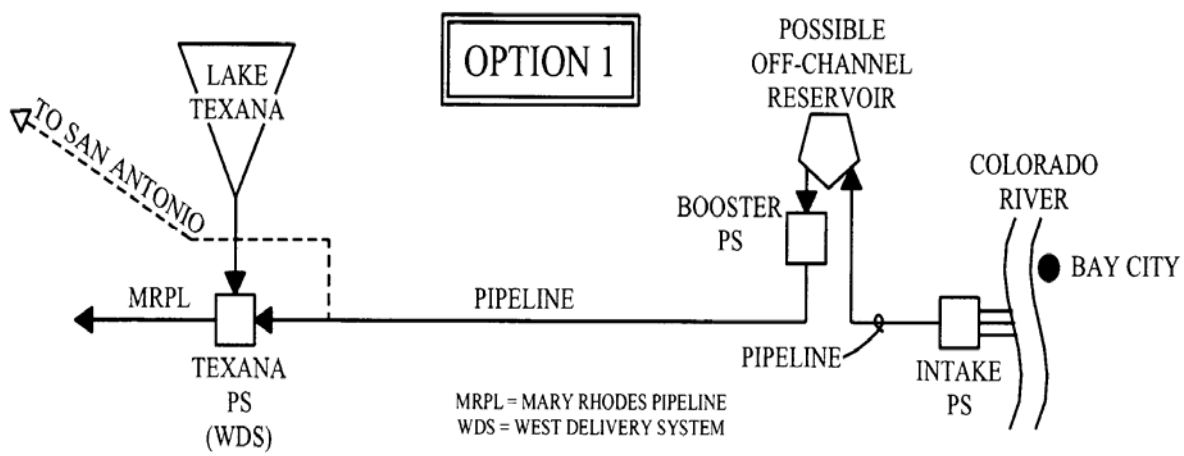


Figure 4C-14.2 Delivery Option 1 – Combined Facilities with LCRA/SAWS

[4] Descriptions of delivery option and schematics obtained from "Garwood Water Project - Phase I Report," 2004.

4C.14.1.2 Option 5 – Garwood Town Canal to West Mustang Creek[5]

Option 5 involves the diversion of water from the Garwood Irrigation District's Town Canal into West Mustang Creek and ultimately Lake Texana as shown in Figure 4C-14.3. This option involves minimal facilities at a low construction cost. However, it will require coordination with LCRA for operations and a possible upgrade to the Garwood Pump Station and Town Canal to provide capacity for the City's diversion. This option presents permitting challenges including a revision to the water right, a bed and banks permit, and cooperation with the Lavaca Navidad River Authority (and USBR) for storage of Garwood water in Lake Texana.

An environmental study with regard to interbasin transfer of species from the Colorado River Basin to the Lavaca-Navidad River Basin would need to be conducted prior to implementing the project. Preliminary studies show low channel losses for West Mustang Creek and low evaporation losses from Lake Texana. A more detailed study of infiltration and evaporative losses will need to be conducted. By considering Option 5, the City of Corpus Christi could delay high construction costs associated with other options to take the full amount of the water right.

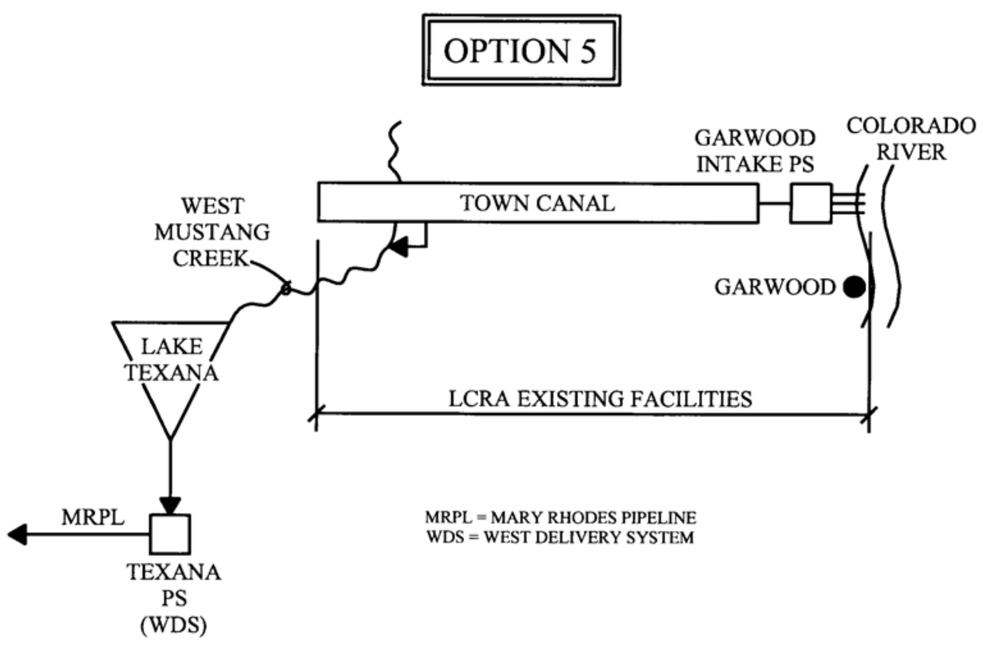


Figure 4C-14.3 Delivery Option 5 – Garwood Town Canal to West Mustang Creek

[5] Descriptions of delivery option and schematics obtained from "Garwood Water Project - Phase I Report," 2004.

4C.14.1.3 Option 6 – Gulf Coast Furbor Canal to Mary Rhodes Pipeline[6]

Option 6 includes a new 4500 horsepower pump station located on the LCRA Gulf Coast Irrigation District's Furbor Canal near F.M. 2431 and a 29-mile 54-inch pipeline with a capacity of 62 MGD (peaking factor of 2) to the existing Mary Rhodes Pipeline at Lake Texana, as shown in Figure 4C-14.4. This option will require an agreement and coordination with the LCRA to deliver the City's water to the Furbor Canal within the Gulf Coast Irrigation District. LCRA Gulf Coast Irrigation District Operations staff indicated that the Furbor Canal serves Texas Brine Corporation and is operational at all times except for routine maintenance. A portion of the conveyance is within the existing canal system, therefore requiring less facilities and pipeline length than other options. There are lower environmental concerns and permitting would not be as difficult because this option does not require construction of an intake pump station on the Colorado River, the pipeline is shorter, and no off-channel storage is required. This option may be adaptable for participation with other partners.

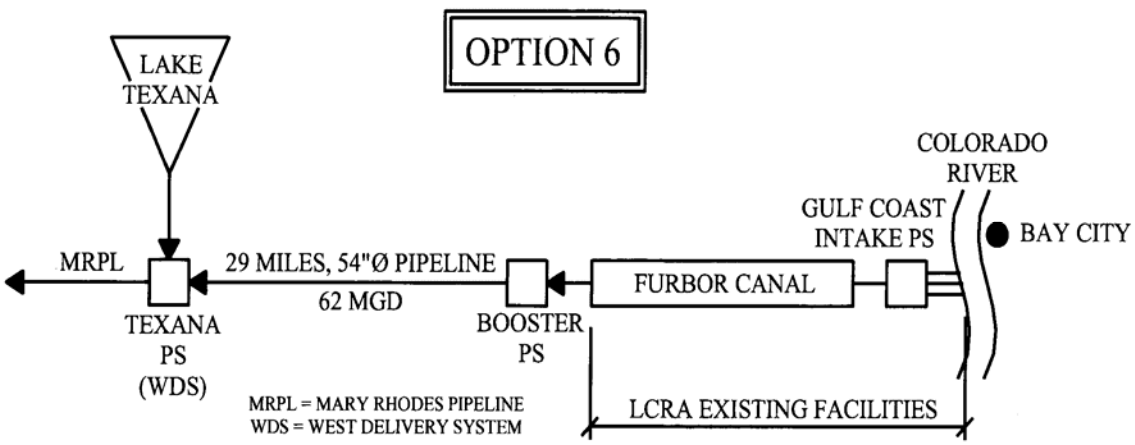


Figure 4C-14.4 Delivery Option 6 – Gulf Coast Furbor Canal to Mary Rhodes Pipeline

The study[7] recommended a maximum peaking factor of 2.0 be applied to the Garwood Water—35,000 acft/yr (31 MGD)—resulting in maximum design flow rate of 62 MGD for the City of Corpus water. Delivery of the Garwood Purchase at a peak diversion rate directly to the Texana Pipeline requires the capacity in both the Garwood Pipeline and the Texana Pipeline to

[6] Descriptions of delivery option and schematics obtained from "Garwood Water Project - Phase I Report," 2004.
[7] Freese and Nichols, Garwood Water Project- Phase 1 Report: Pipeline Route Screening Report, November 2004.

pump a maximum diversion rate from the Colorado River during periods of high flow. In order to accomplish the second delivery option, the water must be "firmed up" during periods of drought when it is not available directly from the Colorado River. One option for "firming up" the water is to utilize an off-channel storage site, such as a ring-dike reservoir. This provides a dependable water source during periods of drought for uniform delivery of the Garwood Purchase to the Texana Pipeline.

4C.14.2 Available Yield

Previous studies[8,9] have analyzed the impacts and the water availability of the Garwood right under numerous diversion scenarios and priority dates. The results of this previous work were used to evaluate the availability of the Garwood Purchase for the conditions set forth in the amended Certificate of Adjudication No. 14-5434B. The availability of the Garwood Purchase was evaluated using the City of Corpus Christi's Lower NUBAY Model, a multi-basin model used to the City's water supply yield for the CCR/LCC System including Lake Texana supplies, and is capable of simulating the 2001 Agreed Order pass-through for the Nueces Bay and Estuary. The NUBAY model predicts that the full 35,000 acft/yr of the Garwood Purchase can be diverted during nearly all conditions including the critical drought under the maximum diversion rate of 150 cfs.

Various diversion rates and off-channel storage volumes were analyzed to determine the most dependable uniform delivery of 35,000 acft/yr Garwood water. It was determined that 8,000 acft of storage adequately "firms up" the uniform delivery of the Garwood Purchase during periods when it is not available directly from the Colorado River.[10] In addition, it was determined that the water should be pumped from the Colorado River at the maximum diversion rate, which is 150 cfs.

[8] HDR, "Trans-Texas Water Program—Corpus Christi Study Area—Phase II Report," City of Corpus Christi, et al., September 1995.
[9] HDR, "Dependability and Impact Analyses of Corpus Christi's Purchase of the Garwood Irrigation Company Water Right," Draft Report, September 1998.
[10] Coastal Bend Regional Water Plan, January 2001.

4C.14.3 Environmental Issues

The potential environmental issues related to diverting the Garwood Purchase from the Colorado River and delivering it directly to the Texana Pipeline intake pumping station can be enumerated as follows:

- Effects to the Colorado River downstream from the diversion, including the Lavaca-Colorado Estuary;
- Effects to the Nueces Estuary;
- Effects along the pipeline right-of-way from the diversion point on the Colorado River to the delivery point at the Texana Pipeline intake pumping station.

For options 5 and 6 involving interbasin transfer to surface waters, studies will need to be conducted to evaluate undesirable species from transferring from one basin to another. Although no federal or state protected species are known to be present within the project area, important species may be present in the surrounding areas and are listed in Table 4C.14-1. Several species of migratory birds, marine turtles, and mammals considered by USFWS and National Marine Fisheries Service to be endangered or threatened are believed to utilize the Lavaca-Colorado Estuary.

Colorado River, Lavaca-Colorado Estuary

The Colorado River flows from west to southeast through Texas from the Llano Estacado in New Mexico, across the Western High Plains Ecoregion through the Central Plains and across the Central Texas Plateau before crossing the Balcones Escarpment and flowing through the Blackland Prairies and East Central Plains to the Western Gulf Plains. In Wharton County, the Colorado River is a large, low gradient stream generally exhibiting fine-grained sediments in extensive sandy braided reaches and occasional cobble and gravel riffles. As is commonly the case in coastal plain reaches, pool-riffle sequences are poorly developed. Low head dams impound two significant reaches of the river below Wharton. In addition to the numerous impoundments on the upper river and on major and minor tributaries, the Highland Lakes (large mainstream reservoirs constructed on the Edwards Plateau) are operated by the LCRA to provide hydropower, flood control, and water storage in the Lower Colorado River Basin. Operation of these reservoirs, particularly winter storage and summer releases of water for rice irrigation in

Table 4C.14-1. Important Species Having Habitat or Known to Occur in Counties Potentially Affected by Interbasin Transfer of Garwood Purchase*

Common Name	Scientific Name	Summary of Habitat Preference	Listing Agency			Potential Occurrence in County
			USFWS[1]	TPWD[1]	TOES[2,3,4]	
American Peregrine Falcon	*Falco peregrinus anatum*	Open country; cliffs	E	E	E	Nesting/Migrant
Arctic Peregrine Falcon	*Falco peregtinus tundrius*	Open country; cliffs	T/SA	T	T	Nesting/Migrant
Atlantic Hawksbill Sea Turtle	*Eretmochelys imbricata*	Coastal waters	E	E	E	Resident
Attwater's Prairie-Chicken	*Tympanuchus cupido attwateri*	Gulf coastal prairies	E	E	E	Resident
Bald Eagle	*Haliaeetus leucocephalus*	Large bodies of water with nearby resting sites	T	T	E	Nesting/Migrant
Black Bear	*Ursus americanus*	Mountains, broken country, woods, brushlands, forests	T/SA	T	T	Resident
Black-spotted Newt	*Notophthalmus meridionalis*	Wet or temporally wet arroyos, canals, ditches, shallow depressions; aestivates underground during dry periods	E	T		Resident
Brown Pelican	*Pelecanus Occidentalis*	Coastal islands; shallow Gulf and bays	E	E	E	Resident
Coastal Gay-feather	*Liatris bracteata*	Black clay soils of midgrass grasslands on coastal prairie remnants			WL	Resident
Eskimo Curlew	*Numenius borealis*	Coastal prairies	E	E	E	Migrant
Green Sea Turtle	*Chelonia mydas*	Gulf Coast	T	T	T	Resident
Guadalupe Bass	*Micropterus treculi*	Streams of eastern Edwards Plateau			WL	Resident
Gulf Saltmarsh Snake	*Nerodia clarkii*	Coastal waters		T	NL	Resident
Henslow's Sparrow	*Ammodramus henslowii*	Weedy fields or cut over areas; bare ground for running and walking			NL	Nesting/Migrant
Interior Least Tern	*Sterna antillarum athalassos*	Inland river sandbars for nesting and shallow waters for foraging	E	E	E	Nesting/Migrant
Jaguarundi	*Felis yagouaroundi*	South Texas thick brushlands, favors areas near water	E	E	E	Resident
Keeled Earless Lizard	*Holbrookia propinqua*	Coastal dunes, Barrier islands and sandy areas			NL	Resident
Kemp's Ridley Sea Turtle	*Lepidochelys kempii*	Coastal waters; bays	E	E	E	Resident
Leatherback Sea Turtle	*Dermochelys coriacea*	Coastal and offshore waters	E	E	E	Resident
Loggerhead Sea Turtle	*Caretta caretta*	Coastal waters; bays	T	T	T	Resident
Mulenbrock's Umbrella Sedge	*Cyperus grayioides*	Prairie grasslands, moist meadows	C2	NL	NL	Resident
Ocelot	*Felis pardalis*	Dense chaparral thickets; mesquite-thorn scrubland and live oak mottes; avoids open areas; primarily extreme south Texas	E	E	E	Resident
Peregrine Falcon	*Falco peregrinus*	Open country, cliffs, occasionally cities[5]	E/SA	NL	NL	Nesting/Migrant
Piping Plover	*Charadrius melodus*	Beaches, flats	T	T	T	Resident
Red Wolf (extirpated)	*Canis rufus*	Woods, prairies, river bottom forests	E	E	E	Resident
Reddish Egret	*Egretta rufescens*	Coastal islands for nesting; shallow areas for foraging		T	NL	Nesting/Migrant
Scarlet Snake	*Cemophora coccinea*	Sandy soils	NL	T	WL	Resident
Smooth Green Snake	*Liochlorophis vernalis*	Coastal grasslands		T	NL	Resident
Snowy Plover	*Charadrius alexandrus*	Beaches, flats, streamsides	NL		NL	Winter resident

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Table 4C.14-1 concluded

Common Name	Scientific Name	Summary of Habitat Preference	Listing Agency			Potential Occurrence in County
			USFWS[1]	TPWD[1]	TOES[2,3,4]	
Sooty Tern	*Sterna fuscata*	Coastal islands for nesting; deep Gulf for foraging	NL	T	WL	Resident
Texas Asaphomyian Tabanid Fly	*Asaphomyia texanus*	Near slow moving water, wait in shady areas for host			WL	Resident
Texas Diamondback Terrapin	*Malaclemys terrapin litoralis*	Bays and coastal marshes		T	T	Resident
Texas Garter Snake	*Thamnophis sirtalis annectens*	Varied, especially wet areas; bottomlands and pastures			NL	Resident
Texas Horned Lizard	*Phrynosoma cornutum*	Varied, sparsely vegetated uplands		T	T	Resident
Texas Tortoise	*Gopherus berlandieri*	Open brush with grass understory; open grass and bare ground avoided; occupies shallow depressions at base of bush or cactus, underground burrows, under objects; active March to November		T	T	Resident
Threeflower Broomweed	*Thurovia triflora*	Black clay soils of remnant coastal prairie grasslands			WL	Resident
Timber/Canebrake Rattlesnake	*Crotalus horridus*	Bottomland hardwoods		T	T	Resident
Welder Machaeranthera	*Psilactis heterocarpa*	Mesquite-huisache woodlands, shrub-invaded grasslands in clay and silt soils			WL	Resident
West Indian Manatee	*Trichechus manatus*	Warm, vegetated coastal waters	E	E	E	
White-faced Ibis	*Plegadis chihi*	Varied, prefers freshwater marshes, sloughs and irrigated rice fields; Nests in low trees		T	T	Nesting/Migrant
White-tailed Hawk	*Buteo albicaudatus*	Prairies, mesquite and oak savannahs, scrub-live oak, cordgrass flats		T	T	Nesting/Migrant
Whooping Crane	*Grus americana*	Potential migrant	E	E	E	Migrant
Wood Stork	*Buteo americana*	Prairie ponds, flooded pastures or fields; shallow standing water		T	T	Nesting/Migrant

[1] Texas Parks and Wildlife Department. Unpublished 1999. September 1999, Data and map files of the Natural Heritage Program, Resource Protection Division, Austin, Texas.
[2] Texas Organization for Endangered Species (TOES). 1995. Endangered, threatened, and watch list of Texas vertebrates. TOES Publication 10. Austin, Texas. 22 pp.
[3] Texas Organization for Endangered Species (TOES). 1993. Endangered, threatened, and watch list of Texas plants. TOES Publication 9. Austin, Texas. 32 pp.
[4] Texas Organization for Endangered Species (TOES). 1988. Invertebrates of Special Concern. TOES Publication 7. Austin, Texas. 17 pp.
[5] Peterson, R.T. 1990. A Field Guide to Western Birds. Houghton Mifflin Company, Boston. pg. 86.

* E = Endangered T = Threatened C1 = Candidate Category, Substantial Information C2 = Candidate Category
C3 = No Longer a Candidate for Protection PE/PT = Proposed Endangered or Threatened
WL = Potentially endangered or threatened Blank = Rare, but no regulatory listing status NL = Not listed

Colorado, Wharton, and Matagorda Counties, has substantially altered the annual hydrography of the lower river (below Austin) from its historical condition.[11]

In order to establish minimum flow guidelines that would protect existing biological communities in the Lower Colorado River while continuing to provide water for its traditional uses, LCRA conducted extensive instream flow studies on Segments 1428 and 1402 (from

[11] Mosier, D.T. and R.T. Ray, "Instream flows for the Lower Colorado River," Lower Colorado River Authority (LCRA), Austin, Texas, 1992.

Austin to Bay City).[12] Also, based on the distribution and abundance of habitat suitable for the maintenance of populations of a set of representative native riverine species, LCRA divided the lower river into five distinct reaches, of which the lowest—the Egypt reach—encompasses the proposed intake location for this alternative. Instream flow guidelines were established for each reach based on evaluations of habitat use by representative fish species, coupled with an assessment of the effect of river discharge on the amount of suitable habitat at selected locations within each reach. In the Egypt reach, monthly target flows (those to be maintained when supplies are adequate, but to be considered interruptible subject to demand curtailment during drought periods) range from 160 cfs during August to 670 cfs in May and 540 cfs in June. The target flows are substantially lower than the corresponding modern monthly medians at Columbus and lower than the target flows developed for the upstream reaches. The disparity is due to the general lack of suitable habitat for the primary evaluation species (blue sucker, Cycleptus elongatus) and other flow-sensitive forms in the Egypt reach. The proposed diversion of water held under existing water rights will meet the LCRA's instream flow targets.

Below Bay City, the Colorado River is tidally influenced (Segment 1401), and its aquatic community is characterized by more marine species. The river mouth has recently been relocated by the USCOE so that it no longer discharged directly into the Gulf of Mexico but into the eastern arm of Matagorda Bay, as it did prior to its rapid delta progradation some 60 years ago. This action is expected to increase Colorado River inflows to Matagorda Bay by about 30 percent (from an average of 1.2 million to approximately 1.7 million acft/yr).[13]

Nueces Estuary

Following use in the Corpus Christi area, a portion of the combined Lake Texana and Garwood water would be returned to the Nueces Estuary system as treated wastewater. Previous studies reported that average monthly salinities in Upper Nueces Bay would decrease with the implementation of this option. Increased freshwater inflows into Nueces Estuary are expected to benefit shrimp and some other aquatic species.

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[12] Ibid.

[13] Texas Water Development Board (TWDB), Unpublished data, "Bay and Estuaries Study Program," TWDB, Austin, Texas, 1990.

Proposed Pipeline Route

The potential pipeline route includes the gulf Prairies vegetational area, the Western Gulf Coastal Plan ecoregion, and the Texan biotic province. Post oak savannah and tall grass prairies dominated by oaks, mesquites (*Prosopis glandulosa*), acacias and prickly pears (*Opuntia spp*.) characterize the Gulf Prairies vegetational area. This vegetation is supported by acidic clays and clay loams interspersed by sandy loams.

Plant and animal species listed by TPWD, USFWS, and TOES that may be within the vicinity of the pipeline routes were listed in Table 4C.14-1.

All potential route passes through or is in the vicinity of Bald Eagle (in 1999, downgraded from endangered to threatened status) habitat. The NHP has mapped Bald Eagle habitat from Lake Texana along the Lavaca and Navidad Rivers. Construction of either pipeline could disturb this habitat. Other protected species that were not mapped in the project area but that could have habitat in the vicinity either of the proposed alternatives, include the black bear, jaguarundi, ocelot, and the Texas tortoise. The animals depend on brushland and mesquite scrubland habitats in the coastal prairies. The Texas tortoise occupies shallow depressions at the base of bushes and cacti and underground burrows. Another reptile, the timber/canebrake rattlesnake is usually found in bottomland habitats that support hardwoods.

The white-tailed hawk (*Buteo albicaudatus*), interior least tern (*Sterna antillarum athalassos*), and Eskimo curlew (*Numensis borealis*) also inhabit the coastal prairies. The white-tailed hawk can be found in open prairies and mesquite/oak savannah, while the interior least tern inhabits barren to sparsely vegetated sandbars along river, lake, and reservoir shorelines. The Eskimo curlew has historically migrated through the coastal prairies in March and April.

Most of the affected land would be expected to be returned to agricultural uses following construction. Pipeline construction would include some impact to woods; however, such impacts would be reduced from the figures given above by judicious pipeline alignment. Several small creeks would be crossed by the proposed pipeline. Vegetation in cropland and pastures, and animal species associated with these habitats, would be expected to return to near original condition following seeding.

Archeological and Cultural Resources

A cultural resource/archeological survey will need to be conducted prior to implementing project according to Antiquities Code of Texas requirements. Archeological or historical sites should be avoided in the design phase of the project.

4C.14.4 Engineering and Costing

The major facilities required for pumping the Garwood Purchase from an off-channel storage reservoir near Bay City at a uniform rate to the Texana Pipeline facilities and then to the City of Corpus Christi via the Texana Pipeline (Option 1) are:

- Surface water intake and pump station near Bay City;
- Transmission pipeline from the Colorado River near Bay City to a new off-channel storage site near Bay City;
- Surface water intake and pump station at the off-channel storage site;
- Transmission pipeline (36 miles) from the off-channel storage site to a terminal storage tank at the Texana Pipeline intake pumping station, and;
- Junction piping and appurtenances to tie the Garwood Pipeline to the Texana Pipeline.

The major facilities required for pumping the Garwood Purchase from Bay City to West Mustang Creek (Option 5) and then to the City of Corpus Christi via the Texana Pipeline are:

- Surface water intake and pump station near Bay City; and
- Upsized Texana Pipeline intake and intermediate pumping stations.

The major facilities required for pumping the Garwood Purchase from Bay City to Furbor Canal (Option 6) and then to the City of Corpus Christi via the Texana Pipeline are:

- Surface water intake and pump station near Bay City;
- Transmission pipeline (29 miles) from booster station at the end of Furbor Canal to a terminal storage tank at the Texana Pipeline intake pumping station;
- Junction piping and appurtenances to tie the Garwood Pipeline to the Texana Pipeline; and,
- Upsized Texana Pipeline intake and intermediate pumping stations.

4C.14.4.1 Uniform Peak Delivery (such as Option 1)

The City of Corpus Christi study did not include costs for Option 1. The costs presented in the 2001 Plan for uniform delivery rate were updated to reflect Second Quarter 2002 Prices.

The estimated capital cost for building the transmission facilities to deliver the water at a uniform delivery rate from Bay City to the Texana Pipeline is $54,156,000 as shown in Table 4C.14-2. After land acquisition costs and cost for engineering, legal, environmental mitigation, and interest during construction, the total project cost comes to $81,117,000. The debt service at 6 percent over 30 years and the annual operations and maintenance costs, including energy, result in a total annual cost of $9,804,000. The additional power costs necessary to deliver the 35,000 acft/yr through the Texana Pipeline are included in the annual energy costs. Dividing by 35,000 acft/yr equates to an annual cost of $280 per acft.

4C.14.4.2 Option 5 – Garwood Town Canal to West Mustang Creek

The estimated capital cost for building the transmission facilities to deliver the water to the Texana Pipeline via Town Canal and West Mustang Creek is $3,257,000 as shown in Table 4C.14-3. After costs for engineering, legal, environmental mitigation, and contingencies at approximately 35 percent capital costs, the total project cost comes to $4,397,000. Annual costs were not presented in the study.[14]

4C.14.4.3 Option 6 – Gulf Coast Furbor Canal to Mary Rhodes Pipeline

These costs shown in Table 4C.14-4 assume LCRA existing facilities are used to transport water from Bay City through the Furbor Canal. The cost of a new 4500 horsepower pump station on the Furbor Canal is $11,161,000, which includes engineering and administrative contingencies at 35 percent. The 29-mile pipeline to transmit water from the pump station to the Texana pump station is expected to cost $36,615,000. Annual costs were not presented in the study.[15]

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[14] Costs obtained from "Garwood Water Project – Phase I Report," 2004. Costs are presented in Second Quarter 2002 Prices, but were reported as 2004 Dollars.
[15] Ibid.

Table 4C.14-2.
Cost Estimate Summary for
Garwood Pipeline – Off-Channel Storage Option
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Off-Channel Storage Reservoir (8,000 acft)	$10,105,000
Intake and Pump Station at Colorado River (150 cfs)	6,858,000
Intake and Pump Station at Off-Channel Storage (48 cfs)	4,743,000
Transmission Pipeline (64-inch from Colorado River, 5.9 miles)	5,591,000
Transmission Pipeline (48-inch from Off-Channel Storage, 35.6 miles)	24,805,000
Storage Tank	1,221,000
Other (Access Roads/Stilling Basin)	833,000
Total Capital Cost	**$54,156,000**
Engineering, Legal Costs and Contingencies	$16,502,000
Environmental & Archaeology Studies and Mitigation	1,736,000
Land Acquisition and Surveying (781 acres)	3,266,000
Interest During Construction (2 years)	5,457,000
Total Project Cost	**$81,117,000**
Annual Costs	
Debt Service (6 percent, 30 years)	$4,421,000
Reservoir Debt Service (6 percent, 40 years)	1,032,000
Operation and Maintenance:	
Intake, Pipeline, Pump Station	615,000
Dam and Reservoir	152,000
Pumping Energy Costs[1]	3,584,000
Total Annual Cost[2]	**$9,804,000**
Available Project Yield (acft/yr)	**35,000**
Annual Cost of Water ($ per acft)	**$280**
Annual Cost of Water ($ per 1,000 gallons)	**$0.86**

[1] Includes cost of pumping additional 35,000 acft/yr in Texana Pipeline.
[2] Total Annual Cost does not include the cost previously incurred for the purchase of the 35,000 acft/yr from the Garwood Irrigation Company.

Table 4C.14-3.
Cost Estimate Summary for
Option 5 – Garwood Town Canal to West Mustang Creek
(Second Quarter 2002 Prices)

Item	***Estimated Costs for Facilities***
Capital Costs	
Tie-in at Town Canal	$465,000
Upgrade to Existing Pump Station	2,792,000
Total Capital Cost	**$3,257,000**
Engineering, Legal Costs and Contingencies	$1,140,000
Total Project Cost	**$4,397,000**

Table 4C.14-4.
Cost Estimate Summary for
Option 6 – Gulf Cost Furbor Canal to Mary Rhodes Pipeline
(Second Quarter 2002 Prices)

Item	***Estimated Costs for Facilities***
Pipeline	
54-inch Diameter Pipeline	$25,384,000
Cathodic Protection	1,154,000
6-inch Air Valves	540,000
8-inch Blow off Valves	372,000
Environmental Permitting	115,000
Tunneled Road Crossings:	
SH71	154,000
SH172	154,000
River Crossing	93,000
Engineering, Admin and Contingency @ 30 percent	8,649,000
Pipeline Total	**36,615,000**
Pump Station	
4500 HP Pump Station	8,268,000
Engineering, Legal Costs and Contingencies	2,894,000
Pump Station Total	**11,161,000**
Total Project Cost	**$47,776,000**

4C.14.5 Implementation Issues

This option requires the construction of new facilities as well as the upgrade and use of the pumping facilities owned and operated by the LNRA. Implementation of this option would require an agreement with the LNRA.

In addition to the differences in cost, the water treatment operations associated with delivery should be analyzed in greater detail. Delivery of the Colorado River water at a uniform annual rate to the Texana Pipeline offers a significant benefit to the operations of the O.N. Stevens Water Treatment Plant by reducing rapidly changing raw water characteristics that could occur with the Colorado River water delivered directly to the Texana Pipeline at a peak flow rate. The only opportunities for the Lake Texana water and Colorado River water to blend would be in the Texana Pipeline and in the presedimentation basin at the water treatment plant. Corpus Christi has already conducted extensive studies on the treatment of Colorado River water with consideration of their existing raw water supply sources. The results of these studies should be used to analyze and evaluate the impact that fluctuating raw water qualities and quantities from the Texana Pipeline will have on the treatment plant operations.

Requirements Specific to Interbasin Transfer of Water

1. It will be necessary to obtain these permits:
   a. Coastal Coordinating Council review.
   b. TPWD Sand, Gravel, and Marl permit.
   c. GLO Sand and Gravel Removal permits.
2. Permitting, at a minimum, will require these studies:
   a. Evaluation of instream flow impacts.
   b. Habitat mitigation plan.
   c. Environmental studies.
   d. Cultural resource studies.
3. Land and easements will need to be acquired by negotiations or condemnation.

Requirements Specific to Pipelines

1. Necessary permits:
   a. U.S. Army Corps of Engineers Sections 10 and 404 dredge and fill permits for stream crossings.
   b. General Land Office Sand and Gravel Removal permits.
   c. General Land Office easement if pipeline crosses any state owned riverbeds.
   d. Coastal Coordinating Council review.

   e. Texas Parks and Wildlife Department Sand, Gravel, and Marl permit for river crossings.
2. Run-of-river and easement acquisition.
3. Approval from various agencies for these crossings:
   a. Highways and railroads.
   b. Creeks and rivers.
   c. Other utilities.

Requirements Specific to Off-Channel Storage

1. Permitting, at a minimum, will require these studies:
   a. Habitat mitigation plan.
   b. Environmental studies.
   c. Cultural resource studies.
2. Land will need to be acquired by negotiations or condemnation.
3. TPDES General Permit for Construction Activity.

4C.14.6 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 4C.14-5.

Table 4C.14-5.
Evaluation Summary of the Garwood Pipeline

Impact Category	*Comment(s)*
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Firm Yield: 35,000 per acft/yr. 2. Good reliability. 3. Approximately $280 per acft.
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. Some impact to Colorado River, due to utilization of water rights. Possible adverse impact to instream flows during drought conditions. 2. Negligible impacts to Lavaca-Colorado Estuary. Possible adverse impact to bay and estuary inflows during drought conditions. Potential benefit to Nueces Estuary from increased freshwater inflows. 3. Some impacts due to pipeline (and/or off-channel). 4. Some impacts due to pipeline (and/or off-channel). 5. Low impact to threatened/endangered species. 6. Cultural resource surveys will be required to avoid any significant sites. 7. Low water quality impacts unless water delivered at high flow rates.
c. Impacts to State water resources	• No apparent negative impacts on water resources
d. Threats to agriculture and natural resources in region	• None
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Standard analyses and methods used
g. Interbasin transfers	• Rights to transfer Colorado River water to Nueces River Basin were obtained.
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None

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4C.15 Brush Management (N-15)

4C.15.1 Description of Strategy

The interest in brush management as a means to increase water supply has its roots in (1) the belief that Texas rangelands changed after settlement and use by Europeans from predominantly open grasslands to increasing domination of brush, and (2) the significantly greater interception of water by brush than grasses. The former suggests that the "natural" character of Texas rangelands would be grassland. The latter suggests the possibility of increasing aquifer recharge and streamflow by controlling and limiting growth of brush and trees in areas where grasslands would have naturally dominated. For this brush management option, brush management methods will be described, and estimates of cost and potential water supply effects will be presented.

Documentation of early European settlers[1] described Texas rangelands as grasslands. Prior to settlement by Europeans, with its associated grazing, significant brush growth was inhibited due to several natural conditions. Tree seeds commonly die following germination in grass cover because they cannot compete with grasses for sunlight and moisture. Also, any surviving seedlings are destroyed typically in periodic wildfires that occur in natural grasslands. Heavy grazing lessens the competitiveness of grass relative to brush and removes the fuel (grass) from rangeland wildfires. The result of heavy grazing is the increased dominance of trees and brush in grasslands.[2] This pattern of vegetation was common worldwide with the advent of European settlement of rangelands.[3]

In view of the consequences of heavy grazing on rangelands, ranchers have a compelling interest in controlling brush (i.e., the livestock-carrying capacity of rangeland is reduced by large increases in woody cover).[4] The brush in the Coastal Bend Region includes but is not limited to common species such as blackbrush, granjeno, mesquite, live oak, and pricklypear. The effect

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[1] Smiens, F., S. Fuhlendorf, and C. Tayor, Jr., "Environmental and Land Use Changes: A Long-Term Perspective," Juniper Symposium Proceedings, Texas A & M Agricultural Experiment Station, Sonora, Texas, 1997.
[2] Thurow, T. L., "Assessment of Brush Management as a Strategy for Enhancing Water Yield," Proceedings of the 25th Water for Texas Conference, Texas Water Resources Institute, Texas A & M University, 1998.
[3] Archer, S., "Woody Plant Encroachment into Southwestern Grasslands and Savannas: Rates, Pattern and Proximate Causes," Ecological Implications of Livestock Herbivory in the West, M. Vavra, W. Laycock, and R. Piper (editors), Society for Range Management, Denver, Co, 1994.
[4] Redecker, E. J., "The Effects of Vegetation on the Water Balance of an Edwards Plateau Watershed: A GIS Modeling Approach," M.S. Thesis, Texas A & M University, 1998.

on livestock-carrying capacity results from the decrease in grasses that are of significant nutritional value to the livestock. Livestock avoid grazing the brush and thus provide these brush species a competitive advantage over the grasses preferred by livestock. For a unit grazing area, fewer livestock can be supported as the percentage of brush increases. This suggests there would be some economic incentive for ranchers to control brush, and to the extent that reductions in brush cover on rangeland results in larger quantities of recharge to aquifers and run-off to streams, brush management may result in increased water supplies for municipal, industrial, irrigation and other uses.

More problematic for brush management, however, is the evidence that more Texas ranches are being purchased for reasons other than grazing.[5] A survey of the Edwards Plateau[6] found that ranch owners who are not dependent on livestock income are less interested in investing in brush management. Some within this group of ranchers may practice brush management, but they do so for reasons other than agricultural economics.

According to previous studies, brush management may have detrimental effects on certain types of wildlife. Brush species constitute a significant portion (>58 percent) of nutritious forage for white tailed deer, and provide shelter and hiding cover for wildlife. In 1996, hunting and wildlife watching contributed $2.6 billion to the Texas economy. Hunting is popular in South Texas and reportedly generates approximately 75 percent of total income to landowners in the Coastal Bend Region.[7] Previous studies recommend maintaining 40 to 60 percent brush to provide good deer habitat.[8] Consequently, it may provide greater regional benefits to leave more untreated brush to maintain diversity essential to good wildlife habitat and hunting.

Brush management is one of many land management practices, collectively referred to as "voluntary land stewardship", that can provide water supply at its origin. Voluntary land stewardship includes (but is not limited to) absorbing rainfall, reducing run-off, using prescribed fire properly, planning and managing grazing, brush management, managing erosion, wildlife and habitat management, and protecting springs and creek banks. With an optimal, voluntary

[5] Rowen, R. C., "Are Small-Acreage Livestock Producers Real Ranchers?," Rangelands 16:161-166, 1994.
[6] Garriga, M. D., "Tradeoffs Associated with Increasing Water Yield from the Edwards Plateau, Texas: Balancing Private Costs and Public Benefits," M.S. Thesis, Texas A & M University, 1998.
[7] Josephine Miller, CBRWPG meeting, May 2004.
[8] Lyons, Robert K. and Tim F. Ginnett, "Integrating Deer, Quail, and Turkey Habitat: Brush Management Effects on Deer Habitat", Texas Agricultural Extension Service E-98, September 2001.

land stewardship program, floods are reduced, aquifers are replenished, and water is released more slowly and steadily into streams, rivers, lakes and bays.[9] Although this water management strategy specifically addresses supplies attributable to brush management, additional water supply benefits, including additional inflow to reservoir systems, may be achieved with a comprehensive land stewardship program.

4C.15.2 Potential Water Yield from Brush Management

In terms of water supply, yield is the quantity of water available in a year for municipal, industrial, agricultural, and other uses. Firm yield is the quantity of water available during a critical drought. From the water supply perspective, yield is expressed as acre-feet (acft) per year. However, increasing the quantity of water that is not intercepted by brush on rangelands does not necessarily increase yield as defined by water supply. This is because there are other factors that could prevent this water from being available. For example, the water could enter the soil as deep percolation. It could also be captured in a rangeland impoundment.

A water balance is used to estimate the runoff and/or deep percolation from rangeland. The water balance is described in the following equation,[10]

$$\text{Runoff} + \text{Deep Percolation} = \text{Precipitation} - \text{Evapotranspiration}$$

and its variables are defined as follows:

Runoff is water that leaves the watershed through surface flow;

Deep Percolation is water that leaves the watershed by percolating through soil beyond the reach of the root zone; and

Evapotranspiration is water vapor entering the atmosphere through both leaf tissue and the drying of wet soil.

According to the water balance, runoff and/or deep percolation can be increased by decreasing evapotranspiration, which can be accomplished by managing vegetation. There are large differences in interception loss (water in the canopy that can be evaporated) among the common brush (mesquite, blackbrush, and granjeno) and grasses. Interception losses in Texas range from 14 percent for grass to 46 percent for live oak and 73 percent for juniper.[11] Thus, a

[9] Letter from Texas Wildlife Association to Ms. Carola Serrato, Co-Chair Region N, September 21, 2005.
[10] Thurow, T.L., Op. Cit., 1998.
[11] Thurow, T. L. and Hester, J. W., "How an Increase in Juniper Cover Alters Rangeland Hydrology," Proceedings Juniper Symposium, Texas A & M Agricultural Experiment Station Technical Report 97-1, 1997.

strategy of limiting brush cover and increasing grass cover would presumably increase runoff and/or deep percolation.

There has been significant research on the effects of controlling juniper on water yield. Some of the information generated from juniper research will apply to the Coastal Bend Region, even though there is no evidence of juniper in the region. The seasonal water use differences among trees, brush, and grasses common to the Edwards Plateau and northern Rio Grande Plains is demonstrated in Table 4C.15-1. The average unit water consumption for mesquite and Ashe Juniper is more than twice the average of the common grasses in the region. Also notable is the impact of goat grazing (biological brush management) on water consumption. At the Sonora Research Station, there were 309 Ashe Juniper trees per acre in an ungrazed enclosure and 114 per acre in a nearby pasture having a history of grazing by Angora goats.[12] Converting these densities to leaf area in order to calculate the transpiration rate, it was determined that water use in the ungrazed tract was 1.12 acft/acre and only 0.28 acft/acre in the grazed tract for the growing season period, approximately April through September.[13]

Table 4C.15-1.
Densities and Seasonal Water Use for Common Plant Species

Species	***Density***	***Seasonal Water Use[1] (acft)***
Mesquite	307 plants/acre	0.93
Juniper (no grazing)	309 plants/acre	1.12
Juniper (goat grazing)	114 plants/acre	0.28
Oak	50 plants/acre	0.96
Sideoats grama grass	890 lbs./acre	0.20
Kleingrass	1,525 lbs./acre	0.59
Buffalograss	1,340 lbs./acre	0.53

[1] The growing season of April through September.

Source: (Owens and Knight, 1992)

[12] Smiens, F., "Ashe Juniper: Consumer of Edwards Plateau Rangeland," Grazing Management Field Day, Sonora, Technical Report 90-1, Pages 17-21, 1990.
[13] Owens, M.K. and R.W. Knight, "Water Use on Rangelands," Water for South Texas, The Texas Agricultural Experiment Station, Pages 1-13, October 1992.

4C.15.2.1 Areas in Coastal Bend Region Where Potential Yield Increase Exists

An increase in runoff resulting from brush management could result in two potential water supply benefits: increasing recharge of groundwater due to increased sheet and/or stream flow traversing recharge outcrops or faults, or enhancing stream flows and existing water supply reservoirs. In addition, the construction of catchment dams at appropriate locations to redirect floodwaters into the aquifer would increase recharge. Consequently, additional water might be available for recharge due to increased runoff from rangeland where brush could be reduced in favor of grass. In the Coastal Bend Region nearly all the groundwater is in either the Gulf Coast or Carrizo-Wilcox Aquifers. Neither of these aquifers offers the same degree of recharge that the Edwards Aquifer offers due to its karst characteristics.

Reservoir water supply could also be enhanced. In 1985, the Texas State Soil and Water Conservation Board (TSSWCB) and the Texas Water Development Board identified a list of water supply reservoirs that might benefit from brush management. In the Coastal Bend Region, Lake Alice was listed for enhancing the water supply of the City of Alice.

4C.15.2.2 Best Management Practices for Brush Management

In Texas, brush management authorization was granted in 1985 by the Legislature to the TSSWCB. The purpose of the program is to provide "selective control, removal, or reduction of noxious brush such as mesquite, salt cedar, or other brush species that consume water to a degree that is detrimental to water conservation." The draft State plan delineates a critical area in Texas for brush management. The counties in the area are those having 16 to 36 inches of precipitation per year. Cost of brush management in the draft plan would be shared between landowners and the State. Local soil conservation districts would determine the maximum and average costs for different control methods and the cost share rates. The methods of brush management that the TSSWCB can approve are those that:

1. Are proven effective and efficient for brush management,
2. Are cost effective,
3. Have beneficial impact on wildlife habitat,
4. Will maintain topsoil to prevent erosion or siltation, and
5. Will allow for revegetation of the area with plants that are beneficial to livestock and wildlife.[14]

[14] Texas State Soil and Water Conservation Board, "Draft State Brush Control Plan," April 1, 1999

Acceptable brush management methods vary depending upon the extent of control needed as well as the type of brush present. The U.S. Department of Agriculture, Natural Resources Conservation Service has a conservation practice standard for brush management.[15] The standard includes biological, chemical, mechanical and burning methods for brush management. The biological method describes the use of goats for specific vegetation goats eat. The method involves defoliation of brush systematically. Another standard is for the use of herbicides for brush management. A review of Texas Agricultural Extension Service on-line Expert System for Brush and Weed Control Technology Selection, Version 1.09 (Excel)[16] for Jim Wells County provided information on chemical agents for control of brush (Table 4C.15-2).

The mechanical standard prescribes plowing, grubbing, chaining, and dozing as primary brush management methods. Studies on plowing and chaining have shown negative effects on white-tailed deer habitat destroying cover and diminishing availability of forage affecting wildlife food supply.[17] In most cases Natural Resources Conservation Service recommends burning to control sprouts. Prescribed burning is a very cost-effective method for controlling the sprouts and is desirable for deer habitat since it results in vegetation diversity. In addition, it is how nature controlled the brush before the grassland fires were suppressed.

Table 4C.15-2.
Chemical Agents for Control of Brush

Brush	*Chemical Agent*	*Control Level* [1]
Blackbrush	Remedy (triclopyr) Spike 20P	Very high control level Very high control level
Granjeno	Spike 20P	Very high control level
Live Oak	None recommended	
Mesquite	Remedy (triclopyr) Reclaim (clopyralid) Tordon 22K Velpar L	Very high control level Very high control level Very high control level High control level
Post Oak	Velpar L Spike 20P Crossbow	Very high control level Very high control level High control level
[1] Very high means 76 to 100 percent of plants killed; High means 56 to 75 percent killed.		

[15] Natural Resources Conservation Service, Conservation Practice Standard, Brush Management (Acre) Code 314.
[16] http://cnrit.tamu.edu/rsg/exsel/work/exsel.cgi
[17] Richardson, C.L, "Brush Management Effects on Deer Habitat", Texas Agricultural Extension Service L-2347, 1990.

The State of Texas, through the TSSWCB, approaches the cost of brush management on a cost-sharing basis with the ranchers. The presumption in the state brush management program is to equate rancher costs with rancher benefits. The benefit to ranchers would be the increases in income from cattle, sheep, and wildlife businesses that result from brush management. For the livestock businesses, other things equal, increasing the amount of useable vegetation could increase the net economic return to the rancher because the grazing capacity of the rangeland would be expanded through controlling brush. Economic benefits received by ranchers who practice brush management will be attributed largely to the economy of scale realized through increased production without a corresponding increase in costs. Once the total cost of brush management is determined, then the difference between the total cost and the benefit to the rancher would be the cost that might be attributed to the additional water yield. Rangeland owners who do not depend on agricultural income may not have direct economic benefits from brush management. Presumably, if the rancher receives no benefits, then the rancher would not be interested in engaging in practices that increase costs. Furthermore, if a land is predominantly used for hunting then brush management may be detrimental and result in income loss to landowner. Brush control costs in this case would probably be borne by the State or the regional water authority that would benefit from the increased water supply resulting therefrom.

4C.15.2.3 Cost of Brush Management

Studies have been done to determine brush management costs for rangelands in Texas.[18,19] Since these studies have occurred in the Edwards Plateau area which overlays part of the Coastal Bend Region and contains a similar vegetation profile, including watersheds within the Nueces and Frio River watersheds, the evaluation of this option is based on the assumption that the costs developed from these studies are relevant for use in evaluating this option. Nueces and Frio River watersheds were subdivided into Upper (Edwards) and Lower watersheds and cost separately. Table 4C.15-3 shows the present value in Second Quarter 2002 prices for controlling three different levels of mesquite based on previous study of Lower Nueces River

[18] Texas Agricultural Experiment Station Blackland Research and Extension Center, "Brush Management/Water Yield Feasibility Studies for Eight Watersheds in Texas", Compilation of Papers/Chapters by Various Authors, November 2000.
[19] Walker, J.W., F. B. Dugas, F. Baird, S. Bednarz, R. Muttiah, and R. Hicks, "Site Selection for Publicly Funded Brush Control to Enhance Water Yield," Proceedings, Water for Texas Conference, Austin, Texas, December 1998.

Watershed near junction at Three Rivers (downstream of Choke Canyon Reservoir). The costs for brush management of Lower Frio River watershed, which drains into Choke Canyon Reservoir, were the same. Costs are presented on a present worth basis because brush management requires an initial (year "0") investment plus a periodic future investment to maintain control.

4C.15.2.4 Potential Increased Runoff and/or Deep Percolation Due to Brush Management

Computer simulations for estimating runoff and/or deep percolation were undertaken for several watersheds: the North Concho River Basin in the northern Edwards Plateau near San Angelo, Texas;[20] Seco Creek watershed in Medina County;[21] Nueces River at confluence with Frio River at Three Rivers; and Frio River near Choke Canyon Reservoir.[22] The results of these simulations were then used in an economic analysis of brush management undertaken to increase the quantity of runoff and/or deep percolation.[23]

Table 4C.15-3.
Initial and Interim Costs[1] for Various Brush Management Methods

Brush Condition (method)	One Time Costs		Recurring Costs	
	Year 0 ($/acre)	Year 4 ($/acre)	Periodic Cost ($/acre)	Frequency of Control (years)
Heavy mesquite	47.05	41.82	26.14	7
Moderate mesquite (chemical then prescribed burn)	41.82	41.82	26.14	7
Light mesquite (chemical then prescribed burn)	41.82	41.82	26.14	7

[1] Initial and recurring costs were adjusted from Second Quarter 2000 prices to Second Quarter 2002.

Source: Bach, Joel P. and J. Richard Connor, "Nueces and Frio River Watershed—Economic Analysis," Brush Management/ Water Yield Feasibility Studies for Eight Watersheds in Texas, November 13, 2000.

[20] Bach, Joel P. and J. Richard Connor, "Economic Analysis of Brush Control Practices for Increased Water Yield: The North Concho River Example," Proceeding, Water for Texas Conference, Austin, Texas, December 1998.
[21] Walker, et al., Op. Cit., December 1998.
[22] Rosenthal, Wesley, "Frio and Nueces River Watershed- Hydrologic Simulation", Brush Management/Water Yield Feasibility Studies for Eight Watersheds in Texas, November 13, 2000.
[23] Bach, Joel P. and J. Richard Connor, Op. Cit., November 2000.

The estimated runoff and/or deep percolation from these brush management simulations varied significantly between the four sites. The runoff and/or deep percolation per unit area of brush management ranged from 7,495 gallons/acre in the North Concho simulation to 82,561 gallons/acre in the Frio River simulation (Table 4C.15-4). The values reported in Table 4C.15-4 represent an estimate of the enhanced runoff and/or deep percolation that could be expected from brush management (i.e., the difference between the current condition with brush and the condition without brush).

Other studies in Texas have shown similar effects to those simulated for the Frio River site. For example, at the Texas Agriculture Experiment Station at Sonora, a 10-year catchment-level study of brush removal in concert with grass replacement showed an estimated 100,500 gallons per acre per year of increased deep percolation in soils with high infiltration rates.[24] However, improvements in deep percolation and runoff quantities would not necessarily result in an increase in aquifer or reservoir yields.

Table 4C.15-4. Annual Runoff and/or Deep Percolation for Brush Management Watersheds

Site	Brush Management Scenario	Annual Runoff and/or Deep Percolation	
		gallons/ acre	acft/acre
North Concho[1]	Remove all brush	7,495	0.023
Seco Creek[2]	Remove all brush	35,192	0.108
Nueces River (to confluence with Frio River at Three Rivers)[3]	Remove all brush	66,791	0.205
Frio River (to Choke Canyon Reservoir)[3]	Remove all brush	82,561	0.253

[1] Source: Bach and Connor, December 1998.
[2] Source: Walker, et al., December 1998.
[3] Source: Bach and Connor, November 2000.

In November 2000, SWAT models[25] were used to simulate effects of brush removal on increased runoff water for Upper Nueces River watershed (at junction with Frio River just below Choke Canyon Lake) and Frio River (upstream of Choke Canyon Lake) during 1960 through 1998. For the upper Nueces River watershed, the results indicated that if 74 percent of the

[24] Thurow, T. L., Op. Cit., 1998
[25] Rosenthal, Wesley, "Nueces and Frio River Watershed- Hydrologic Simulation", Brush Management/Water Yield Feasibility Studies for Eight Watersheds in Texas, Nov 2000.

4,283,000 acre watershed was treated for brush removal (i.e., 3,188,800 acres) then an additional flow of 523,141 acft to Lake Corpus Christi could be expected.[26] The Frio River results indicated that if 66 percent of the 1,329,094 acre watershed was treated for brush removal (i.e., 882,883 acres) then an additional average flow of 59,806 acft to Choke Canyon could be expected.[27] Over 50 percent of the watershed area where brush removal was simulated contained slopes less than 10 percent, replacing brush with grass.

For the 2006 South Central Texas Regional Water Plan[28], an Hydrologic Simulation Program – Fortran (HSPF) model was used to evaluate Nueces and Blanco River Watersheds for a 65-year simulation (1934 – 1998) to determine the effects of brush management. The Nueces Basin shady area included contributing watershed area upstream of USGS Gage 08192000 (Nueces River below Uvalde). The Blanco Basin study area included Blanco River watershed area upstream of USGS Gage 08171300 (Blanco River near Kyle).

According to HSPF model results, brush management on the Nueces River watersheds is estimated to increase recharge in the Nueces Recharge Basin an average of 9,862 acft/yr (or 8.6% increase when compared to recharge without brush management. For the 5-year drought period[29] (1952 – 1956), the estimated increase in Edwards Recharge in the Nueces Basin is 920 acft/yr (or 2.2%).

Brush management on the Blanco River watershed is estimated to increase recharge in the Blanco Recharge Basin an average of 4,815 acft/yr. For the 5-year drought (1952 – 1956), the estimated increase in Edwards Recharge in the Blanco Basin is 2,215 acft/yr (or 7.3%).

This recharge enhancement information was then processed by an Edwards Aquifer model (GWSIM4) to quantify potential increases in sustained yield.[30] GWSIM4 Edwards Aquifer groundwater flow model developed by the Texas Water Development Board simulates Edwards Aquifer response in terms of water levels and springflows for specified recharge and

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[26] Assumes a delivery rate of 80 percent, which accounts for stream channel transmission losses from junction at Three Rivers to Lake Corpus Christi and shallow soils that allow for percolation.
[27] Assumes a delivery rate of 26 percent to account for stream channel losses that occur after water leaves each subbasin.
[28] South Central Texas Regional Water Plan, 2006.
[29] The Nueces and Blanco Basins drought of record was from 1952 through 1956, according to NWS precipitation gage data (16.8 inches of rainfall in Nueces Basin and 25.4 inches of rainfall in Blanco Basin, based on 5-year precipitation average from 1934 – 1998).
[30] Sustained yield of the Edwards aquifer is defined as the amount of pumped from the Edwards such that a simulated minimum flow at Comal Springs is protected during the drought of record (in this case, 60 cfs).

pumping rates. The brush management option evaluated for the Nueces and Blanco Basins is calculated to increase sustained yield by 1,728 acft/yr and 540 acft/yr, respectively. It is emphasized, however, that these recharge estimates pertain only to the Edwards Aquifer area and are not necessarily applicable to other aquifers. For a more detailed discussion of this brush management study, see Section 4C.28 in the 2006 South Central Texas Regional Water Plan.

Although these brush management projects[24,27] could potentially provide additional water opportunities for Region N, to determine these benefits would require additional studies to translate increased annual flow to Choke Canyon Reservoir and Lake Corpus Christi to firm yield.

4C.15.2.5 Preliminary Evaluation of Areas within the Coastal Bend Region where Brush Management Can Potentially Increase Runoff and/or Deep Percolation

There are an estimated 4.26 million acres of brush cover located on 10 percent slopes in the Coastal Bend Region (Table 4C.15-5).

Table 4C.15-5. Approximate Brush Covered Areas with Slopes less than 10 Percent[1]

County	Live Oak Woods/ Parks (acres)	Mesquite and Blackbrush Brush (acres)	Mesquite, Live Oak, and Blue Wood Parks (acres)	Mesquite and Granjeno Parks (acres)	Mesquite and Granjeno Woods (acres)	Totals	Percentage of Total County Area (percent)
Aransas	37,692	0	0	10,050	0	47,742	30
Bee	0	137,430	118,344	0	0	255,774	45
Brooks	121,823	2,331	0	434,802	0	558,956	93
Duval	0	667,796	0	84,884	22,201	774,881	68
Jim Wells	0	64,153	0	36,472	173,228	273,853	49
Kenedy	217,111	0	0	662,644	4,512	884,267	95
Kleberg	2,021	0	0	362,302	97,794	462,117	83
Live Oak	0	262,232	0	0	0	262,232	40
McMullen	0	510,629	0	0	7,539	518,168	73
Nueces	2,689	36,807	0	29,567	0	69,063	13
San Patricio	17,738	34,212	40,970	0	0	92,920	21
Totals	399,074	1,715,590	159,314	1,620,721	305,274	4,199,973	—

[1] Based on Texas Parks and Wildlife GIS database, assuming 15 percent of total areas are suitable for viable grasses replacing brush (i.e., slopes less than 10percent).

4C.15.3 Environmental Issues

The process of brush management targets blackbrush, mesquites and other brush that compete with native grasses for water and nutrients. Recent studies conducted on Blackland prairie demonstrated both a rebound of grasses and increased surface water. However, there are concerns about the techniques used to remove brush. These concerns are mention and described below.

Chaining, cabling, disking and other mechanical methods that strip brush also remove wildlife habitat and expose surfaces to erosion by wind and water. Species that reside in brush habitat can be killed by these techniques. Low impact, hand techniques, that clear brush in a patchwork fashion, leaving brush berms to control erosion and provide protection for wildlife have proven effective in allowing native range recovery and would be consistent with the brush management option. A range management plan to protect well-populated species, and federal and state protected species should be designed to implement this option and avoid taking protected species. Important species that could possibly be affected by a decrease in brushland are notable. The endangered Ocelot and Jaguarundi reside in dense brushlands, along with the Texas Horned Lizard, Texas Tortoise and Spot-tailed Earless Lizard to name a few. Conversely, allowing the brush to remain may also yield consequences. Brush populations that rapidly expand can result in a decrease in favorable vegetation for livestock and wildlife.[31] Occasionally the overwhelming density of brush can even limit the movement of wildlife within the vicinity. A survey of species that may inhabit any possible study areas would need to be conducted and evaluated.

The chemical method of controlling brush should be implemented only after very thorough evaluation because of the risk of chemical runoff into streams and penetration into the underlying aquifers. The chemicals used to remove unwanted vegetation may also be detected in surface water sources or affect air quality as they can be sprayed from the air or directly onto the brush. The concentration, type and quantity of chemicals applied should be very carefully assessed to determine exact consequences.

[31] Hart, Charles and Allan McGinty, "Treatment Life Following Control of Mixed Brush in the Davis Mountain Area," 1998.

4C.15.4 Engineering and Costing

The 2006 South Central Texas Regional Water Plan estimates unit water costs range from $1,952 to $2,080 per acft. These costs are based on increases in sustained yields from the Edwards Aquifer (540 acft/yr and 1,728 acft/yr attributed to brush management in the Blanco Basin and Nueces Basin, respectively). These costs are not necessarily applicable to other basins and effects of brush management projects would be different for other aquifer systems.

The cost of enhanced water yield from brush management cannot be estimated for the Coastal Bend Region because associated hydrologic data are not adequate to determine any increases in water supply yield for Choke Canyon Reservoir/Lake Corpus Christi system. However, the costs of brush management can be reasonably estimated because of the studies of brush management practices in Texas, for Nueces and Frio River watersheds (Table 4C.15-6). The costs in Table 4C.15-6 were computed using 30 years as the project horizon, 6 percent interest, and the initial, year 4, and periodic costs in Table 4C.15-3 for brush management.

Three assumptions have been made to simplify the estimation of brush management cost:

1. The removal of the brush in the Coastal Bend Region that contains a significant population of live oak trees would cost about the same as removal of heavy mesquite ($13.28/acre/year, Second Quarter 2002 prices), as with the mesquite and granjeno woods.
2. The "mesquite and blackbrush" and the "mesquite and granjeno parks" areas in the Texas Parks and Wildlife Department database are the equivalent of moderate growths shown in Table 4C.15-7 and are estimated to cost $12.66 per year per acre.

Table 4C.15-6.
Present Worth and Uniform Annual Costs for
30-Year Brush Management Projects under Varying Brush Conditions

Brush Condition	Total Discounted Present Value Per Acre (2nd Quarter 2002 Costs)	Discounted (Uniform) Annual Cost (per acre)[1]
Heavy mesquite	$182.77	$13.28
Moderate mesquite	$174.30	$12.66
Light mesquite	$174.30	$12.66

[1] Amortized over 30 years at 6 percent interest.

The average annual cost per acre for each county (Table 4C.15-8) is determined by dividing the total annual costs in Table 4C.15-7 by the estimated acreages in Table 4C.15-5, which are the estimated areas that might increase runoff and/or deep percolation as a result of brush management. Estimated annual costs of brush management in counties in the Coastal Bend Region range from $627,740 in Aransas County to $11.3 million in Kenedy County (Table 4C.15-7).

Table 4C.15-7.
Annual Cost of Brush Management for Counties in the Coastal Bend Region

County	Live Oak Woods/ Parks	Mesquite and Blackbrush Brush	Mesquite, Live Oak, and Blue Wood Parks	Mesquite and Granjeno Parks	Mesquite and Granjeno Woods	Totals
Aransas	$500,478	—	—	$127,262	—	$627,740
Bee	—	$1,740,258	$1,571,388	—	—	$3,311,646
Brooks	$1,617,579	$29,518	—	$5,505,830	—	$7,152,927
Duval	—	$8,456,195	—	$1,074,872	$294,793	$9,825,860
Jim Wells	—	$812,358	—	$461,834	$2,300,135	$3,574,327
Kenedy	$2,882,825	—	—	$8,390,952	$59,905	$11,333,682
Kleberg	$26,841	—	—	$4,587,768	$1,298,515	$5,913,124
Live Oak	—	$3,320,606	—	—	—	$3,320,606
McMullen	—	$6,466,016	—	—	$100,102	$6,566,119
Nueces	$35,705	$466,078	—	$374,405	—	$876,187
San Patricio	$235,533	$433,227	$544,005	—	—	$1,212,765
Totals	**$5,298,961**	**$21,724,256**	**$2,115,392**	**$20,522,922**	**$4,053,451**	**$51,714,981**

Table 4C.15-8.
Average Annual Cost of Brush Management for Counties in the Coastal Bend Region

County	Annual Average Cost per Acre	County	Annual Average Cost per Acre
Aransas	$13.15	Kleberg	$12.80
Bee	$12.95	Live Oak	$12.66
Brooks	$12.80	McMullen	$12.67
Duval	$12.68	Nueces	$12.69
Jim Wells	$13.05	San Patricio	$13.05
Kenedy	$12.82		

4C.15.5 Implementation Issues

Several implementation issues pertain to this potential water supply option. *In situ* brush management studies are only available for catchment-level examples comprising an area 1,000 acres or less. It is not proven that a large-scale brush management program would be practical because it would require the cooperation of many different landowners having different interests in their property. To make a significant impact upon increasing the yield of recharge to the Carrizo-Wilcox, Gulf Coast Aquifers and/or the CCR/LCC System, brush management would have to be practiced over a considerable area. In a specific target watershed, there may be property owners who are not dependent on grazing income and therefore have limited interest in brush management. To ensure cooperation of these ranch owners, additional subsidies or other consideration may be required which could alter the cost profiles for brush management.

Another issue is that most of the assumptions and results presented above are based on computer modeling rather than *in situ* examples that have the benefit of several years of performance to demonstrate results. It would be recommended that much more research be performed *in situ* at specific sites before public funds are invested in major projects.

One critical implementation issue is how the increase in runoff and/or recharge resulting from brush management would be related to water supply yield. Key questions that need answers are:

- How are the increased runoff and/or recharge verified?
- How much of the increased runoff and/or recharge results in yields of affected aquifers and/or reservoirs? and
- How is the increased yield of the affected aquifers and/or reservoirs verified?

4C.15.6 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 4C.15-9.

Table 4C.15-9.
Evaluation Summary of Brush Management to Enhance Water Supply Yield

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Indeterminate reliable quantity 2. Unknown 3. Unknown
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. May increase water runoff and instream flows 2. May increase bay and estuary inflows. 3. Brush control techniques may adversely affect existing wildlife populations 4. None or low impact. 5. May have negative affect on habitats for endangered species. 6. Chemical brush management methods may result in residual chemicals in aquifers and streams. 7. None or low impact.
c. Impacts to State water resources	• No apparent negative impacts on other water resources • Potential benefit to Gulf Coast and Carrizo-Wilcox water resources due to increased water for recharge • Potential benefits to surface reservoirs from increased runoff
d. Threats to agriculture and natural resources in region	• Potential threats to habitat due to removal of brush
e. Recreational impacts	• Could impact hunting
f. Equitable comparison of strategies	• Cost model for brush management is based on literature values • No estimate made for cost of water supply yield because yield not determined
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Improvement over current conditions
j. Effect on navigation	• None

4C.16 Weather Modification (N-16)

4C.16.1 Description of Strategy

Weather modification as it has been applied in Texas over the past 25 to 30 years involves cloud seeding to increase rain above what would have naturally occurred. The result of cloud seeding is referred to as rainfall enhancement. The concept of how this occurs is described below.

In natural rainfall, droplets are created from the presence of ice particles (crystals) in the cloud. These crystals are formed when freezing water contacts particles of dust, salt or sand. The ice crystals form a nucleus around which water droplets attach to make the size of the droplet increase. When the size of a droplet increases sufficiently, it becomes a raindrop and falls from the cloud. Cloud seeding is thought to increase the number of these "nuclei" available to take advantage of the moisture in the cloud to form raindrops that would not have otherwise formed. To be effective, seeding must be done at the correct time and in the correct manner.

As a cloud grows taller, the air temperature in the cloud cools and falls below the freezing point of water. This cooling effect means that the cloud droplets, which are much too small to fall as rain, are also cooled to a point where they respond to crystallization when contacted by an ice particle. Consequently, when there are fewer crystals to act as nuclei for raindrops, there will be less rain than would have been if more crystals were present. Although crude experiments to enhance rainfall were attempted in the U.S. as early as the mid-1800s, modern weather modification was begun in 1946 through an unintended laboratory event.

In 1946, V. Schaefer was involved with the General Electric Laboratory doing research to create artificial clouds in a chilled chamber. During one experiment, Schaefer believed the chamber was too warm and, to cool it, he placed dry ice in the chamber. With the chilled water vapor in the chamber, ice crystals formed a cloud around the dry ice. Believing dry ice would not be practical to transport to emerging rain clouds, Schaefer's colleague, Bernard Vonnegut, searched for a chemical that almost exactly matched the chemical structure of ice crystals. It was found that silver iodide (AgI) was such a chemical.[1] Silver iodide is termed "glaciogenic" because its chemical structure is like ice crystals. The other seeding chemical used when the cloud temperature is too warm for forming ice is calcium chloride (CaCl). Calcium chloride is "hygroscopic," which means it attracts water.

[1] Jensen, Ric, "Does Weather Modification Really Work?" Texas Water Resources, Summer 1994.

When silver iodide is introduced into a cloud, the number of ice crystals increases and the crystals contact water vapor causing it to freeze to the crystal. Considerable heat is released to the atmosphere during the freezing and crystal formation phase. The released heat causes the cloud to grow taller and its vertical wind velocity (updraft) to increase. This results in the cloud being able to pull in more moist air and, thus, create more raindrops. However, not all clouds are potential rainmakers. Generally, cloud seeding is performed with a meteorologist working in tandem with the pilot of the cloud seeding aircraft so that, with direction from the meteorologist, the pilot can target the most promising cloud(s).[2] The criteria used in Texas to find promising clouds, is to locate "feeder" cells near developing cloud formations that have temperatures below 23^{o} F. The target cloud must also have sufficient moisture and airflow to be a candidate. About 20 or 30 minutes prior to the desired rainfall event, the candidate cloud is seeded when the airplane releases silver iodide particles in a plume, typically at the base of the cloud so the updraft can draw the particles upward and make more contact with water in the cloud. Seeding has another effect on large, potentially dangerous thunderstorms capable of causing hail. Seeding tends to mitigate the extreme freezing that results in forming large particles of ice (hail) and makes the moisture more likely to fall as rain.

The criteria for cloud seeding based on experience in Texas since the early 1970s are the following:

- The cloud must be "convective," meaning that it displays instability in the atmosphere.
- Temperature at the top of the cloud must be 23^{o} F or less.
- The base of the cloud must be less than 12,000 feet elevation.

Clouds having the characteristics listed above exhibit a warm base, a strong updraft, and sufficient heat to carry water vapor to the cloud top.

A summary of recent cloud seeding experiments in Texas, Florida, Cuba, and Southeast Asia has been presented by TCEQ."[3] The TCEQ concludes the following:

- Cloud seeding with silver iodide increases rain generated by these clouds by extending the life of the clouds, by allowing the clouds to enlarge laterally so that they cover more area, and by slightly increasing the height of the clouds.

[2] Clouds may also be seeded using ground-based silver iodide dispensers. However, in this discussion, only the aircraft method is considered.

[3] Bomar, George, "Some Facts about Cloud Seeding from Recent Research on Rain Enhancement in Texas," Texas Commission on Environmental Quality, 1999.

- Rain production of seeded clouds is more efficient than for non-seeded clouds.
- The timing of seeding and the selection of clouds are fundamental. These are such critical factors that "…seeding at the wrong time and in the wrong place(s) may actually decrease the rainfall."[4]

4C.16.2 Potential Rainfall Quantities from Weather Modification

The findings from several Texas cloud seeding programs are summarized below. This information provides a basis for evaluating the reasonableness of assumptions for weather modification in the Coastal Bend Region. The programs to be discussed are the Southwest Cooperative Program (SWCP), the Texas Experiment in Augmenting Rainfall through Cloud-Seeding (TEXARC), the Colorado River Municipal Water District (CRMWD) Program, the Edwards Aquifer Authority (EEA) Program, the South Texas Weather Modification Association (STWMA) Program, and the Southwest Texas Rain-Enhancement Association (SWTREA) Program. Each of these programs is described below.

Southwest Cooperative Program (SWCP): The program was begun in 1986 as a cooperative effort between Oklahoma and Texas "…to develop a scientifically sound, environmentally sensitive, and socially acceptable, applied weather modification technology for increasing water supplies…in the southern High Plains."[5] The area involved was 5,000 square miles located between Midland-Odessa and Lubbock. Random cloud seeding experiments were conducted in 1986, 1987, 1989, 1990, and 1994.

During the period 1987 through 1990, 183 experiments were made (93 seeded, 90 non-seeded). The criteria for selection were the following:

- Liquid water content had to be at least 0.5 gm/m^3 and updrafts had to be at least 1,000 ft/min.
- The target had to be a multiple-cell convective unit.
- No cloud or cell height could exceed 10 km (above ground level).
- Some of the tops had to have temperatures -10^{o} C or colder.

The results confirmed increased rainfall. Compared to the non-seeded cells, the seeded cells displayed an increase in maximum height of 7 percent, an increase in the coverage of the rainfall

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[4] Ibid.
[5] Bomar, George, William L. Woodley, and Dale L. Bates, "The Texas Weather Modification Program: Objectives, Approach, and Progress," Journal of Weather Modification, April 1999.

event of 43 percent, an increase in the storm duration of 36 percent, and an increase in rain volumes of 130 percent.[6]

Texas Experiment in Augmenting Rainfall through Cloud Seeding (TEXARC): The State of Texas implemented the program in 1994 and 1995 to investigate physical processes within large storms in the San Angelo area. This research was focused on understanding the best ways of seeding clouds to make them more efficient producers of water, rather than quantifying the results. The results showed that seeding must be within the super-cooled updraft region of the cloud in order to increase rainfall. From this research it was shown that the seeding agent must be carefully placed either directly in the top of the updraft, or at the entrance to the updraft at the base of the cloud.

Colorado River Municipal Water District (CRMWD) Program: Having been started in 1971, this is the longest-running operational weather modification program in Texas. The target area is roughly the upper Colorado River Basin upstream from Spence Reservoir, comprising some 3,600 square miles. The goals for the program have always been first, to increase water supplies to Lake Thomas and Spence Reservoir, and secondly, to increase rainfall to agricultural areas. The reported long-term results are that there was a 34 percent increase (above normal historic precipitation) in the seeded areas and a 13 percent increase in non-seeded areas.[7,8]

Edwards Aquifer Authority (EAA) Program: (*substantial portions of this program description were reproduced from the EEA web page, e-aquifer.com, and are presented here unedited*)

"The Edwards Aquifer Authority board of directors voted in the fall of 1997 to obtain a permit to conduct precipitation enhancement, or cloud seeding, from the Texas Natural Resources Conservation Commission (now TCEQ). The Authority contracted with Weather Modification, Inc., to complete and submit the permit application on the Authority's behalf, and work with the TCEQ. The permit was granted by TCEQ in October 1998 and was valid for 4 years from January 1999 through December 2002. The permit allowed the Authority to conduct precipitation enhancement anytime during the year, including the traditional period of

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[6] Rosenfeld, D. and W. L. Woodley, "Effects of Cloud Seeding in West Texas: Additional Results and New Insights," Journal of Applied Meteorology, 1993.

[7] Jones, R., "A Summary of the 1988 Rainfall Enhancement Program and a Review of the Area Rainfall and Primary Crop Yield," Report 88-1 of the Colorado River Municipal Water District, 75 pages, 1988.

[8] Jones, R., "A Summary of the 1997 Rainfall Enhancement Program and a Review of the Area Rainfall and Primary Crop Yield," Report 97-1 of the Colorado River Municipal Water District, 54 pages, 1997.

April through September. The Authority committed $500,000 for the 1999 program with half the expenses reimbursed by the TCEQ."

"Each county in the target and South Central Texas Water Advisory Committee (SCTWAC) areas of the program can appoint a representative to sit on a Precipitation Enhancement Advisory Group. The group will work with the Authority in alerting the contractor about local conditions. The ways this committee has worked included communicating saturation conditions so that flights are suspended to avoid flood conditions and suspending flights during harvesting of crops. The assumption for enhanced aquifer recharge was 10 percent above the recharge quantity, which would occur without enhancement."

From 1999 through 2001, the Edwards Aquifer Authority contracted Weather Modification Inc. to perform weather modification services for the EAA Precipitation Enhancement Program over the 12 target counties presented in Table 4C.16-1. Woodley Weather Consultants[9] evaluated the data collected, which included 39 seeding events for the Blanco Basin and 21 seeding events for the Nueces Basin. This study area included six of the 12 target counties, including Kendall, Blanco, Hays, Comal, Real, and Uvalde Counties. In 2003, a study[10] was conducted to determine enhanced recharge attributable to the 1999 to 2001 seeding events, which concluded that the total increased recharge during the 3-year period was 1,972 acft in the Nueces Basin (a 0.29 percent increase) and 1,332 acft in the Blanco Basin (1.13 percent increase).[11]

Table 4C.16-1.
Edwards Aquifer Authority Weather Modification Program Counties

Target Counties	***Operational Counties***	***SCTWAC Counties[1]***
Bandera, Bexar, Blanco, Caldwell, Comal, Guadalupe, Hays, Kendall, Kerr, Medina, Real (east of U.S. Highway 83), and Uvalde	Gillespie, portions of Atascosa, Burnet, Frio, Kimble, Llano, Real, Wilson, and Zavala	Calhoun, DeWitt, Goliad, Gonzales, Karnes, Nueces, Refugio, San Patricio, Victoria, Atascosa, Wilson, Uvalde, Medina, Bexar, Comal, Hays, Guadalupe, and Caldwell
[1] Coastal Bend Water Advisory Committee (SCTWAC), as created by Senate Bill 1477.		

[9] Edwards Aquifer Authority, "Rainfall Data Summary and Assimilation," December 2002.
[10] LBG-Guyton Associates, "Assessment of Recharge Benefit from Enhanced Rainfall," June 2003.
[11] Note: Only half of the Nueces Basin was in the cloud seeding zone, which may have reduced the impact of cloud seeding on recharge in that basin.

In 2002, the Authority's Precipitation Enhancement Program was reduced to target Bandera, Bexar, Medina, and Uvalde Counties. South Texas Weather Modification Association was contracted by the Authority to seed Bexar, Bandera, and Medina Counties. Southwest Texas Rain Enhancement Association was contracted to seed Uvalde County. The current weather modification programs in South Central Texas and counties where they operate are presented in Figure 4C.16-1.

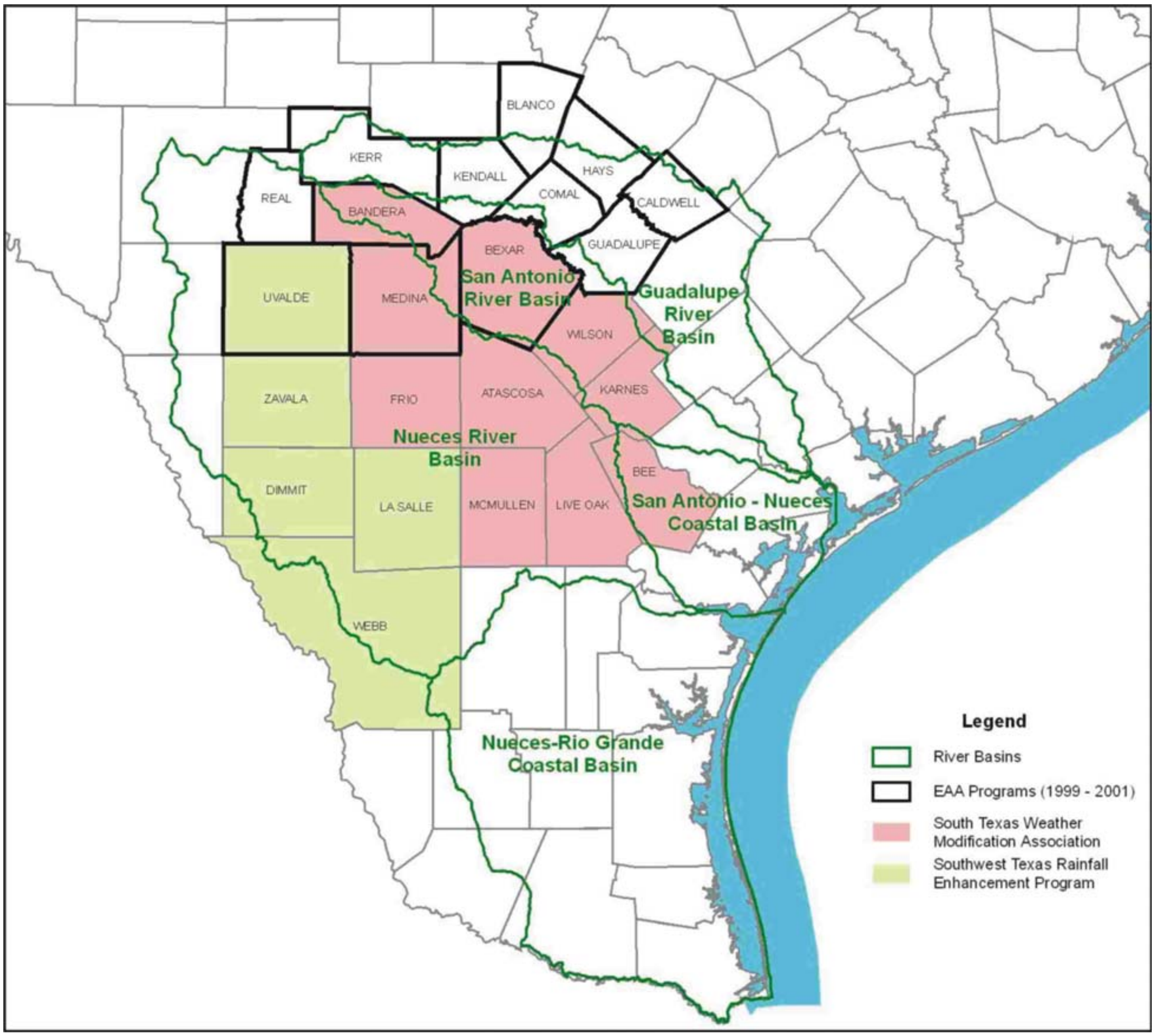

Figure 4C.16-1. South Central Texas Weather Modification Programs

South Texas Weather Modification Association (STWMA) Program: This program started in 1997 when the Evergreen Water District hired a contractor to conduct cloud seeding. In 1998, the addition of two pilots, a meteorologist, and the purchase of two planes enhanced this program considerably. The counties involved in the cloud seeding include Atascosa, Bee, Frio, Karnes, Live Oak, McMullen, and Wilson Counties. Since 2002, Bexar, Bandera, and Medina Counties have been added to the program. According to the 2004 STWMA Annual Evaluation Report, an increase of 1,225,900 acft (2.23 inches) was reported across the ten-county program area attributable to 45 seeding events between April 2, 2004, and October 27, 2004. This translates to a precipitation increase of 10.4 percent, on average, with the weather modification program. The highest precipitation increase was recorded for Atascosa County, at 14.8 percent. The three counties in Region N included in the program with reported precipitation increases are presented in Table 4C.16.2.

Table 4C.16-2.
Weather Modification Precipitation Enhancements in Region N Counties (2004)

Region N Counties	***Increases in Precipitation***		
	(acft)	***(inches)***	***(% increase)***
Bee	123,900	2.64	12.2
Live Oak	117,500	2.13	11.0
McMullen	126,800	2.14	10.2

Southwest Texas Rainfall Enhancement Association (SWTREA) Program: This program began in 1999 and is currently operated by the Wintergarden Groundwater Conservation District in Carrizo Springs, Texas. This program was the first of the nine existing weather modification programs in Texas to evaluate the suppression of hail. The original program consisted of Dimmit, LaSalle, and Webb Counties but was expanded in 2002 to include Uvalde County. According to the 2003 SWTREA Annual Evaluation Report, an increase of 36,773 acft (0.78 inches)[12] was reported over Uvalde County associated with 18 seeding events between May 26, 2003, and October 6, 2003. This translates to a precipitation increase of 5 percent for Uvalde County with the SWTREA weather modification program. The SWTREA four-county

[12] Precipitation increase (in inches) was calculated by dividing acft increase by area of seeded sample (acres).

program area lies within the Nueces River Basin, and although it may increase water availability in Region N, it is difficult to quantify the additional supply produced by weather modification programs due to high variability in additional rainfall and lack of reliability.

Rainfall Enhancement Programs Underway in Texas during spring 2004: There are nine cloud seeding programs in Texas that are funded, at least partially, by State funds from the Texas Department of Licensing and Regulation. The funds are apportioned in amounts up to $0.045 per acre to help counties pay for weather modification programs. The State contributed $1.82 million to sponsoring programs during the spring and summer of 2003. No new funds were appropriated by the most recent (78th) Legislative Session and State funds were anticipated to be exhausted by spring 2004. It is anticipated that these programs continued through the seeding season of 2004 despite a lack of State support. The programs, the counties they cover and the approximate areas of coverage are presented in the Table 4C.16-3.

Table 4C.16-3.
Cloud Seeding Programs Underway in Texas during Spring 2004

Cloud Seeding Program	*Counties Involved*	*Area (sq. miles)*
Colorado River Municipal Water District	Borden, Mitchell, and parts of Dawson, Howard, Sterling, Nolan, and Scurry	3,500
West Texas Weather Modification Association	Glasscock, Reagan, Crockett, Sutton, Schleicher, Irion and part of Tom Green	9,688
South Texas Weather Modification Association	Frio, Atascosa, McMullen, Live Oak, Bee, Karnes, Wilson, Bexar, Medina, Bandera	10,318
Southern Ogallala Aquifer Rain Program	Gaines, Terry, and Yoakum (Texas); and 2 million acres in eastern New Mexico near Gaines and Yoakum Counties	3,192 (in Texas)
North Plains Groundwater Conservation District	Dallam, Sherman, Hansford, Ochiltree, Lipscomb, and parts of Hartley, Moore, and Hutchinson	6,563
Panhandle Groundwater Conservation District	Carson, Donley, Gray, Roberts, and Wheeler	6,309
West Central Texas Weather Modification Association	Nolan, Taylor, Callahan, Eastland, Coke, Runnels, Coleman, Brown, and Comanche	7,656
Trans Pecos Weather Modification Association	Culberson, Loving, Reeves, and Ward	7,958
Southwest Rain Enhancement Association	Uvalde, Dimmit, La Salle, Zavala, and Webb	9,141

Although rainfall enhancement through cloud seeding has been practiced and studied in Texas and other states for many years, the benefits of rainfall enhancement for increasing water yield are not well determined. There is documentation regarding other benefits of cloud seeding, particularly with regard to impacts on agricultural production. The following section provides descriptions of quantified benefits resulting from cloud seeding in Texas and an estimate of the benefits to the region.

4C.16.3 Potential Quantities of Water Supply Resulting from Weather Modification in the Coastal Bend Region

The benefits resulting from cloud seeding in the Coastal Bend Region may include improvements in environmental and economic conditions. Environmental conditions in a stream, estuary, or lake can be improved by increased freshwater flows and the improvements can be measured using water quality parameters and aquatic life. Economic conditions can be improved by increasing crop production, by increasing animal production as a result of increasing the food supply, and by increasing ground and surface water supplies. Increasing water supplies can further improve economic conditions by affecting recreation, agriculture, municipal, and industrial activities in beneficial ways.

Performance data from cloud seeding programs typically focus on the rainfall event and parameters such as storm duration, cloud height, storm coverage (cloud area), and rainfall amount, rather than water supply parameters like increased stream flows and increased reservoir storage. Where water supply parameters have been measured in cloud seeding programs, the results appear to be positive. For example, CRMWD reservoir storage increased from 14,000 acft to 200,000 acft in Lake Spence and from 26,000 acft to 30,000 acft in Lake Thomas since the inception of cloud seeding in the Big Spring and Snyder areas.[13] Also, the Twin Buttes and Fisher Reservoirs increased from a combined 40,000 acft to a combined 230,000 acft during a cloud seeding program sponsored by the City of San Angelo between 1985 and 1989.[14]

To determine how much additional water supply can be developed from weather modification in the Coastal Bend Region requires a sequence of information. This information sequence includes: (1) the quantity of additional rainfall developed through cloud seeding; (2) the quantity of additional runoff; and (3) the quantity of additional runoff that was ultimately

[13] Jensen, Ric, Op. Cit., Summer 1994.
[14] Ibid.

transported to a reservoir or was recharged to an aquifer. Both the STWMA and SWTREA Programs have reported additional rainfall through cloud seeding, described above, that could have potential benefits to the Coastal Bend Region. Further studies are necessary to quantify additional water supply in the Coastal Bend Region attributable to these programs. To consider enhanced rainfall as a water management strategy would require the additional water supply to be reliable, dependable, and consistent over long-term, all of which are current limitations to weather modification programs.

In the 1994 Edwards Aquifer Recharge Enhancement Project, Phase IV A, normal and enhanced recharge rates were computed for target recharge sites. The enhanced rates were developed to simulate the additional quantities of recharge that would naturally enter the aquifer without the benefit of manmade recharge structures. This 1994 Edwards Aquifer recharge study provides a baseline case from which to compute an example of potential water supply development from weather modification, as is explained below.

One way to estimate the potential for enhancing recharge through weather modification would be to increase the precipitation at an assumed rate and recompute enhanced recharge. The EAA program described above covers the same region as the areas modeled in the 1994 study. Therefore, an estimate has been made using the Sabinal River watershed (241 square miles) model with an assumed increase in rainfall over the same years studied previously in order to determine whether estimates for recharge would show increases if rainfall increased. This modeling and resulting computations show an annual average increase in estimated recharge of 9 percent, assuming a 15 percent increase in rainfall during the warm months (April through September) for the years 1990 through 1996 (Table 4C.16-4). The model shows an annual average estimated increase of 3,173 acft (0.02 acft/acre) of recharge from the Sabinal River watershed. Although the EAA cloud seeding program covers the same areas previously modeled, an estimate of total increase in recharge resulting from the program was not developed. Since the increase in rainfall in an area where there is no pre- or post- cloud seeding data can only be assumed, it would be an inequitable comparison with most other options to extrapolate computer modeling results for the Sabinal River over the entire region. To be an equitable comparison, the results of cloud seeding in terms of increased rainfall, aquifer recharge, and reservoir storage would have to be predictable, verifiable, and comparable to unit firm yields developed from other options. Since these criteria cannot be met at this time, no such estimates can be made.

Table 4C.16-4.
Simulation of Increased Annual Edwards Aquifer Recharge
Due to a 15 Percent Increase in Precipitation — Sabinal River Watershed

Year	*Baseline Recharge Estimate (acft)*	*Recharge Estimate with 15 percent Increased Precipitation (acft)*	*Difference (acft)*	*Percent Difference*
1990	32,526	35,822	3,296	10%
1991	41,319	45,361	4,042	10%
1992	67,724	72,719	4,995	7%
1993	27,761	29,745	1,984	7%
1994	24,219	26,833	2,614	11%
1995	30,855	33,574	2,719	9%
1996	10,537	13,093	2,556	24%
Average	33,563	36,736	3,173	9%

[1] The Sabinal River watershed has an area of 241 square miles, or 154,240 acres.

The SCTRWPG requested for their 2006 Regional Water Plan a more detailed analysis of a long-term weather modification program. This effort included application of HDR's Pilot Recharge Models of the Nueces and Blanco River Basin[15] to quantify increases in streamflow and recharge enhancement to the Edwards Aquifer associated with weather modification. The Nueces Basin shady area included contributing watershed area upstream of USGS Gage 08192000 (Nueces River below Uvalde). The Blanco Basin study area included Blanco River watershed area upstream of USGS Gage 08171300 (Blanco River near Kyle).

According to HSPF model results, weather modification on the Nueces River watersheds is estimated to increase recharge in the Nueces Recharge Basin an average of 7,659 acft/yr (or 6.7% increase when compared to recharge without weather modification. For the 5-year drought period[16] (1952 – 1956), the estimated increase in Edwards Recharge in the Nueces Basin is 2,639 acft/yr (or 6.3%).

Weather modification on the Blanco River watershed is estimated to increase recharge in the Blanco Recharge Basin an average of 4,250 acft/yr (or 6.4%). For the 5-year drought

[15] HDR Engineering Inc., "Pilot Recharge Models of the Nueces and Blanco River Basins," 2002.
[16] The Nueces and Blanco Basins drought of record was from 1952 through 1956, according to NWS precipitation gage data (16.8 inches of rainfall in Nueces Basin and 25.4 inches of rainfall in Blanco Basin, based on 5-year precipitation average from 1934 – 1998).

(1952 – 1956), the estimated increase in Edwards Recharge in the Blanco Basin is 1,093 acft/yr (or 9.2%).

This recharge enhancement information was then processed by an Edwards Aquifer model (GWSIM4) to quantify potential increases in sustained yield.[17] GWSIM4 Edwards Aquifer groundwater flow model developed by the Texas Water Development Board simulates Edwards Aquifer response in terms of water levels and springflows for specified recharge and pumping rates. Weather modification evaluated with 5 percent precipitation increase in the Nueces Recharge Basin and 6.5 percent precipitation increase in the Blanco Recharge Basin is calculated to increase sustained yield by 1,916 acft/yr and 488 acft/yr, respectively. The Nueces Basin has greater water supply benefits with a weather modification program due to its higher average annual recharge as compared with the Blanco Basin. It is emphasized, however, that these recharge estimates pertain only to the Edwards Aquifer area and are not necessarily applicable to other aquifers. For a more detailed discussion of this weather modification study, see Section 4C.29 in the 2006 South Central Texas Regional Water Plan.

Although these weather modification projects[24,27] could potentially provide additional water opportunities for Region N, to determine these benefits would require additional studies to translate increased annual flow to Choke Canyon Reservoir and Lake Corpus Christi to firm yield.

4C.16.4 Environmental Issues

Although weather modification is not a new technique, its effectiveness has been difficult to measure. Since Texas has established a permit procedure, administered by TCEQ, data are being collected for a more scientific study of cloud seeding effectiveness and management. Originally conceived as a means to help end droughts, experience shows that cloud seeding may work best during periods of normal rainfall. In some areas of the State, weather modification is considered a long-term water augmentation strategy for freshwater supplies.[18]

The amount of silver iodide and calcium chloride used during a seeding event is negligible and too dispersed to have a measurable effect on the environment. Safe handling and storage of these materials prior to dispersal are a larger concern. Both are normally used in

[17] Sustained yield of the Edwards aquifer is defined as the amount of pumped from the Edwards such that a simulated minimum flow at Comal Springs is protected during the drought of record (in this case, 60 cfs).
[18] Bomar, George, TNRCC Senior Meteorologist, Austin, Texas.

industrial applications and printing. Therefore, procedures for handling and storing silver iodide are well documented. There are no known environmental problems associated with this option.

4C.16.5 Engineering and Costing

For 2004, the Edwards Aquifer Authority contracted SWTREA as part of their Precipitation Enhancement Program to perform cloud-seeding over Uvalde County at a cost of $37,951 or $0.04 per acre. The Authority also contracted STWMA to perform cloud seeding in Bandera, Bexar, and Medina Counties at a cost of $86,825 or $0.03 per acre. According to Mike Mahoney at Evergreen UWCD, the full cost of the program for STWMA's 10-county region (6,603,520 acres) was $428,067 in 2003, including $215,387 in initial capital costs and $212,680 Operations and Maintenance costs, or $0.65 per acre.

The 2006 South Central Texas Regional Water Plan estimates unit water costs range from $74-$77 per acft. These costs are based on increases in sustained yield from the Edwards Aquifer (1,916 acft/yr and 488 acft/yr attributed to weather modification in the Nueces Basin and Blanco Basin, respectively). For the Nueces Recharge Basin, the total annual cost for a weather modification program for Edwards, Real, Kinney, and Uvalde Counties (3,693,440 acres) is estimated at $147,740, assuming an annual cost of $0.04 per acre. For the Blanco Recharge Basin, the total annual cost for a weather modification program for Blanco and Hays Counties (901,120 acres) is estimated at $36,050, assuming an annual cost of $0.04 per acre. This cost is based on increases in sustained yield from the Edwards Aquifer and is not necessarily applicable to other basins or aquifers.

4C.16.6 Implementation Issues

Weather modification in the form of cloud seeding is a beneficial, but uncertain, source of usable water. However, data are not adequate to quantify firm yield in terms of a measurable and dependable regional water supply option.

One important potential benefit of cloud seeding is that a part of the agricultural water supply needs (irrigated and dryland crops and rangelands) could be met. For example, higher rainfall would lower the quantities of irrigation water that has to be withdrawn from the aquifers and streams of the Coastal Bend Region, and dryland production would benefit from increased rainfall. This could be a significant water supply option for agricultural uses. Over a sufficient period, agricultural production data could be developed to demonstrate that crop yield, animal production, and other measurable agricultural parameters have increased as compared to the same data prior to beginning the cloud seeding program. For a relatively minor cost, cloud seeding could meet some of the agricultural needs, as well as contribute to aquifer recharge and streamflows of the region.

4C.16.7 Evaluation Summary

An evaluation summary of this strategy is included in Table 4C.16-5.

Table 4C.16-5.
Evaluation Summary of Weather Modification to Enhance Water Supplies

Impact Category	Comment(s)
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Variable, indeterminate quantity. 2. Low, uncertain timing. 3. Low cost.
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. May slightly increase instream flows. 2. May slightly increase bay and estuary flows. 3. None or low impact. 4. None or low impact. 5. None or low impact. 6. None or low impact. 7. Low impact with potential for limited benefits.
c. Impacts to State water resources	• No apparent negative impacts on other water resources • Potential benefit to Gulf Coast and Carrizo Aquifers water resources due to increased water for recharge • Potential benefit to farmers and ranchers through increased rainfall
d. Threats to agriculture and natural resources in region	• Potential threats due to limited potential for increased flooding
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Cost reported in annual unit area cost only
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Improvement over existing conditions
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• None

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4C.17 Seawater Desalination (N-17)

4C.17.1 Description of Strategy

Desalting seawater from the Gulf of Mexico is a potential source of freshwater supplies for municipal and industrial uses. Significant cost savings may be realized from co-siting a seawater desalination facility with a power plant utilizing once-through cooling water. Therefore, the desalination facility for this option is co-sited with Barney M. Davis Power Station in Corpus Christi near Laguna Madre, Oso Bay, and Corpus Christi Bay.

This section describes seawater desalination information for large-scale facilities producing desalinated water at flows between 25 to 100 MGD (28,000 to 112,000 acft/yr). Also included is an evaluation of utilizing a combination of brackish groundwater and seawater in a desalination plant producing 25, 19, or 14 MGD of desalinated water.

4C.17.1.1 General Desalination Background

Commercially available processes that are commonly used to desalt seawater to produce potable water are:

- Distillation (thermal) Processes, and
- Membrane (non-thermal) Processes.

The following section describes each of these processes and discusses a number of issues that should be considered before selecting a process for desalination of seawater.

4C.17.1.1.1 Distillation (Thermal) Processes

Distillation processes produce purified water by vaporizing a portion of the saline feedstock to form steam. Since the salts dissolved in the feedstock are nonvolatile, they remain unvaporized and the steam formed is captured as a pure condensate. Distillation processes are normally very energy-intensive, expensive, and are generally used for large-scale desalination of seawater. Heat is usually supplied by steam produced by boilers or from a turbine power cycle used for electric power generation. Distillation plants are commonly dual-purpose facilities that produce purified water and electricity.

In general, for a specific plant capacity, the equipment in distillation plants tends to be much larger than membrane desalination equipment. However, distillation plants do not have the stringent feedwater quality requirements of membrane plants. Due to the relatively high temperatures required to evaporate water, distillation plants have high energy requirements, making energy a large factor in their overall water cost. Their high operating temperatures can result in scaling (precipitation of minerals from the feedwater), which reduces the efficiency of the evaporator processes, because once an evaporator system is constructed, the size of the exchange area and the operating profile are fixed, leaving energy transfer as a function of only the heat transfer coefficient. Therefore, any scale that forms on heat exchanger surfaces reduces heat transfer coefficients. Under normal circumstances, scale can be controlled by chemical inhibitors, which inhibit but do not eliminate scale, and by operating at temperatures of less than 200 degrees Fahrenheit.

Distillation product water recoveries normally range from 15 to 45 percent, depending on the process. The product water from these processes is nearly mineral-free, with very low total dissolved solids (TDS) (less than 25 mg/L). However, this product water is extremely aggressive and is too corrosive to meet the Safe Drinking Water Act corrosivity standards without post-treatment. Product water can be stabilized by chemical treatment or by blending with other potable water.

The three main distillation processes in use today are Multistage Flash Evaporation (MSF), Multiple Effect Distillation (MED), and Vapor Compression (VC). All three of these processes utilize an evaporator vessel that vaporizes and condenses the feedstock. The three processes differ in the design of the heat exchangers in the vessels and in the method of heat introduction into the process. Since there are no distillation processes in Texas that can be shown as comparable installations, distillation will not be considered here. However, there are membrane desalination operations in Texas, so the following discussion and analyses are based upon information from the use of membrane technology for desalination.

4C.17.1.1.2 Membrane (Non-thermal) Processes

The two types of membrane processes use either pressure—as in reverse osmosis (RO)—or electrical charge—as in electrodialysis reversal (EDR)—to reduce the mineral content of water. Both processes use semi-permeable membranes that allow selected ions to pass through while other ions are blocked. EDR uses direct electrical current applied across a vessel to attract the dissolved salt ions to their opposite electrical charges. EDR can desalinate brackish water with TDS up to several thousand milligrams per liter, but energy requirements make it economically uncompetitive for seawater, which contains approximately 35,000 mg/L TDS. As a result, only RO is used for seawater desalination.

RO utilizes a semi-permeable membrane that limits the passage of salts from the saltwater side to the freshwater side of the membrane. Electric motor-driven pumps or steam turbines (in dual-purpose installations) provide the 800 to 1,200 pounds per square inch (psi) pressure to overcome the osmotic pressure and drive the freshwater through the membrane, leaving a waste stream of brine/concentrate. The basic components of an RO plant include pre-treatment, high-pressure pumps, membrane assemblies, and post-treatment. Pretreatment is essential because feedwater must pass through very narrow membrane passages during the process and suspended materials, biological growth, and some minerals can foul the membrane. As a result, virtually all suspended solids must be removed and the feedwater must be pre-treated so precipitation of minerals or growth of microorganisms does not occur on the membranes. This is normally accomplished by using various levels of filtration and the addition of various chemical additives and inhibitors. Post-treatment of product water is usually required prior to distribution to reduce its corrosivity and to improve its aesthetic qualities. Specific treatment is dependent on product water composition.

A "single-pass/stage" seawater RO plant will produce water with a TDS of 300 to 500 mg/L, most of which is sodium and chloride. The product water will be corrosive, but this may be acceptable, if a source of blending water is available. If not, and if post-treatment is required, the various post-treatment additives may cause the product water to exceed the desired TDS levels. In such cases, or when better water quality is desired, a "two-pass/stage" RO system is used to produce water typically in the 200 mg/L TDS range. In a two-pass RO system, the concentrate water from the first RO pass/stage is further desalted in a second RO pass/stage, and the product water from the second pass is blended with product water from the first pass.

Recovery rates up to 45 percent are common for a two-pass/stage seawater RO facility. RO plants, which comprise about 47 percent of the world's desalting capacity, range from a few gallons per day to 35 MGD. The largest RO seawater plant in the United States is the 25-MGD plant in Tampa Bay, Florida. The current domestic and worldwide trend seems to be for the adoption of RO when a single purpose seawater desalting plant is to be constructed. RO membranes have been improved significantly over the past two decades (i.e., the membranes have been improved with respect to efficiency, longer life, and lower prices). Municipal use desalination plants in Texas that use lake water, river, or groundwater are shown in

Table 4C.17-1. The plant capacities range from 0.1 MGD (Homestead MUD-El Paso) to 10 MGD (Lake Granbury).

Table 4C.17-1.
Municipal Use Desalt Plants in Texas
(>25,000 gpd and as of June 2004)

Location	Source	Total Capacity (MGD)	Desalt Capacity (MGD)	Membrane Type[1]
Abilene, City of	Lake Water	5	3	RO
Bardwell, City of	Groundwater	0.12	0.12	RO
Bayside, City of	Groundwater	0.15	0.15	RO
Brownsville, City of	Groundwater	7.5	7.5	RO
Burleson County MUD 1	Groundwater	0.43	0.43	RO
Country View Estates	Groundwater	0.18	0.18	RO
Dell City, City of	Groundwater	0.11	0.11	EDR
Electra, City of	Groundwater	2.23	2.23	RO
El Paso County Water Auth.	Groundwater	2.29	2.29	RO
Ft. Stockton, City of	Groundwater	6.5	3.67	RO
Granbury, City of	Lake Water	0.35	0.35	EDR
Haciendas del Norte (El Paso)	Groundwater	0.12	0.12	RO
Homestead MUD (El Paso)	Groundwater	0.1	0.1	RO
Kenedy, City of	Groundwater	2.86	0.72	RO
Lake Granbury	Lake Water	10	10	RO
Lake Granbury	Lake Water	5	5	EDR
Los Ybanez, City of	Groundwater	0.11	0.11	RO
Oak Trail Shores	Lake Water	0.72	0.72	EDR
Robinson, City of	River	2.38	2.38	RO
Seadrift, City of	Groundwater	0.24	0.17	RO
Sherman, City of	Lake Water	5.6	5.6	EDR
Sportsman's World	Lake Water	0.17	0.17	RO
Tatum, City of	Groundwater	1.14	1.14	RO
Texas Resort Co.	Lake Water	0.144	0.144	EDR

[1] RO = Reverse Osmosis EDR = Electrodialysis Reversal

Source: Partial information obtained from Texas Commission on Environmental Quality, 2003.

4C.17.1.1.3 Examples of Relevant Existing Desalt Projects

Seadrift, Texas: In 1996, Seadrift (retail population 1,890) was dependent on the Gulf Coast Aquifer for its water supply. TDS and chlorides had reached unacceptable levels of 1,592 mg/L and 844 mg/L, respectively. These values exceeded the primary drinking water standard for TDS (1,000 mg/L) and the secondary drinking water standard for chlorides (300 mg/L). Since the community was not located near an adequate quantity of freshwater or a wholesaler of drinking water, the decision was made to install RO to treat this slightly brackish groundwater. The city installed pressure filters, two RO units, antiscalant chemical feed equipment, and a chlorinator. The capital cost for the system was $1.2 million and the annual operation and maintenance (O&M) cost is $56,000, resulting in a total debt service plus O&M cost of about $0.88 per 1,000 gallons treated by RO. The capital cost included the cost of facilities in addition to the RO units and their appurtenant equipment. Product water from the RO units is blended with groundwater to meet an acceptable quality level. About 60 percent of the total is from the desalt units.

Tampa, Florida: The water utility, Tampa Bay Water, selected a 30-year design, build, operate, and own (DBOO) proposal to construct a nominal 25 MGD seawater desalt plant. The plant will use RO as the desalt process. The proposal included total capitalization and operations costs for producing high quality drinking water (chlorides less than 100 mg/L). The total cost to Tampa Bay Water in the original proposal was to be $2.08 per 1,000 gallons on a 30-year average, with first year cost being $1.71 per 1,000 gallons. However, subsequent issues with the original design including significant problems in obtaining adequate pretreatment have increased the projected total cost to Tampa Bay Water by $0.72 per 1,000 gallons for a total projected cost of $2.80 per 1,000 gallons on a 30-year average.[1] The results of Tampa Bay's competition has attracted international interest in the current cost profile of desalting seawater for drinking water supply, since these costs are only about one-half the levels experienced in previous desalination projects.

Tampa Bay Water selected the winning proposal from four DBOO proposals submitted, which ranged from $2.08 to $2.53 per 1,000 gallons. The factors listed below may be all or partially responsible for these seemingly low costs:

1. Salinity at the Tampa Bay sites ranges from 25,000 to 30,000 mg/L, lower than the more common 35,000 mg/L for seawater. RO cost is sensitive to salinity.

[1] Associated Press, "Tampa Bay Water to Hire Group to Fix Desalination Plant," September 21, 2004.

2. The power cost, which is interruptible, is below $0.04 per kilowatt-hour (kWh).
3. Construction cost savings through using existing power plant canals for intake and concentrate discharge.
4. Economy of scale at 25 MGD.
5. Amortizing over 30 years.
6. Use of tax-exempt bonds for financing.

The Tampa bids contrast with another current large-scale desalination project in which distillation is proposed. The current desalt project of the Singapore Public Utility Board, which proposes a 36 MGD multi-stage flash distillation plant, will cost an estimated $5.76 per 1,000 gallons for the first year operation.[2]

City of Corpus Christi Desalination Study: The TWDB funded several studies to evaluate the feasibility of large-scale desalination in Texas. As part of this initiative, the City of Corpus Christi was selected as one of three potential locations for large-scale seawater desalination and a feasibility study was conducted. The draft report[3] from this study was completed in August 2004. The study evaluated several options and concluded that the most feasible large-scale desalination project for the Corpus Christi area was a 25 MGD seawater desalination treatment plant located at the Barney M. Davis Power Station.

4C.17.2 Available Yield

Seawater from the Gulf of Mexico is assumed to be available in an unlimited quantity within the context of a supply for the Coastal Bend Region. Also, it is assumed that the cost of Gulf water is zero prior to extraction from the source. For the combined brackish water and seawater desalination option, the quantity of suitable brackish groundwater is the limiting factor.

The target area for well field development for brackish groundwater is in the vicinity of the Barney M. Davis Power Station. In this area, the Gulf Coast Aquifer System is the only source of substantial groundwater supplies. The primary water-bearing zone is the Goliad Sand, which is also known as the Evangeline Aquifer. The outcrop of the Goliad Sand is about 50 to 75 miles inland. It dips toward the coast at about 20 feet per mile. In the western part of the county, a high capacity well is about 700 feet deep and yields up to 750 gallons per minute (gpm). Near the coast, a high capacity well would be about 1,500 feet deep and yield about 500 gpm.

[2] Desalination & Water Reuse Quarterly, vol. 7/4, Feb/Mar 1998.
[3] City of Corpus Christi, Draft Report "Large Scale Demonstration Desalination Feasibility Study," August 2004.

For purposes of this evaluation, three potential well fields were considered. As shown in Figure 4C.17-1, a coastal well field is just west of Laguna Madre; a south central Nueces County well field is near the Nueces-Kleberg County line and has two east-west rows of wells; and a northwest Nueces County well field is just south of the Nueces River and west of U.S. Highway 77.

A preliminary groundwater model of the Goliad Sand for an area centered on Nueces and Kleberg Counties was developed to calculate the availability of brackish groundwater from these well fields. The model had one active layer (Goliad Sand), used generalized aquifer parameters determined by other groundwater models, and predevelopment water levels for minor calibration adjustments of the aquifer's hydraulic conductivity. The model's grid spacing was half-mile and was oriented along the regional groundwater flow lines, which are perpendicular to the coast.

Following the criteria established by the CBRWPG, water level declines from well fields were allowed to decline up to 250 feet in the confined zone of the Goliad Sand. Considering these criteria and in consideration of other well fields in the area, allowable drawdown of 200 to 250 feet was used to establish the availability of groundwater from these well fields.

In the coastal well field, the analysis suggests that a 4-MGD well field could be developed on a long-term basis and meet the established criteria. The tested well field would consist of nine wells spaced 2 miles apart. Each well would yield an average of 300 gpm. The rather low productivity is caused by the relatively low hydraulic conductivity, reduced leakage from overlying formation, and faults in the area. Because of the depth of the Goliad Sand and the salinity of the groundwater, no water quality data are available. As a result, the groundwater salinity is estimated from geophysical logs of oil and gas wells. Calculations from these logs indicate groundwater salinity ranges from 5,000 to 20,000 mg/L. For planning purposes, groundwater salinity is expected to average about 15,000 mg/L.

In the south central Nueces County well field, an analysis of well field simulations by the groundwater model suggests that 10 MGD could be developed on a long-term basis and meet the established criteria. The selected well field would consist of 14 wells averaging 1,000 feet deep, spaced 1 mile apart, and divided into two rows about 5 miles apart. Each well would yield an average of 500 gpm. Limited water quality data in the area suggest salinity ranges from 2,000 to 2,500 mg/L.

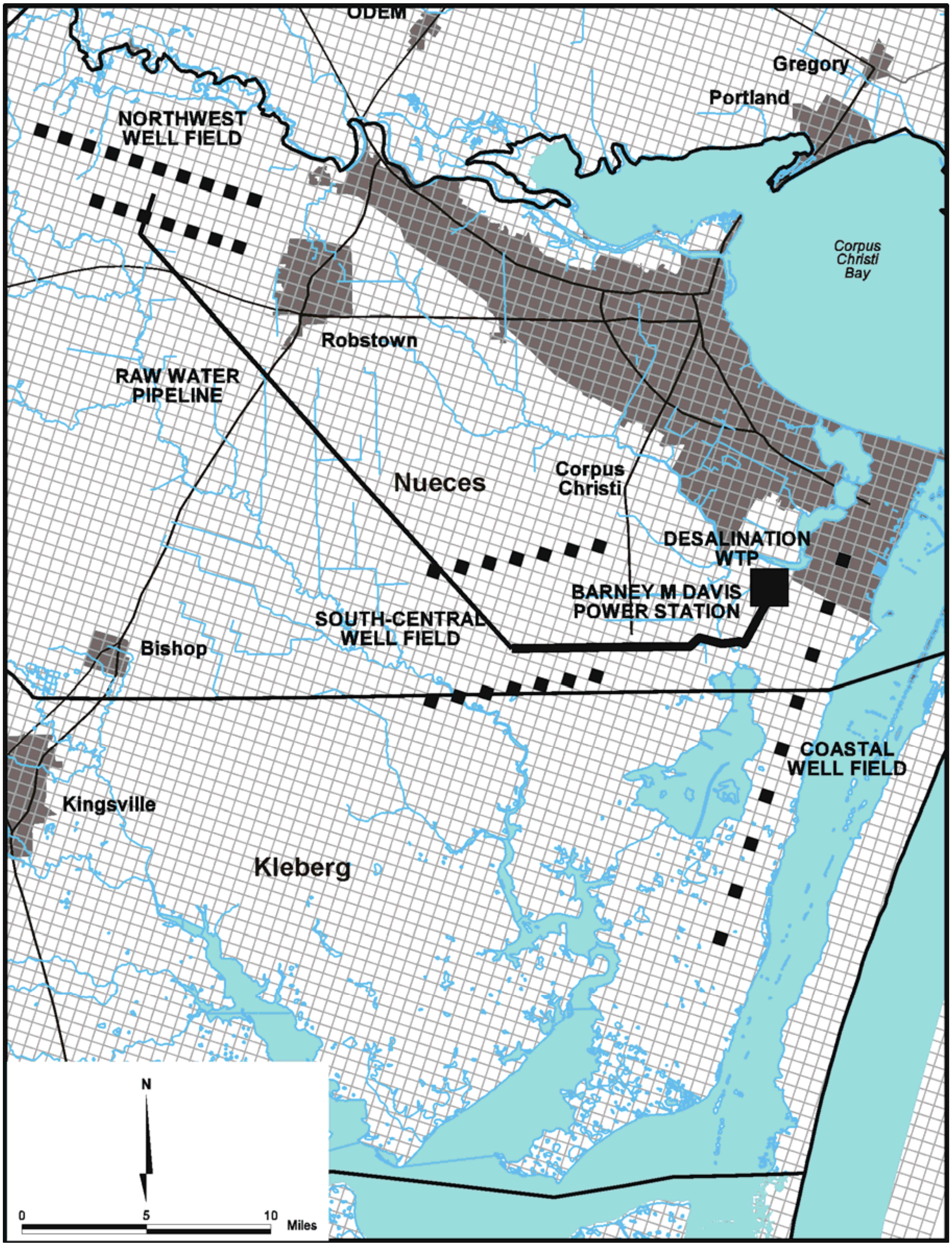

Figure 4C.17-1. Combined Seawater and Brackish Groundwater Desalination at Barney M. Davis Power Plant

In the northwest Nueces County well field, simulations by the groundwater model suggests that 12 MGD could be developed on a long-term basis and meet the established criteria. The selected well field consisted of 17 wells averaging 700 feet deep, spaced 1 mile apart, and divided into two rows about 2 miles apart. Each well would yield an average of 500 gpm. Water quality data in the TWDB database suggest salinity ranges from 2,000 to 2,500 mg/L.

The south central and northwest Nueces County well fields were tested together to determine the combined capacity. Limited by the criteria described earlier and the interference between the well fields would limit the production of the northwest well field to 10 MGD and the south central well field to 8 MGD, for a combined 18 MGD. The groundwater salinity in these two well fields is about the same.

Due to the high salinity and low yield apparent from the coastal well field, options for utilizing brackish groundwater for a desalinated municipal water use assumed that only the south central and northwest Nueces County well fields will be used. A summary of the available yield from the three discussed well fields is shown in Table 4C.17-2.

Table 4C.17-2.
Available Yield from Nueces County Brackish Groundwater Well Fields

Well Field Option	***Available Yield (MGD)***	***TDS (mg/L)***	***Number of Wells***
Northwest	12	2,000 - 2,500	17
South Central	10	2,000 - 2,500	14
Coastal	4	5,000 - 20,000	9
Combined Use			
Northwest	10	2,000 - 2,500	14
South Central	8	2,000 - 2,500	11
Combined Use Total	18	2,000 - 2,500	25

4C.17.3 Environmental Issues

The project area for the proposed desalination plant is adjacent to the Barney M. Davis Power Station in South Corpus Christi near Laguna Madre, Oso Bay, and Corpus Christi Bay. It is assumed that the seawater desalination plant will utilize the existing cooling water intake for the Davis Power Station. Cooling water for the Davis power station is drawn from Laguna Madre and discharged to Oso Bay. The desalination concentrate for the seawater only option is not discharged into the Davis outfall but instead is piped out to the open Gulf of Mexico to be discharged in waters over 30 feet deep. The desalination concentrate for the combined options which consider mixing seawater and groundwater is discharged into the Davis outfall due to lower concentrate levels.

Estuaries serve as critical habitat and spawning grounds for many marine species and migratory birds. Estuaries are marine environments maintained in a brackish state by the inflow of freshwater from rivers and streams. The high productivity characteristic of estuaries arises from the abundance of terrigenous nutrient input, shallow water, and the ability of a few marine species to exploit environments continually stressed by low, variable salinities, temperature extremes, and, on occasion, low dissolved oxygen concentrations. The potential environmental effects resulting from the construction of a desalination plant in the vicinity of Laguna Madre will be sensitive to the siting of the plant and its appurtenances. The existing intake structure and volume of water taken from the bay would not be impacted because the desalination plant would take its raw water feed from the discharge of the Davis Power Station cooling water. Since the brine concentrate for the seawater only option is planned to be located off-shore in the open Gulf of Mexico, there would be no impact of this feature upon the estuary. Also, it is assumed that the seawater only outfall will be located and constructed so as to result in little or no effect upon the environment at the discharge location. Brine concentrate for the combined seawater/ groundwater options will be discharged into the existing power plant outfall therefore requiring no additional construction in the estuary. Brine concentrate from the combined seawater/ groundwater options will be of similar or lower salinity than the seawater that is currently being discharged from the power plant. Therefore, it is anticipated that there would be minimal effect on the estuary from this discharge.

The water transmission pipeline between the desalination plant and the O.N. Stevens Water Plant would be approximately 29 miles long. A construction right-of-way, approximately 140 feet wide, would affect a total area of approximately 492 acres. The construction of the pipeline would include the clearing and removal of woody vegetation. A 40-foot-wide right-of-way corridor, free of woody vegetation and maintained for the life of the project, would total 141 acres. Destruction of potential habitat can be avoided by diverting the corridor through previously disturbed areas. A cultural resource survey of the plant and pipeline routes will need to be performed consistent with requirements of the Texas Antiquities Commission.

The northwest and south central Nueces County well fields are in farming area and the coastal well field is in low-lying lands next to Laguna Madre. The well field facilities would require the construction of wells, collector pipelines, pipelines, pump stations and ground storage facilities. The wells, collection system within the well field, and transmission system to Barney Davis Power Station would be sited in such a way as to avoid or minimize impacts to sensitive resources such as small creeks and wetlands.

Because of the relatively small areas involved, construction and maintenance of surface facilities are not expected to result in substantial environmental impacts. Where environmental resources (e.g., endangered species habitat and cultural resource sites) could be impacted by infrastructure, changes in facility siting and pipeline alignment would generally be sufficient to avoid or minimize adverse effects.

The pumping of groundwater from the Gulf Coast Aquifer, especially in the updip area, could cause a very slight reduction on baseflow in downstream reaches. However, many of the streams are dry most of the time; thus, no measurable impact on wildlife along the streams is expected.

Minor land surface subsidence could potentially occur as a result of lowering of groundwater levels. If this happens, drainage patterns and other habitats might change to a small extent.

4C.17.4 Engineering and Costing

4C.17.4.1 Seawater Desalination

This option provides the cost estimates for a major desalination water treatment plant on the Texas coast and the infrastructure for transferring potable water from the coast to the major municipal demand center of Corpus Christi. The estimated seawater desalination facility is located next to the Barney M. Davis Power Station between Laguna Madre and Oso Bay in south Corpus Christi. Davis is a once-through cooling water power plant with an existing reported cooling water flow of 467 MGD (521 MGD maximum capacity). Cooling water is diverted from Laguna Madre and returned to Oso Bay. Figure 4C.17-2 shows the desalination plant location, finished water pipeline route to the O.N. Stevens Water Treatment Plant, and concentrate pipeline route. Engineering assumptions for the Davis seawater desalination facility are shown in Table 4C.17-3.

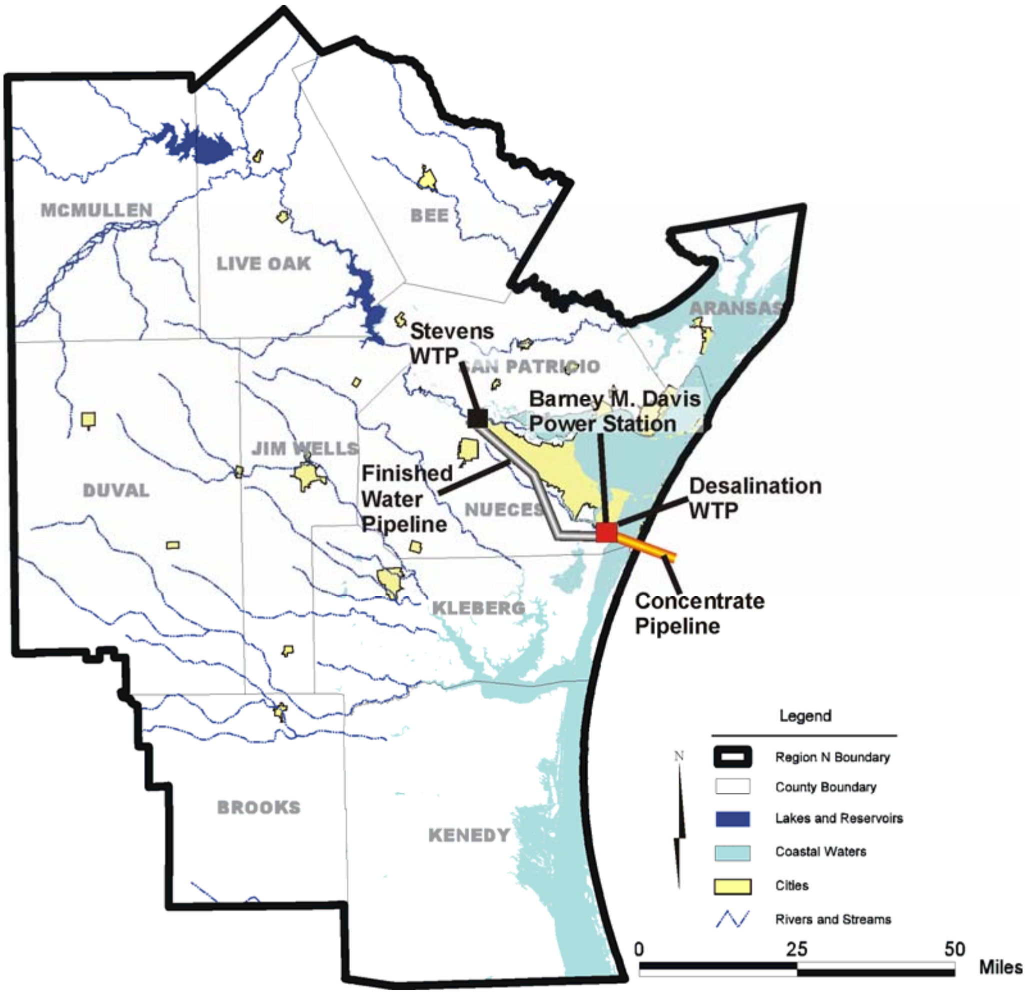

Figure 4C.17-2. Desalination Plant Location and Pipeline Route

The basis for estimating the seawater desalination plant costs were developed from evaluation of recent experience of other utilities that are involved in similar projects (e.g., technical data from the Tampa Bay Water proposal, referenced in subsection 4C.17.1.1.3) and from information and estimating models developed in a previous desalination study).[4]

Estimates are based on utilizing the existing power plant seawater intake to obtain the RO treatment plant feedwater. Pumps and 1,000 feet of intake pipeline are added to transfer the feedwater from the discharge canal to the desalination plant. Drawing the source water from the power plant discharge eliminates the need to draw additional flow from the bay for cooling water to the power plant and supplies feedwater with an increased temperature that is beneficial for the RO process.

[4] HDR Engineering, Inc., "Desalination for Texas Water Supply," Texas Water Development Board, Nueces River Authority, August 2000.

Table 4C.17-3.
Seawater Desalination at Barney M. Davis Power Station
Engineering Assumptions for Base Option

Parameter	***Assumption***	***Description***
Raw Water Salinity	33,000 mg/L	Intake from power plant at Laguna Madre
Raw Water Total Suspended Solids	40 mg/L	
Finished Water Chlorides	100 mg/L	Existing median at Stevens Plant is about 120 mg/L
Finished Water Capacity	25, 50, 75, 100 MGD	
Finished Water Pipeline Length	29 Miles	
WTP Storage	one-half day's capacity	
Concentrate Pipeline Length	10 miles	Diffused in open gulf in over 30 ft of water
Treated Water Pipeline Length	29 miles	Distance to Stevens Plant or port industries
Feedwater Pumping Head	900 psi	
Pretreatment	High	Coagulation, media filtration, and chemical addition
Post-treatment	Stabilization & disinfection	Lime and chlorination
Recovery Rate	50 percent	
Flux	8 gfd	Rate product water passes through membrane
Cleaning Frequency	6 months	Membranes cleaned once every 6 months
Membrane Life	5 years	Membrane elements replaced every 5 years
Plant Production Downtime	5 percent	

For the seawater only estimate, a separate RO concentrate disposal outfall is included to pipe the RO concentrate to the open Gulf of Mexico. The outfall would cross Laguna Madre and Padre Island and extend into the Gulf to be diffused in water over 30 feet deep. Seagrass covers the majority of the bay between the mainland and the barrier island. Therefore, costs for appropriate mitigation are included assuming that half of the concentrate pipeline will be located through seagrass beds.

A water storage tank with one-half day's finished water capacity and water transmission pumps and pipeline are included to transport the finished water. For the base option the finished water is to be transported 29 miles to either the Stevens Plant to blend into the city system or to distribution lines supplying industries along the ship channel. An alternate option is included to instead transport the finished water 5 miles to a distribution facility on the south side of Corpus

Christi. The alternate option is identical to the base option in all other aspects. Post-treatment stabilization and disinfection are included.

Water treatment parameters are estimated based on available water quality data for Laguna Madre near the power plant intake. Coagulation and media filtration is included along with other standard pretreatment components (cartridge filtration, antiscalant and acid addition). Included sludge handling consists of mechanical sludge dewatering and disposal to a non-hazardous waste landfill. Capacities for the seawater desalination plant are shown in Table 4C.17-4.

Table 4C.17-4.
Capacities for Seawater Desalination Plant Option

Item/Facility	***Nominal Water Treatment Plant Capacity***			
	25 MGD	***50 MGD***	***75 MGD***	***100 MGD***
Intake Pump Station (MGD)	50	100	150	200
Desalted Product Water (drinking water) (MGD)	25	50	75	100
Concentrate Discharge Pump Station (MGD)	25	50	75	100
Concentrate Discharge Pipeline Diameter (inches)	42	54	64	72
Storage Tank at Plant (million gallons)	25	50	75	100
Finished Water Pump Station at Plant (gpm)	17,361	34,722	52,083	69,444
Finished Water Pipeline Diameter (inches)	42	54	66	78
Total Land Acquisition (acres)	162	171	178	185

Land acquisition for the base option includes 17 acres for the 25-MGD desalination plant and 145 acres for the desalted water storage tank and transmission pipeline.

Tables 4C.17-5 and 4C.17-6 show the cost estimate summaries for seawater desalination at Barney M. Davis Power Station for the base option and the alternate option, respectively. The estimated total costs assume a 95 percent utilization of the desalination facility.

The base option includes a 29-mile pipeline from the desalination plant to the City of Corpus Christi's O.N. Stevens Water Treatment Plant. Once the desalted water is pumped to O.N. Stevens, it can be mixed with treated surface water and put into the City's distribution system. The alternative option takes advantage of the City's plans to develop a new water distribution center on the south side of town. If developed, the desalination plant could pump water 5 miles to the proposed distribution center, saving capital and operating costs in transmission of the potable desalt water into the City's system.

Table 4C.17-5.
Cost Estimate Summary
Seawater Desalination at Barney M. Davis Power Station
for Base Option (29-mile pipeline)
(Second Quarter 2002 Prices)

Item	***Estimated Costs 25 MGD***	***Estimated Costs 50 MGD***	***Estimated Costs 75 MGD***	***Estimated Costs 100 MGD***
Capital Costs				
Seawater Supply	$860,000	$1,400,000	$1,900,000	$2,300,000
Water Treatment Plant (Pre-treatment and Desal)	82,350,000	146,768,000	217,300,000	274,314,000
Concentrate Disposal	34,500,000	52,000,000	70,000,000	90,000,000
Transmission Pipeline	41,954,000	57,830,000	80,901,000	103,424,000
Transmission Pump Station(s)	2,820,000	4,884,000	5,752,000	6,079,000
Total Capital Cost	**$162,484,000**	**$262,882,000**	**$375,853,000**	**$476,117,000**
Engineering, Legal Costs and Contingencies	$54,980,000	$89,486,000	$128,045,000	$162,171,000
Environmental & Archaeology Studies and Mitigation	6,539,000	8,528,000	10,701,000	12,764,000
Land Acquisition and Surveying	2,286,000	2,385,000	2,465,000	2,534,000
Interest During Construction (2.5 years)	22,630,000	36,329,000	51,707,000	65,359,000
Total Project Cost	**$248,919,000**	**$399,610,000**	**$568,771,000**	**$718,945,000**
Annual Costs				
Debt Service (6 percent, 30 years)	$18,084,000	$29,031,000	$41,321,000	$52,231,000
Operation and Maintenance				
Seawater Supply	220,000	325,000	380,000	430,000
Water Treatment Plant	17,018,000	33,580,000	49,559,000	65,127,000
Concentrate Disposal	1,200,000	2,300,000	3,200,000	4,200,000
Finished Water Transmission	1,039,000	1,847,000	2,412,000	2,798,000
Total Annual Cost	**$37,561,000**	**$67,083,000**	**$96,872,000**	**$124,786,000**
Available Project Yield (acft/yr)	**28,000**	**56,000**	**84,000**	**112,000**
Annual Cost of Water ($ per acft)	**$1,341**	**$1,198**	**$1,153**	**$1,114**
Annual Cost of Water ($ per 1,000 gallons)	**$4.12**	**$3.68**	**$3.54**	**$3.42**

Table 4C.17-6.
Cost Estimate Summary
Seawater Desalination at Barney M. Davis Power Station
for Alternate Option (5-mile pipeline)
(Second Quarter 2002 Prices)

	Estimated Costs 25 MGD	*Estimated Costs 50 MGD*	*Estimated Costs 75 MGD*	*Estimated Costs 100 MGD*
Capital Costs				
Seawater Supply	$860,000	$1,400,000	$1,900,000	$2,300,000
Water Treatment Plant (Pretreatment and Desal)	82,350,000	146,768,000	217,300,000	274,314,000
Concentrate Disposal	34,500,000	52,000,000	70,000,000	90,000,000
Transmission Pipeline	10,562,000	15,904,000	22,685,000	29,138,000
Transmission Pump Station(s)	1,381,000	2,392,000	3,065,000	3,623,000
Total Capital Cost	**$129,653,000**	**$218,464,000**	**$314,950,000**	**$399,375,000**
Engineering, Legal Costs and Contingencies	$45,059,000	$76,036,000	$109,640,000	$139,026,000
Environmental & Archaeology Studies and Mitigation	5,939,000	7,928,000	10,101,000	12,164,000
Land Acquisition and Surveying (46 acres)	1,171,000	1,270,000	1,349,000	1,419,000
Interest During Construction (2.5 years)	18,183,000	30,370,000	43,605,000	55,199,000
Total Project Cost	**$200,005,000**	**$334,068,000**	**$479,645,000**	**$607,183,000**
Annual Costs				
Debt Service (6 percent, 30 years)	$14,530,000	$24,270,000	$34,846,000	$44,111,000
Operation and Maintenance				
Seawater Supply	220,000	325,000	380,000	430,000
Water Treatment Plant	17,018,000	33,580,000	49,559,000	65,127,000
Concentrate Disposal	1,200,000	2,300,000	3,200,000	4,200,000
Finished Water Transmission	356,000	658,000	918,000	1,143,000
Total Annual Cost	**$33,324,000**	**$61,133,000**	**$88,903,000**	**$115,011,000**
Available Project Yield (acft/yr)	**28,000**	**56, 000**	**84, 000**	**112, 000**
Annual Cost of Water ($ per acft)	**$1,190**	**$1,092**	**$1,058**	**$1,027**
Annual Cost of Water ($ per 1,000 gallons)	**$3.65**	**$3.35**	**$3.25**	**$3.15**

The cost estimate in Table 4C.17-6 for the 25 MGD option is similar to the cost estimated for a 25 MGD seawater desalination supply presented in a recently completed study for the City of Corpus Christi.[5] The total project cost for a 25-MGD seawater desalination supply located at Barney Davis (Option BD 1) in this previous study was $198,200,000. Using the same assumptions for interest rate and debt period as used in Table 4C.17-6, the total annual costs for debt service along with operations and maintenance in this previous study was $32,016,000 for an annual cost of water of $3.51 per 1,000 gallons.

4C.17.4.2 Combined Seawater and Brackish Groundwater Desalination

This evaluation considers including brackish groundwater as a raw water source or as a supplement to seawater. Brackish groundwater has the benefits of needing little or no pretreatment and lower concentrations of salinity than seawater. The estimate assumes that 18 MGD of brackish groundwater will be available from the combined use of the northwest and south central Nueces County well fields. Infrastructure includes two well fields, brackish raw water transfer pumps and pipelines, desalination plant, and finished water transfer pumps and pipelines from the coast to the major municipal demand center of Corpus Christi. The location of the estimated desalination facility is the same as for the previous seawater desalination facility in subsection 4C.17.4.1 next to the Barney M. Davis Power Station. The location of the two well fields, pipelines, and desalination plant are shown in Figure 4C.17-1. As with the previous estimate seawater is to be diverted from the cooling water intake drawing water from Laguna Madre. However, for this combined seawater and brackish groundwater option it is assumed that the lower salinity concentrate from the combined water desalination process will be discharged back to the power station cooling water outfall and returned to Oso Bay. No costs for a concentrate discharge pipeline to the open ocean have been included.

Three options are included for utilizing the estimated 18 MGD brackish groundwater yield from the northwest and south central well fields. The first option is a combination of 18 MGD of brackish groundwater and 23 MGD of seawater to produce a finished water flow of 25 MGD. The second option is a combination of 18 MGD of brackish groundwater and 10 MGD of seawater to produce a finished water flow of 19 MGD. The third option is desalination of the 18 MGD of brackish groundwater without blending any seawater to produce a finished water

[5] City of Corpus Christi, Draft Report "Large Scale Demonstration Desalination Feasibility Study," August 2004.

flow of 14 MGD. Engineering assumptions utilized for all three options are shown in Table 4C.17-7. Parameters that vary for the three options are shown separately in Table 4C.17-8.

Table 4C.17-7.
Combined Seawater and Brackish Groundwater
Desalination Assumptions Use for All Three Options

Parameter	***Assumption***	***Description***
Raw seawater salinity	33,000 mg/L	Intake from power plant at Laguna Madre Bay
Nueces well field raw water salinity	2,500 mg/L	
Central well field raw water salinity	2,500 mg/L	
Raw seawater total suspended solids	40 mg/L	
Finished water chlorides	Less Than 100 mg/L	Existing median at Stevens Plant is about 120 mg/L
Treated water pipeline length	29 miles	Distance to Stevens Plant or port industries
WTP storage	one-half day's capacity	
Brackish groundwater pretreatment	Low	pH adjustment and antiscalant chemical addition
Seawater pretreatment	High	Coagulation, media filtration, and chemical addition
Post-treatment	Stabilization & disinfection	Lime and chlorination
Flux	8 gfd	Rate product water passes through membrane
Membrane cleaning frequency	6 months	Membranes cleaned once every 6 months
Membrane life	5 years	Membrane elements replaced every 5 years

All options include cost estimates for two well fields and raw water transfer. The northwest well field is assumed to consist of a total of 14 wells arranged in two rows that are 2 miles apart with at least one mile between the wells in each row. The south central well field is assumed to consist of a total of 11 wells arranged in two rows that are 5 miles apart with at least one mile between the wells in each row. Ten (10) MGD of raw brackish groundwater is first transported from the northwest well field to the south central well field through a 27-inch, 17-mile pipeline. The northwest well field groundwater is then combined with 8 MGD of raw brackish groundwater from the south central well field and transported to the Davis power station through a 33-inch, 13-mile pipeline.

Table 4C.17-8.
Parameters for Three Combined Seawater and Brackish Groundwater Desalination Options

Parameter	***Quantity***			***Unit***
	25 MGD Option	***19 MGD Option***	***14 MGD Option***	
Raw Seawater	23	10	0	MGD
Nueces Well Field Raw Water	10	10	10	MGD
Central Well Field Raw Water	8	8	8	MGD
Total Raw Water	41	28	18	MGD
Combined Raw Water Salinity	19,600	13,400	2,500	TDS mg/L
Recovery Rate	62%	68%	78%	%
Reject Concentrate Salinity	51,000	41,900	11,600	TDS mg/L
Reject Concentrate Quantity	16	9	4	MGD
Finished Water Quantity	25	19	14	MGD

A water storage tank with one-half day's finished water capacity and water transmission pumps and pipeline are included to transport the finished water. For the base option the finished water is to be transported 29 miles to either the Stevens plant to blend into the city system or to distribution lines supplying industries along the ship channel. An alternate option is included to instead transport the finished water 5 miles to a distribution facility on the south side of Corpus Christi. The alternate option is identical to the base option in all other aspects. Post-treatment stabilization and disinfection are included.

Pretreatment for the seawater portion of the blend includes coagulation and media filtration along with other standard pretreatment components (cartridge filtration, antiscalant and acid addition). The brackish groundwater does not contain the high level of suspended solids present in the surface seawater and therefore no coagulation or media filtration pretreatment was included for the groundwater; only the other standard pretreatment components were included for the groundwater.

Tables 4C.17-9 and 4C.17-10 show the cost estimate summaries for combined seawater and brackish groundwater desalination at Barney M. Davis Power Station for the base option and the alternate option, respectively. The estimated total costs assume a 95 percent utilization of the desalination facility.

Table 4C.17-9.
Cost Estimate Summary
Combined Seawater and Brackish Groundwater Desalination
for Base Option (29-mile pipeline)
(Second Quarter 2002 Prices)

Item	*Estimated Costs 25 MGD*	*Estimated Costs 19 MGD*	*Estimated Costs 14 MGD*
Capital Costs			
Seawater Supply	$550,000	$330,000	$0
Brackish GW Wells, Pump Station, and Pipeline	30,000,000	30,000,000	30,000,000
Water Treatment Plant (Pretreatment and Desal)	56,138,000	34,659,000	15,452,000
Concentrate Disposal	340,000	216,000	160,000
Transmission Pipeline	41,954,000	34,859,000	30,267,000
Transmission Pump Station(s)	2,820,000	2,638,000	1,943,000
Total Capital Cost	**$131,802,000**	**$102,702,000**	**$77,822,000**
Engineering, Legal Costs and Contingencies	$44,241,000	$34,371,000	$25,853,000
Environmental & Archaeology Studies and Mitigation	3,650,000	3,613,000	2,764,000
Land Acquisition and Surveying (158 acres)	3,465,000	3,088,000	3,033,000
Interest During Construction (2.5 years)	18,316,000	14,378,000	10,948,000
Total Project Cost	**$201,474,000**	**$158,152,000**	**$120,420,000**
Annual Costs			
Debt Service (6 percent, 30 years)	$14,637,000	$11,490,000	$8,748,000
Operation and Maintenance			
Seawater Supply	110,000	45,000	0
Brackish GW Wells, Pump Station, and Pipeline	1,523,000	1,523,000	1,523,000
Water Treatment Plant	10,244,000	5,990,000	2,743,000
Concentrate Disposal	55,000	35,000	11,000
Finished Water Transmission	1,039,000	916,000	683,000
Total Annual Cost	**$27,608,000**	**$19,999,000**	**$13,708,000**
Available Project Yield (acft/yr)	**28,000**	**21,280**	**15,680**
Annual Cost of Water ($ per acft)	**$986**	**$940**	**$874**
Annual Cost of Water ($ per 1,000 gallons)	**$3.03**	**$2.88**	**$2.68**

Table 4C.17-10.
Cost Estimate Summary
Combined Seawater and Brackish Groundwater Desalination
for Alternate Option (5-mile pipeline)
(Second Quarter 2002 Prices)

Item	***Estimated Costs 25 MGD***	***Estimated Costs 19 MGD***	***Estimated Costs 14 MGD***
Capital Costs			
Seawater Supply	$550,000	$330,000	$0
Brackish GW Wells, Pump Station, and Pipeline	30,000,000	30,000,000	30,000,000
Water Treatment Plant (Pretreatment and Desal)	56,138,000	34,659,000	15,452,000
Concentrate Disposal	340,000	216,000	160,000
Transmission Pipeline	10,562,000	8,700,000	7,258,000
Transmission Pump Station(s)	1,381,000	1,201,000	922,000
Total Capital Cost	**$98,971,000**	**$75,106,000**	**$53,792,000**
Engineering, Legal Costs and Contingencies	$34,320,000	$26,021,000	$18,592,000
Environmental & Archaeology Studies and Mitigation	3,050,000	3,013,000	2,164,000
Land Acquisition and Surveying (42 acres)	2,349,000	2,251,000	2,197,000
Interest During Construction (2.5 years)	13,870,000	10,640,000	7,675,000
Total Project Cost	**$152,560,000**	**$117,031,000**	**$84,420,000**
Annual Costs			
Debt Service (6 percent, 30 years)	$11,083,000	$8,502,000	$6,133,000
Operation and Maintenance			
Seawater Supply	110,000	45,000	0
Brackish GW Wells, Pump Station, and Pipeline	1,523,000	1,523,000	1,523,000
Water Treatment Plant	10,244,000	5,990,000	2,743,000
Concentrate Disposal	55,000	35,000	11,000
Finished Water Transmission	356,000	295,000	220,000
Total Annual Cost	**$23,371,000**	**$16,390,000**	**$10,630,000**
Available Project Yield (acft/yr)	**28,000**	**21,280**	**15,680**
Annual Cost of Water ($ per acft)	**$835**	**$770**	**$678**
Annual Cost of Water ($ per 1,000 gallons)	**$2.56**	**$2.36**	**$2.08**

The costs in Tables 4C.17-9 and 4C.17-10 assume that the desalination plant is purchasing power at $0.06 per kWh. Due to the large power usage of a reverse osmosis treatment plant, it is likely that power could be purchased at a cost that is consistent with other large industrial power users in the Corpus Christi area that currently pay approximately $0.04 per kWh. Table 4C.17-11 shows the cost savings that could be realized if a lower price for power is available for the desalination plant. The cost difference shown in Table 4C.17-11 is for a power cost decrease of $0.02 per kWh. This cost difference can also be added to the baseline ($0.06 per kWh) energy costs in Table 4C.17-9 to determine the cost of a $0.02 per kWh increase in power.

Table 4C.17-11.
Impact of a Reduction in Power Cost on the
Total Cost of Combined Desalination Options

Option	Desalt Power (kWh/yr)	Energy Cost at $0.06/kWh	Energy Cost at $0.04/kWh	Difference $/year	Difference $/kgal
25 MGD	85,511,000	$5,130,660	$3,420,440	$1,710,220	$0.19
19 MGD	46,025,000	$2,761,500	$1,841,000	$920,500	$0.13
14 MGD	20,645,000	$1,238,700	$825,800	$412,900	$0.08

4C.17.5 Implementation Issues

4C.17.5.1 Seawater Desalination

Permitting of this facility will require extensive coordination with all applicable regulatory entities. Use of the existing power plant intake should facilitate permitting for the source water because no additional water is to be drawn from the bay. However, permitting the construction of the concentrate pipeline across Laguna Madre and Padre Island and construction of the ocean outfall will be major project issues.

The installation and operation of a seawater desalination water treatment plant may have to address the following issues.

- Disposal of concentrated brine from desalination water treatment plant;
- Permitting and constructing concentrate pipeline through seagrass beds and barrier island;
- Impact on the bays from removing water for consumptive use and altering existing power plant water rights permit;

- Confirming that blending desalted seawater with other water sources in the municipal demand distribution system can be successfully accomplished;
- High power requirements for desalination process dependant on large, reliable power source;
- Skilled operators of desalination water treatment plants;
- Permitting of a pipeline across rivers, highways, and private rural and urban property; and
- Possibility of using a design, build, operate contract for a desalination water treatment plant.

4C.17.5.2 Combined Seawater and Brackish Groundwater Desalination

The development of brackish groundwater supplies from the Gulf Coast Aquifer (Goliad Sand) in Nueces County must address several issues. Major issues include:

- Impact of water levels in the aquifer, potential intrusion of saline groundwater and land surface subsidence;
- Purchase of groundwater rights;
- Competition for groundwater in the area;
- USCOE Section 10 and 404 dredge and fill permits for pipelines;
- General Land Office Sand and Gravel Removal permit for pipeline and crossings of streams and roads;
- General Land Office Easement for use of State-owned lands, if any;
- Texas Parks and Wildlife Department Sand, Gravel, and Marl permit; and
- Mitigation requirements would vary depending on impacts, but could include vegetation restoration, wetland creation or enhancement, or additional land acquisition.

Additional issues from the installation and operation of a combined seawater and brackish groundwater desalination plant include the following:

- Disposal of concentrated brine from desalination water treatment plant. The concentrated brine from a combined seawater and brackish groundwater desalination plant would have a lower salinity than concentrate from a desalination plant treating only seawater, but the concentrated brine may still exceed the ambient salinity of the receiving body and consideration of the concentrates impact will be required.
- Impact on the bays from removing water for consumptive use and altering existing power plant water rights permit.
- Confirming that blending desalted seawater with other water sources in the municipal demand distribution system can be successfully accomplished.
- High power requirements for desalination process dependant on large, reliable power source.

- Skilled operators of desalination water treatment plants.
- Possibility of using a design, build, operate contract for a desalination water treatment plant.

4C.17.6 Evaluation Summary

Evaluation summaries of this regional water management strategy are provided in Tables 4C.17-12 and 4C.17-13.

Table 4C.17-12.
Evaluation Summary of the Seawater Desalination Option

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Variable, ranges from 28,000 to 112,000 acft/yr (for 2006 Plan); actual water supply virtually unlimited. 2. Highly reliable quantity. 3. Generally high cost; between $1,341 to $1,027/acft. Cost could potentially be reduced through Federal participation as may be available through the USCOE Nueces River Basin Feasibility Study.
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. None or low impact. 2. Environmental impact to estuary 3. Disposal of concentrated brine created from process may impact fish and wildlife habitats or wetlands. 4. Disposal of concentrated brine created from process may impact fish and wildlife habitats or wetlands. 5. None identified. Endangered species survey will be needed to identify impacts. 6. Cultural resource survey will be needed to identify any significant sites 7. 7a-b. Total dissolved solids and salinity of water is removed with reverse osmosis treatment. Brine concentrate disposal issues will need to be evaluated.
c. Impacts to State water resources	• No negative impacts on other water resources
d. Threats to agriculture and natural resources in region	• Temporary damage due to construction of pipeline
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Standard analyses and methods used for portions • Seawater desalination cost modeled after bid and manufactures' budgets, but not constructed, comparable project
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• Construction and maintenance of transmission pipeline corridor. Possible impact to wildlife habitat along pipeline route and right-of-way.

Table 4C.17-13.
Summary Evaluation of the Combined Seawater and Brackish Groundwater Desalination Option

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Variable, ranges from 15,680 to 28,000 acft/yr (for 2006 Plan); actual water supply limited by brackish groundwater yield with maximum product water yield of 25 MGD. 2. Highly reliable quantity. 3. Generally high cost; between $986 to $678/acft. Cost could potentially be reduced through Federal participation as may be available through the USCOE Nueces River Basin Feasibility Study.
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	 1. None or low impact. 2. Environmental impact to estuary. 3. Disposal of concentrated brine created from process may impact fish and wildlife habitats or wetlands. 4. Disposal of concentrated brine created from process may impact fish and wildlife habitats or wetlands. 5. None identified. Endangered species survey will be needed to identify impacts. 6. Cultural resource survey will be needed to identify any significant sites. 7. 7a-b. Total dissolved solids and salinity of water is removed with reverse osmosis treatment. Brine concentrate disposal issues will need to be evaluated.
c. Impacts to State water resources	• No negative impacts on other water resources other than lowering Gulf Coast Aquifer levels
d. Threats to agriculture and natural resources in region	• Temporary damage due to construction of pipeline • Insignificant due to water use since very little of water is suitable for use by agriculture
e. Recreational impacts	• None
f. Equitable comparison of strategies	• Standard analyses and methods used for portions. Seawater desalination cost modeled after bid and manufactures' budgets, but not constructed, comparable project.
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None

4C.18 Potential Water System Interconnections (N-18)

4C.18.1 Description of Strategy

In addition to providing backup water supplies for emergencies, water system interconnections for this region are another potential source of freshwater supplies for municipal and industrial uses. This section describes additional community water system candidates for interconnection within the Regional Water Planning Group Area. They are organized by county location.

There are certain municipal water systems that rely totally on local groundwater. Many of these groundwater systems operate under one or more of the following conditions:

- Insufficient groundwater supply
- Insufficient well capacity
- Unsuitable water quality

The Trans-Texas Water Program Phase II Report[1] listed 24 municipal water systems in the Coastal Bend Area that have converted at least a part of their groundwater supply to the regional surface water system. This list is shown in Table 4C.18-1. Most of the water systems shown on this list have converted totally to the regional surface water system.

One example of an existing interconnection between the regional surface water system and a local groundwater system is the City of Kingsville in Kleberg County. The City maintains its groundwater supply as its primary source but also has an interconnection with the South STWA's surface water system.

4C.18.2 Available Yield

4C.18.2.1 Duval County

In 1996, TWDB funded a regional water supply study for Duval and Jim Wells Counties.[2] The study evaluated several alternative surface water supply systems from the City

[1] HDR Engineering, Inc. (HDR), "Trans-Texas Water Program - Corpus Christi Study Area - Phase II Report," City of Corpus Christi, et al, September 1995.
[2] Naismith Engineering, Inc. (NEI), et al., "Regional Water Supply Study, Duval and Jim Wells County, Texas," Nueces River Authority, et al., October 1996.

Table 4C.18-1.
Public Water Suppliers That Have Converted Totally or Partially to Surface Water from the Choke Canyon/Lake Corpus Christi System

Water Supplier	***Conversion Date***	***Currently Supplied By***[1]
Aransas County		
Rockport	1970	Aransas Co. CRD/ San Patricio/Corpus Christi
Copano Cover Water Co.	1972	Rockport
Peninsula Water Co.	1978	Rockport
Bee County		
Beeville	1985	—
Jim Wells County		
Alice	1965	—
Jim Wells Co. FWSD 1	1980	Alice
Kleberg County		
Kingsville	1985	South Texas Water Authority
Ricardo WSC	1985	South Texas Water Authority
U.S. Naval Air Station-Kingsville	1985	South Texas Water Authority
McMullen County		
Choke Canyon Water System	1991	—
Nueces County		
Aqua Dulce	1985	South Texas Water Authority
Bishop	1985	South Texas Water Authority
Corpus Christi	1983-4	—
Driscoll	1985	South Texas Water Authority
Nueces Co. WCID #4-Port Aransas	1958	Corpus Christi & San Patricio MWD
Nueces Co. WCID #5-Banquette Area	1985	South Texas Water Authority
Nueces Co. WCID #6-Robstown	1985	Nueces River[1]
San Patricio County		
Odem	1954	San Patricio MWD
Aransas Pass	1962	San Patricio MWD
Ingleside	1955	San Patricio MWD
Gregory	1954	San Patricio MWD
Mathis	1980	—
Portland	1954	San Patricio MWD
Taft	1965	San Patricio MWD

[1] All surface water is supplied from the CCR/LCC System under water rights held by the City of Corpus Christi except for Robstown, which has their own water rights from the Nueces River at Calallen.

of Alice to various combinations of cities in Duval County. Those cities included San Diego, Freer, Benavides, Realitos, and Concepcion. The alternatives evaluated are:

Alternative 1 - Alice to San Diego, Benavides, Realitos, Concepcion, and Freer (Figure 4C.18-1)

Alternative 2 - Alice to San Diego, Benavides and Freer (Figure 4C.18-2)

Alternative 3 - Alice to San Diego and Benavides (Figure 4C.18-3)

Alternative 4 - Alice to San Diego and Freer (Figure 4C.18-4)

Alternative 5 - Alice to San Diego (Figure 4C.18-5)

An interconnection to the CCR/LCC System to serve community water systems in Duval County via the City of Alice is feasible because the City of Alice has existing raw water pump capacity, treatment capacity, and high service pump capacity to meet the projected peak day demands for all cities in the study area through the near-term (2030) and long-term (2060) planning horizon.

Required regional facilities would include transmission lines ranging in size from 6-inch to 16-inch diameters, and intermediate storage and booster pump stations. Total capital costs and annual costs (debt service, power cost, operation and maintenance (O&M) cost, and treated water cost) were estimated for each alternative and are included in Tables 4C.18-2 through 4C.18-6. These costs have been updated since the 2001 Plan to reflect Second Quarter 2002 price levels.

The 1996 Regional Water Supply Study recommended that surface water projects in Duval County be initiated, constructed, financed, operated and maintained by the Duval County Conservation and Reclamation District (DCCRD).

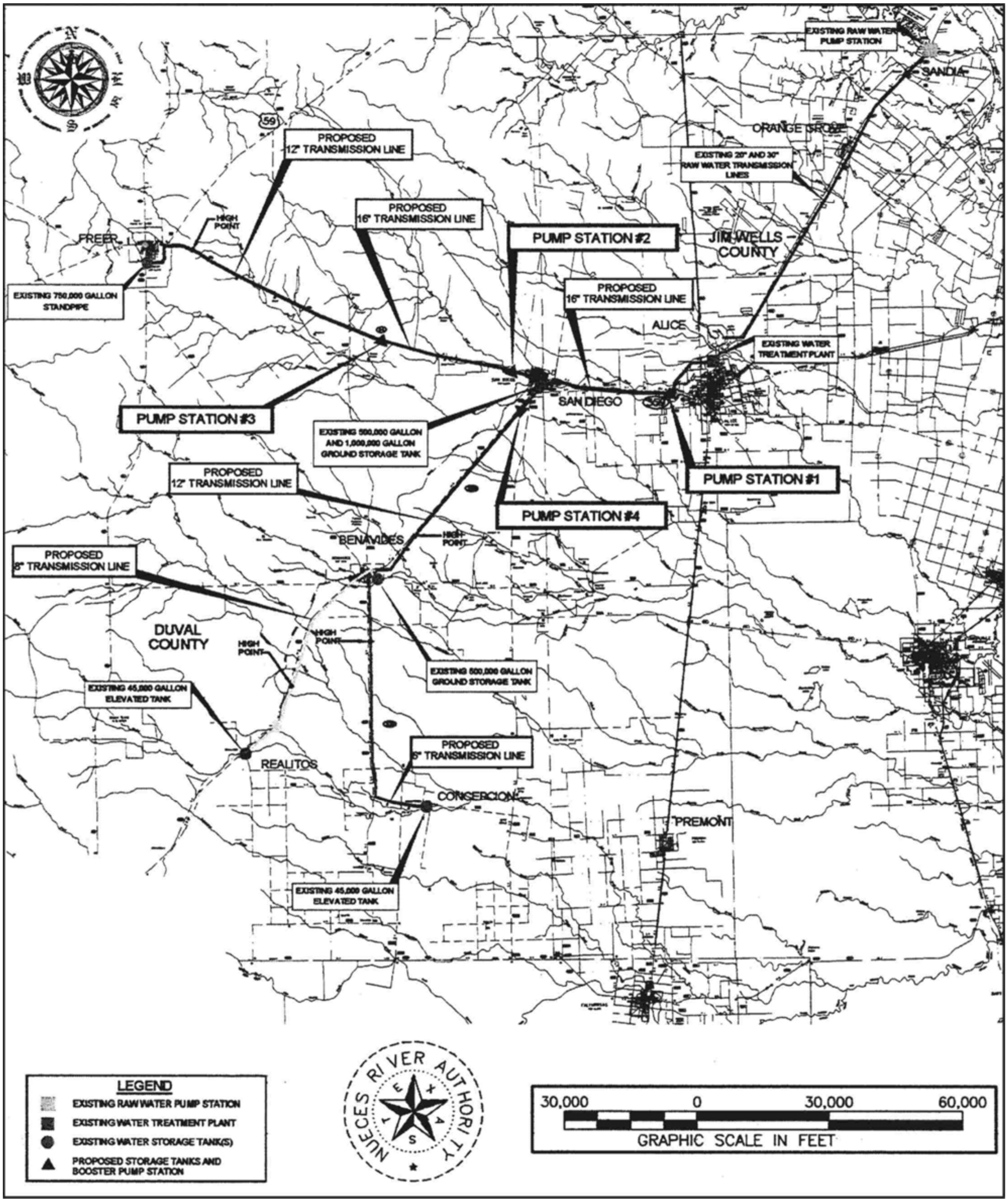

Figure 4C.18-1. Duval County Interconnection Alternative 1

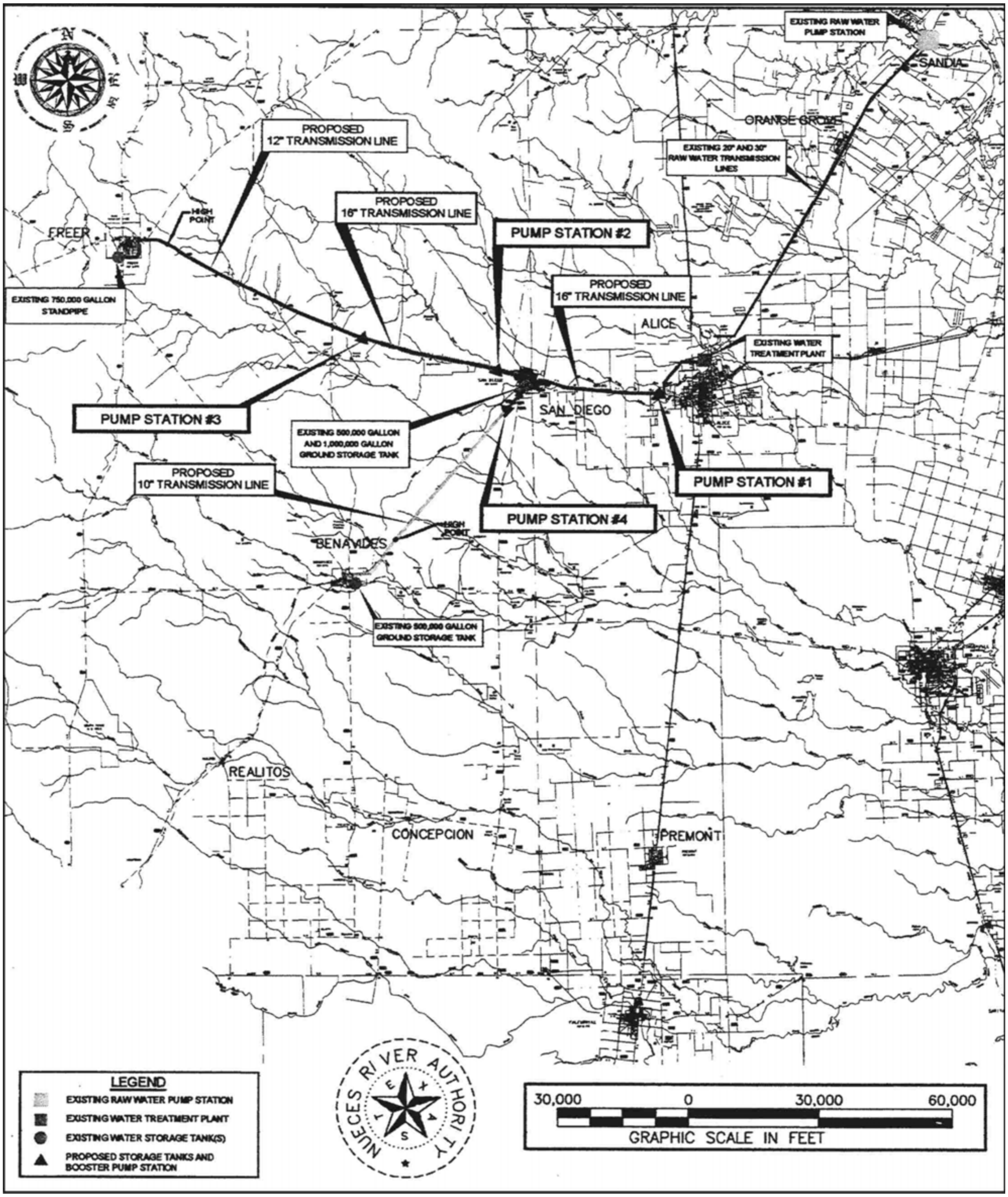

Figure 4C.18-2. Duval County Interconnection Alternative 2

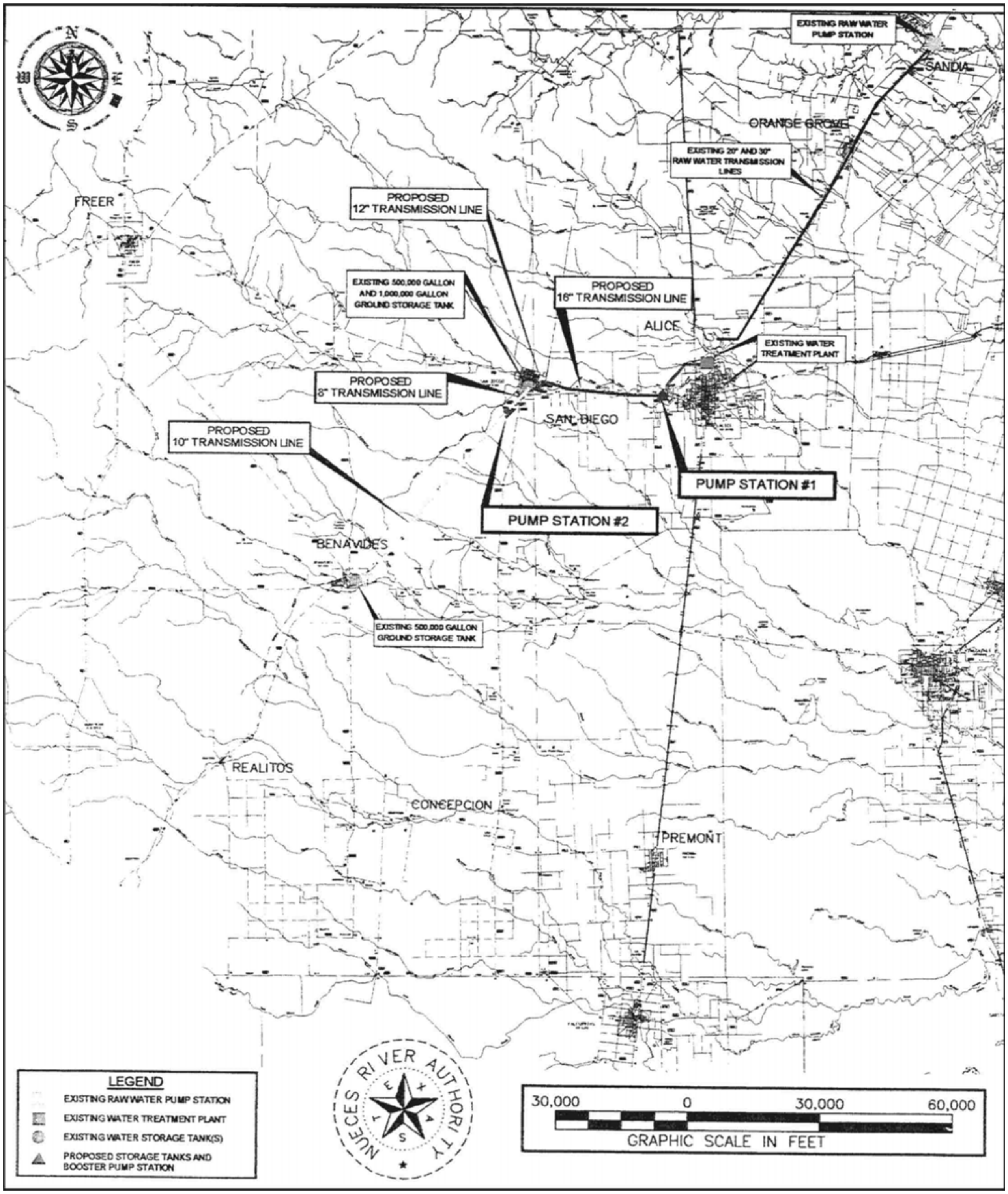

Figure 4C.18-3. Duval County Interconnection Alternative 3

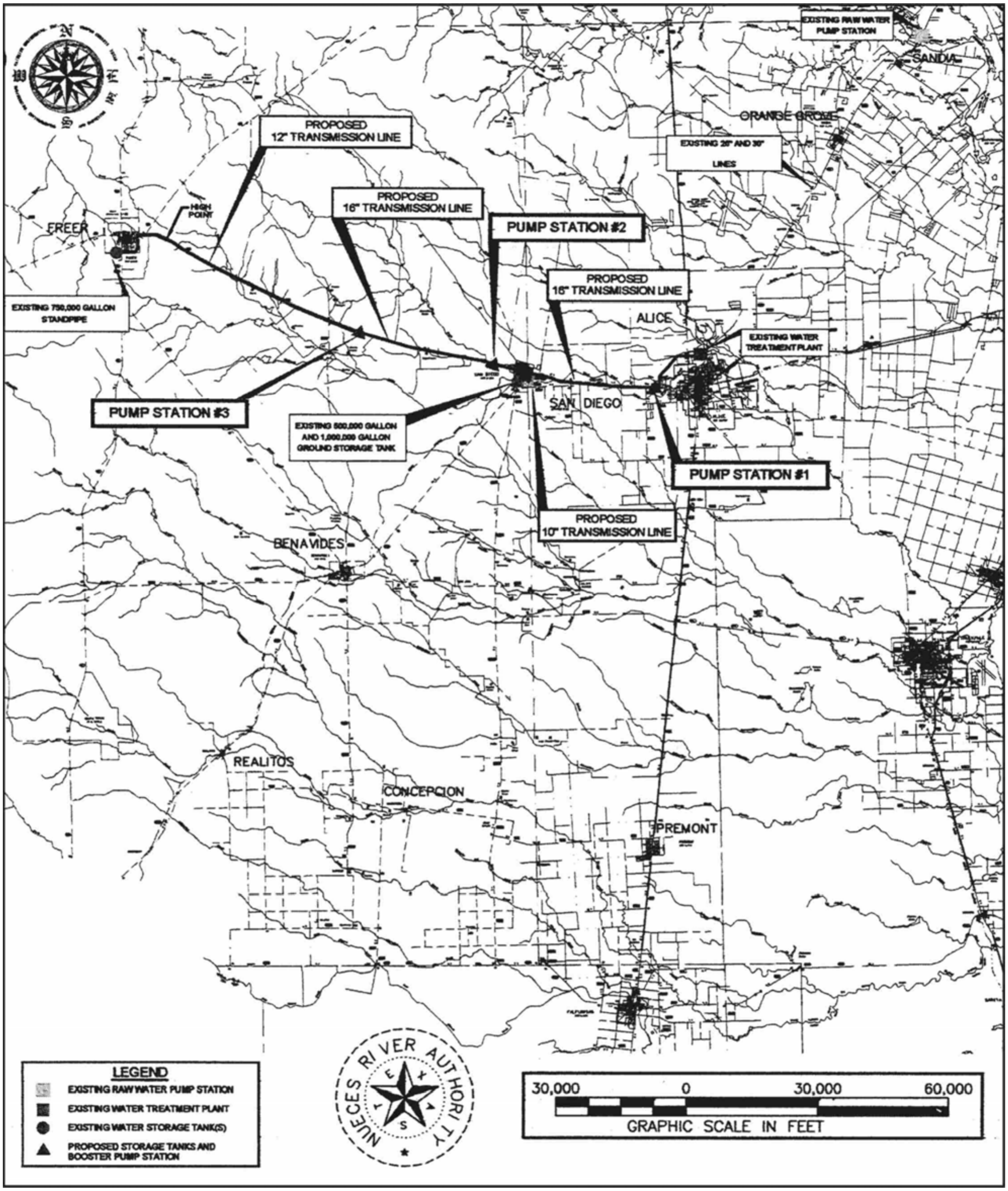

Figure 4C.18-4. Duval County Interconnection Alternative 4

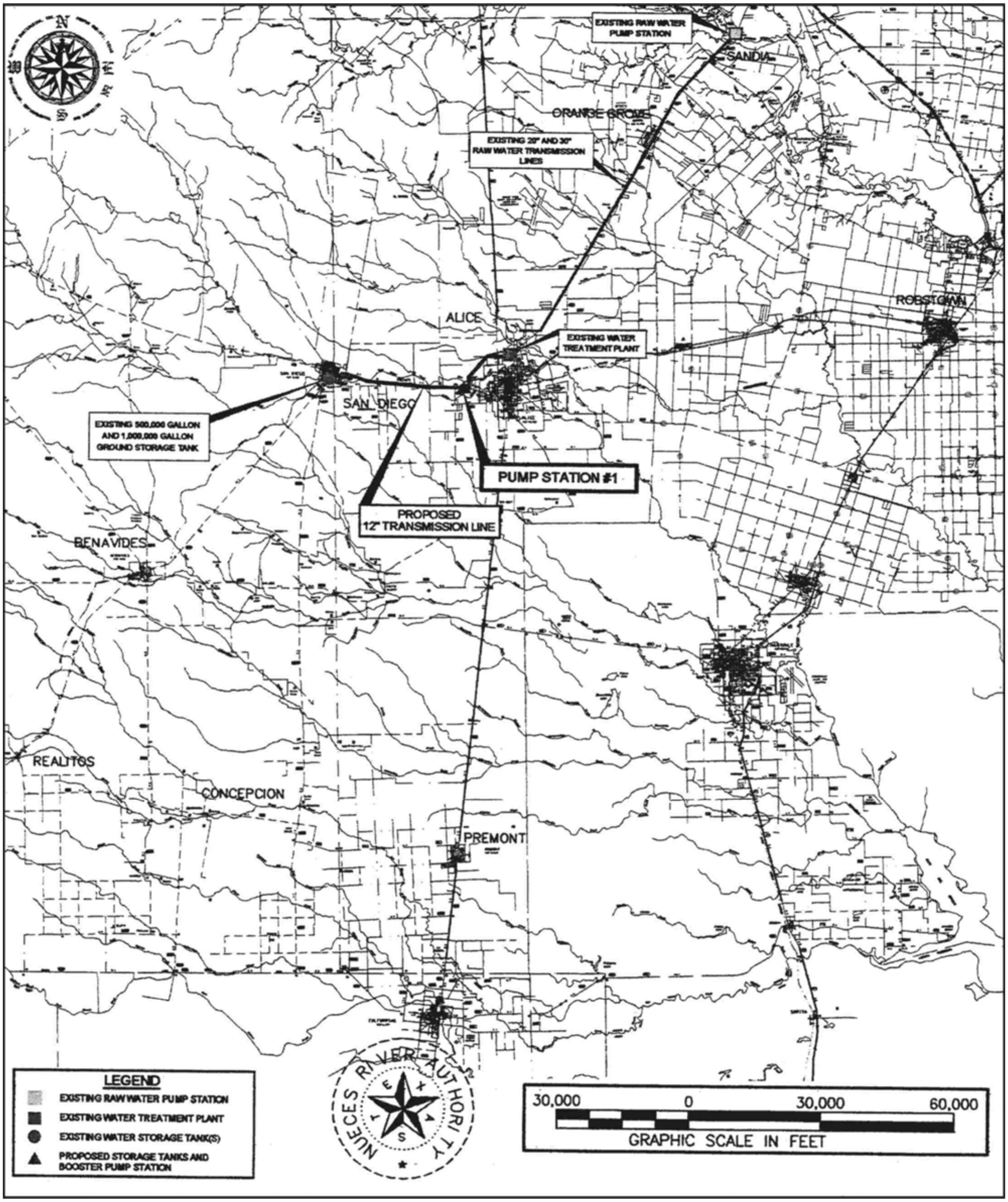

Figure 4C.18-5. Duval County Interconnection Alternative 5

Table 4C.18-2.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 1[1]
(Second Quarter 2002 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (85.4 miles)	$9,507,000
Storage and Pump Stations	2,820,000
Total Capital Costs	**$12,327,000**
Engineering, Legal Costs and Contingencies	$3,839,000
Environmental & Archaeology Studies and Mitigation	2,135,000
Land Acquisition and Surveying	2,905,000
Interest During Construction (2 years)	1,697,000
Total Project Cost	**$22,903,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$1,664,000
Operation and Maintenance:	
Pipelines and Pump Stations	166,000
Pumping Energy Costs	237,000
Treated Water Cost	1,235,000
Total Annual Cost	**$3,302,000**
Available Project Yield[2] (acft/yr)	**2,520**
Annual Cost of Water ($ per ac ft)	**$1,310**
Annual Cost of Water ($ per 1,000 gallons)	**$4.02**

[1] Interconnection between Alice Water Authority Water Treatment Plant, and San Diego, Freer, Benavides, Realitos and Concepcion.
[2] Average Day Demand in Year 2030, based on 2001 Plan.

Table 4C.18-3.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 2[1]
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (54.6 miles)	$6,692,000
Storage and Pump Stations	2,740,000
Total Capital Costs	**$9,432,000**
Engineering, Legal Costs and Contingencies	$2,967,000
Environmental & Archaeology Studies and Mitigation	1,365,000
Land Acquisition and Surveying	1,858,000
Interest During Construction (2 years)	1,250,000
Total Project Cost	**$16,872,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$1,226,000
Operation and Maintenance:	
Pipelines and Pump Stations	135,000
Pumping Energy Costs	204,000
Treated Water Cost	1,191,000
Total Annual Cost	**$2,756,000**
Available Project Yield[2] **(acft/yr)**	**2,430**
Annual Cost of Water ($ per ac ft)	**$1,134**
Annual Cost of water ($ per 1,000 gallons)	**$3.48**

[1] Interconnection between Alice Water Authority Water Treatment Plant and San Diego, Freer, and Benavides.
[2] Average Day Demand in Year 2030, based on 2001 Plan.

Table 4C.18-4.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 3[1]
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (28 miles)	$3,170,000
Storage and Pump Stations	1,419,000
Total Capital Costs	**$4,589,000**
Engineering, Legal Costs and Contingencies	1,448,000
Environmental & Archaeology Studies and Mitigation	700,000
Land Acquisition and Surveying	953,000
Interest During Construction (2 years)	616,000
Total Project Cost	**$8,306,000**
Annual Costs	
Debt Service (6 percent for 30 years)	603,000
Operation and Maintenance:	
Pipelines and Pump Stations	67,000
Pumping Energy Costs	72,000
Treated Water Cost	752,000
Total Annual Cost	**$1,494,000**
Available Project Yield[2] (acft/yr)	**1,534**
Annual Cost of Water ($ per ac ft)	**$974**
Annual Cost of Water ($ per 1,000 gallons)	**$2.99**

1 Interconnection between Alice Water Authority Water Treatment Plant and San Diego and Benavides.
2 Average Day Demand in Year 2030, based on 2001 Plan.

Table 4C.18-5.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 4[1]
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (38.8 miles)	$5,165,000
Storage and Pump Stations	1,957,000
Total Capital Costs	**$7,122,000**
Engineering, Legal Costs and Contingencies	2,235,000
Environmental & Archaeology Studies and Mitigation	970,000
Land Acquisition and Surveying	1,320,000
Interest During Construction (2 years)	932,000
Total Project Cost	**$12,579,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$914,000
Operation and Maintenance:	
Pipelines and Pump Stations	101,000
Pumping Energy Costs	132,000
Treated Water Cost	916,000
Total Annual Cost	**$2,063,000**
Available Project Yield[2] (acft/yr)	**1,870**
Annual Cost of Water ($ per ac ft)	**$1,103**
Annual Cost of Water ($ per 1,000 gallons)	**$3.39**

[1] Interconnection between Alice Water Authority Water Treatment Plant, San Diego and Freer.
[2] Average Day Demand in Year 2030, based on 2001 Plan.

Table 4C.18-6.
Cost Estimate Summary
Regional Surface Water Supply
***Duval County Interconnection Alternative 5*[1]**
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (12.2 miles)	$1,518,000
Storage and Pump Stations	636,000
Total Capital Costs	**$2,154,000**
Engineering, Legal Costs and Contingencies	$678,000
Environmental & Archaeology Studies and Mitigation	305,000
Land Acquisition and Surveying	415,000
Interest During Construction (1 year)	143,000
Total Project Cost	**$3,695,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$268,000
Operation and Maintenance:	
Pipelines and Pump Stations	31,000
Pumping Energy Costs	26,000
Treated Water Cost	478,000
Total Annual Cost	**$803,000**
Available Project Yield[2] (acft/yr)	**974**
Annual Cost of Water ($ per ac ft)	**$824**
Annual Cost of Water ($ per 1,000 gallons)	**$2.53**

1 Interconnection between Alice Water Authority Water Treatment Plant and San Diego.
2 Average Day Demand in 2030.

4C.18.2.2 Jim Wells County

The 1996 Regional Water Supply Study[3] also included two alternative surface water supply systems to deliver water from the CCR/LCC System, via the City of Alice, to Orange Grove (Figure 4C.18-6) and Premont (Figure 4C.18-7) in Jim Wells County.

Required regional facilities for Jim Wells County options would include new transmission lines ranging in size from 8-inches to 18-inches in diameter. Associated total capital costs and annual costs (debt service, O&M cost, and treated water cost) were estimated for each alternative and are included in Tables 4C.18-7 through 4C.18-8.

Although not evaluated, it could be feasible to connect the City of Premont to STWA's system in Kleberg County. Before pursuing an interconnection between the cities of Alice and Premont, a STWA to Premont interconnection should be evaluated.

[3] Ibid.

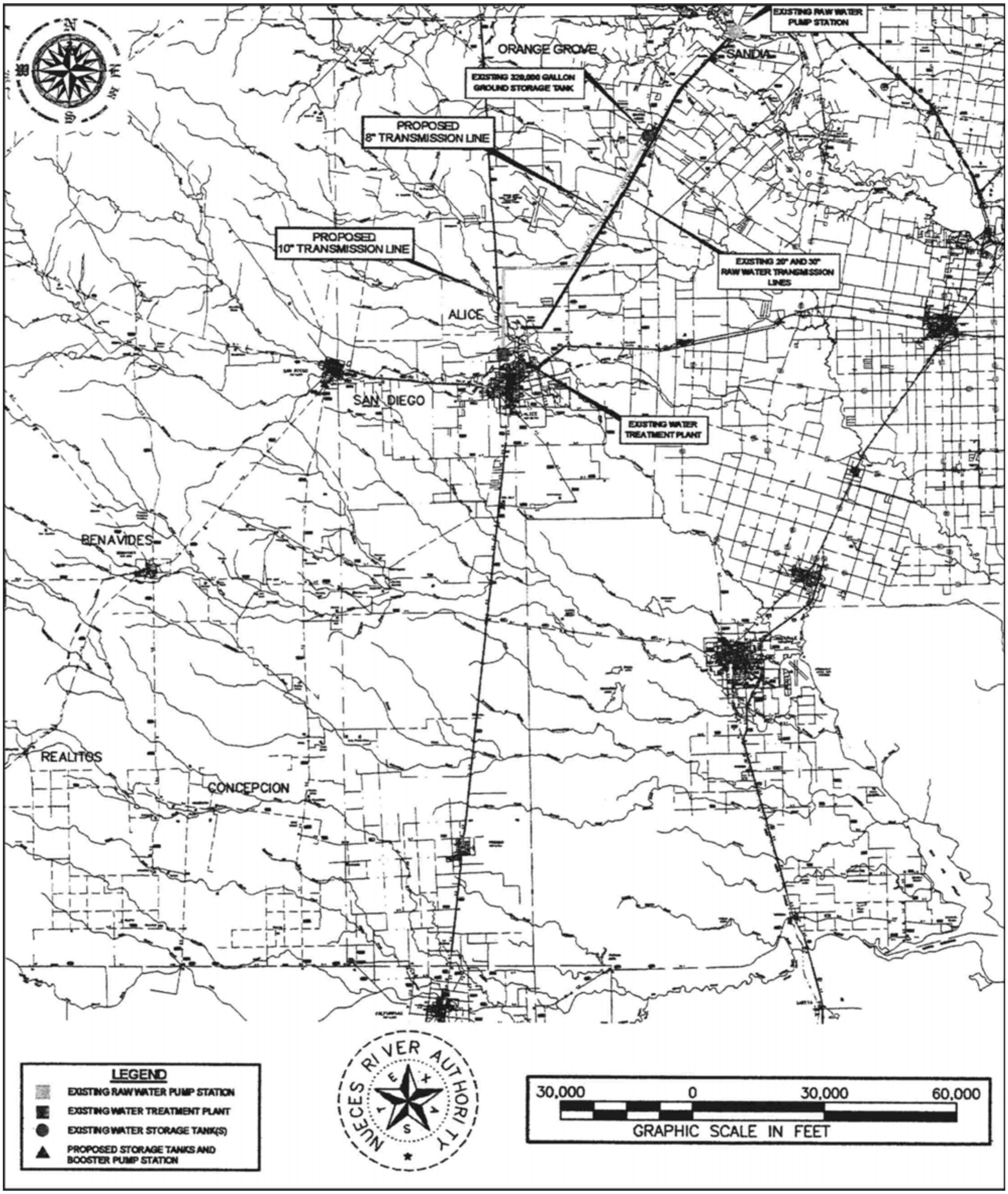

Figure 4C.18-6. Jim Wells County Interconnection Alternative 1

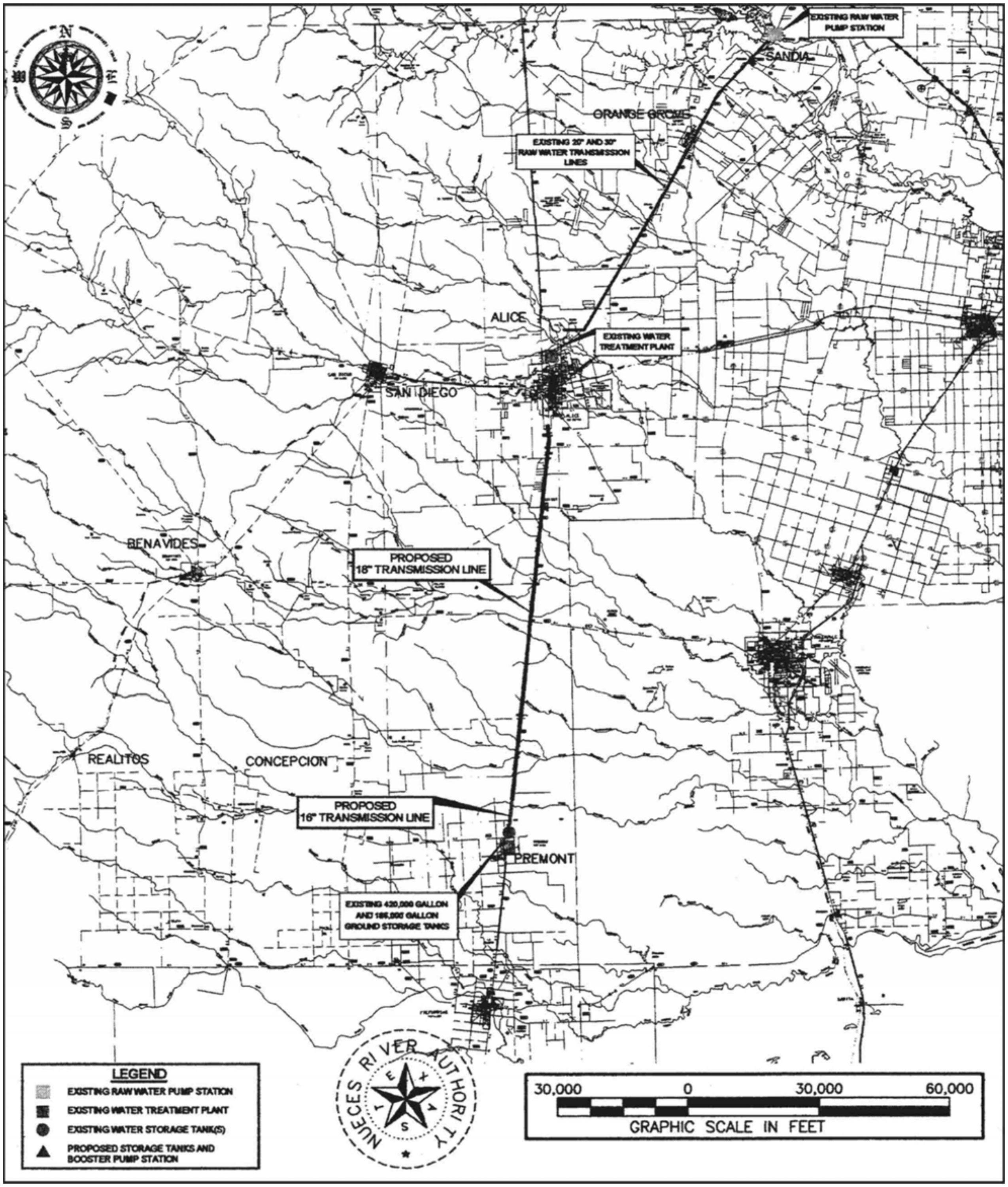

Figure 4C.18-7. Jim Wells County Interconnection Alternative 2

Table 4C.18-7.
Cost Estimate Summary
Regional Surface Water Supply
Jim Wells County Interconnection Alternative 1[1]
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (19.1 miles)	$1,549,000
Total Capital Costs	**$1,549,000**
Engineering, Legal Costs and Contingencies	$465,000
Environmental & Archaeology Studies and Mitigation	478,000
Land Acquisition and Surveying	650,000
Interest During Construction (1 year)	126,000
Total Project Cost	**$3,268,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$237,000
Operation and Maintenance:	
Pipelines and Pump Stations	15,000
Treated Water Cost	120,000
Total Annual Cost	**$372,000**
Available Project Yield[2] (acft/yr)	**246**
Annual Cost of Water ($ per ac ft)	**$1,512**
Annual Cost of Water ($ per 1,000 gallons)	**$4.64**

[1] Interconnection between Alice Water Authority Water Treatment Plant and Orange Grove.
[2] Average Day Demand in Year 2030, based on 2001 Plan.

Table 4C.18-8.
Cost Estimate Summary
Regional Surface Water Supply
Jim Wells County Interconnection Alternative 2[1]
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (26.9 miles)	$4,642,000
Total Capital Costs	**$4,642,000**
Engineering, Legal Costs and Contingencies	$1,393,000
Environmental & Archaeology Studies and Mitigation	673,000
Land Acquisition and Surveying	915,000
Interest During Construction (2 years)	610,000
Total Project Cost	**$8,233,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$598,000
Operation and Maintenance:	
Pipelines	46,000
Treated Water Cost	702,000
Total Annual Cost	**$1,346,000**
Available Project Yield[2] (acft/yr)	**1,434**
Annual Cost of Water ($ per ac ft)	**$939**
Annual Cost of Water ($ per 1,000 gallons)	**$2.88**

1 Interconnection between Alice Water Authority Water Treatment Plant and Premont.
2 Average Day Demand in Year 2030, based on 2001 Plan.

4C.18.2.3 Brooks County

In the 2001 Plan, water demands for the City of Falfurrias were projected to decrease from 2000 to 2050 with projected demands met through 2050 by allocating groundwater from the county supply and using the current well capacity for the community of Falfurrias. Based on recent TWDB demand projections for the 2006 Plan, the previous estimates were underestimated and have been revised to show an increase in water demand for Falfurrias from 2000 to 2060. If future regional surface water supply facilities are constructed from Alice to Premont (Figure 4C.18-8), it may be feasible to extend the system an additional 10.5 miles to Falfurrias. Total capital costs and annual costs for regional surface water supply facilities to serve Premont and Falfurrias are shown in Table 4C.18-9.

Although not evaluated, it could be feasible to connect the cities of Premont and Falfurrias to the STWA system in Kleberg County. Before pursuing an interconnection between Alice and Premont and/or Falfurrias, a STWA interconnection to one or both cities should be evaluated.

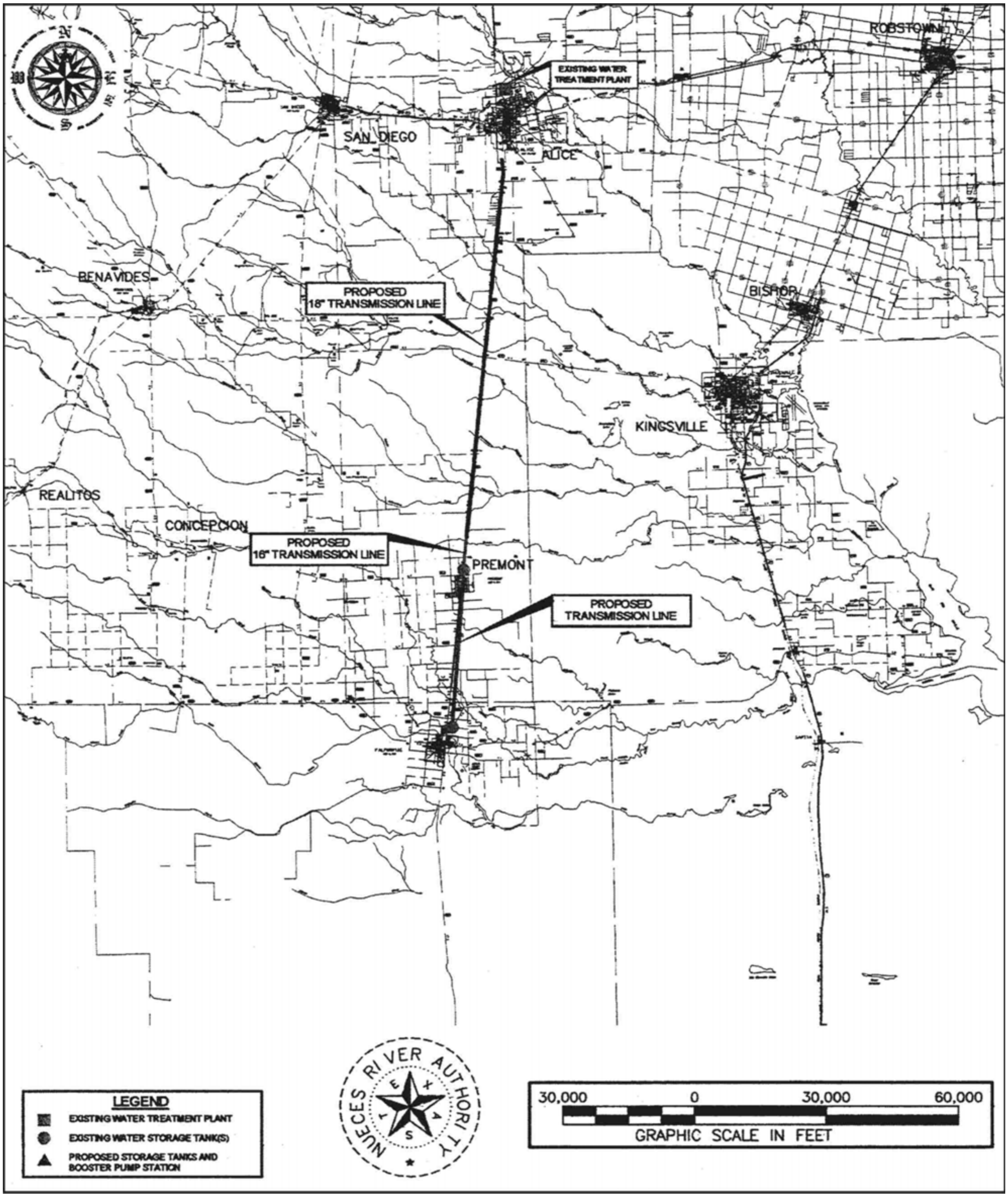

Figure 4C.18-8. Brooks County Interconnection Alternative 1

Table 4C.18-9.
Cost Estimate Summary
Regional Surface Water Supply
***Jim Wells and Brooks County Interconnection Alternative 1*[1]**
(Second Quarter 2002 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (37.4 miles)	$6,461,000
Storage and Pump Station	591,000
Total Capital Costs	**$7,052,000**
Engineering, Legal Costs and Contingencies	$2,145,000
Environmental & Archaeology Studies and Mitigation	935,000
Land Acquisition and Surveying	1,273,000
Interest During Construction (2 years)	913,000
Total Project Cost	**$12,318,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$895,000
Operation and Maintenance:	
Pipelines and Pump Stations	79,000
Pumping Energy Costs	77,000
Treated Water Cost	1,438,000
Total Annual Cost	**$2,489,000**
Available Project Yield[2] (acft/yr)	**2,554**
Annual Cost of Water ($ per ac ft)	**$975**
Annual Cost of Water ($ per 1,000 gallons)	**$2.99**

[1] Interconnection between Alice Water Authority Water Treatment Plant and Premont and Falfurrias.
[2] Average Day Demand in Year 2030, based on 2001 Plan.

4C.18.2.4 Kleberg and Kenedy Counties

Local groundwater in Kleberg County can vary from fresh (less than 1,000 mg/L) to slightly saline (up to 3,000 mg/L). Table 4C.18-1 shows that the Ricardo Water Supply Corporation, located south of Kingsville, converted to surface water from STWA in 1985.

Similar to Kleberg County, local groundwater in Kenedy County can be slightly saline. In the 2001 Plan, an interconnection between South Texas Water Authority transmission main and Riviera (Kleberg County) and Sarita (Kenedy County) was considered based on possible additional water demands for the proposed Spaceport Project in Kenedy County. Since the 2001 Plan, the Spaceport Project is no longer being actively pursued. Due to the rural nature of the county, municipal water demand is not likely to increase in the future, therefore this proposed interconnection has been removed from consideration in the 2006 Plan.

4C.18.2.5 San Patricio County

In San Patricio County, the City of Sinton, along with water supply corporations located in the communities of Edroy and St. Paul, and several residential communities located along Lake Mathis, still rely on groundwater supplies.

Water supply for the City of Sinton is located in two well fields located along US 181 in the vicinity of the Rob and Bessie Welder Park. In the early 1980s, the City recognized that its municipal water supply, which was originally developed in the 1940s and 50s, was rapidly deteriorating and affecting the City's ability to reliably serve potable water to its customers. The corrosive nature of the groundwater supplies from the well fields located approximately 3 miles northwest of the city was causing severe deterioration of the well field casings, screens, and pumping units.

In 1983, the first of three 12-inch diameter stainless steel wells were constructed for the City. The well design included under reaming and gravel packing of the water bearing zones which produced adequate water for depths of approximately 300 to 700 feet. While water quality in the Sinton municipal well field area meets established published secondary drinking water standards, the chemical constituents of total dissolved solids and chlorides only marginally meets these standards.

When developing the final replacement well in the Sinton west field constructed in 1993, careful review of well field logs still could not predict the water quality which would be produced from the final constructed well. When the well was turned on, water quality parameters exceeded secondary drinking water standards for chlorides. Chloride levels for this well fell in the range of 300 to 325 ppm. Permission was sought from the Texas Water Commission (now the Texas Commission on Environmental Quality (TCEQ)) to allow the City to blend its water with its other water well resources in order that water supply delivered to its customers would fall within the recommended secondary drinking water standards. To this date, the City of Sinton is still mandated by the TCEQ to operate this water blending plan.

Water well capacity for the City of Sinton is expected to be sufficient to meet the population demands through the year 2060. However, if groundwater quality continues to degrade, the City could either construct a water treatment facility or connect directly to the San Patricio Municipal Water District's (SPMWD) treated surface water system. The SPMWD could either provide raw water through its 36-inch Nueces River transmission line or the newly constructed connection to the Mary Rhodes pipeline. Treatment for potable use purposes would be required.

A direct connection to the SPMWD's 24-inch treated water transmission line would require approximately 8 miles of 12-inch waterline (Figure 4C.18-9). Connections and modifications to the City's ground storage and pump stations would also be required. Total costs to establish an interconnection for Sinton to the regional surface water system are shown in Table 4C.18-10.

Water service for the Community of Edroy, Texas located along US 77 west of Odem, Texas is provided by the San Patricio Municipal Water District Number 1 (District #1). In 1985, District #1 constructed a community water system complete with two wells, storage facilities and distribution lines. Approximately 200 connections are served through this system. Although the groundwater supply marginally meets secondary drinking water standards, the water is high in hydrogen sulfide (H_2S) making it extremely corrosive. From its initial operations, District #1 has utilized an aeration tower and the addition of chlorine to oxidize the hydrogen sulfide to acceptable odor levels. Corrosion to pump station equipment has been a continual problem. Original construction of the wells for the water supply for the community was based on an economic decision at the time and was limited to available grant funding. It has been anticipated that a conversion to treated surface water via the SPMWD may be required in the future.

During the mid 1990s, the TWDB Economic Development Assistance Program (EDAP) for San Patricio County identified a project which would have extended an 8-inch water line from the SPMWD 24-inch treated water line to the Community of Edroy. This plan included an expansion to the District #1 service area, a new elevated storage tank, pumping facilities, and an interconnection to the existing Edroy system. Figure 4C.18-10 outlines the recommended EDAP plan. The cost of construction for these facilities is shown in Table 4C.18-11.

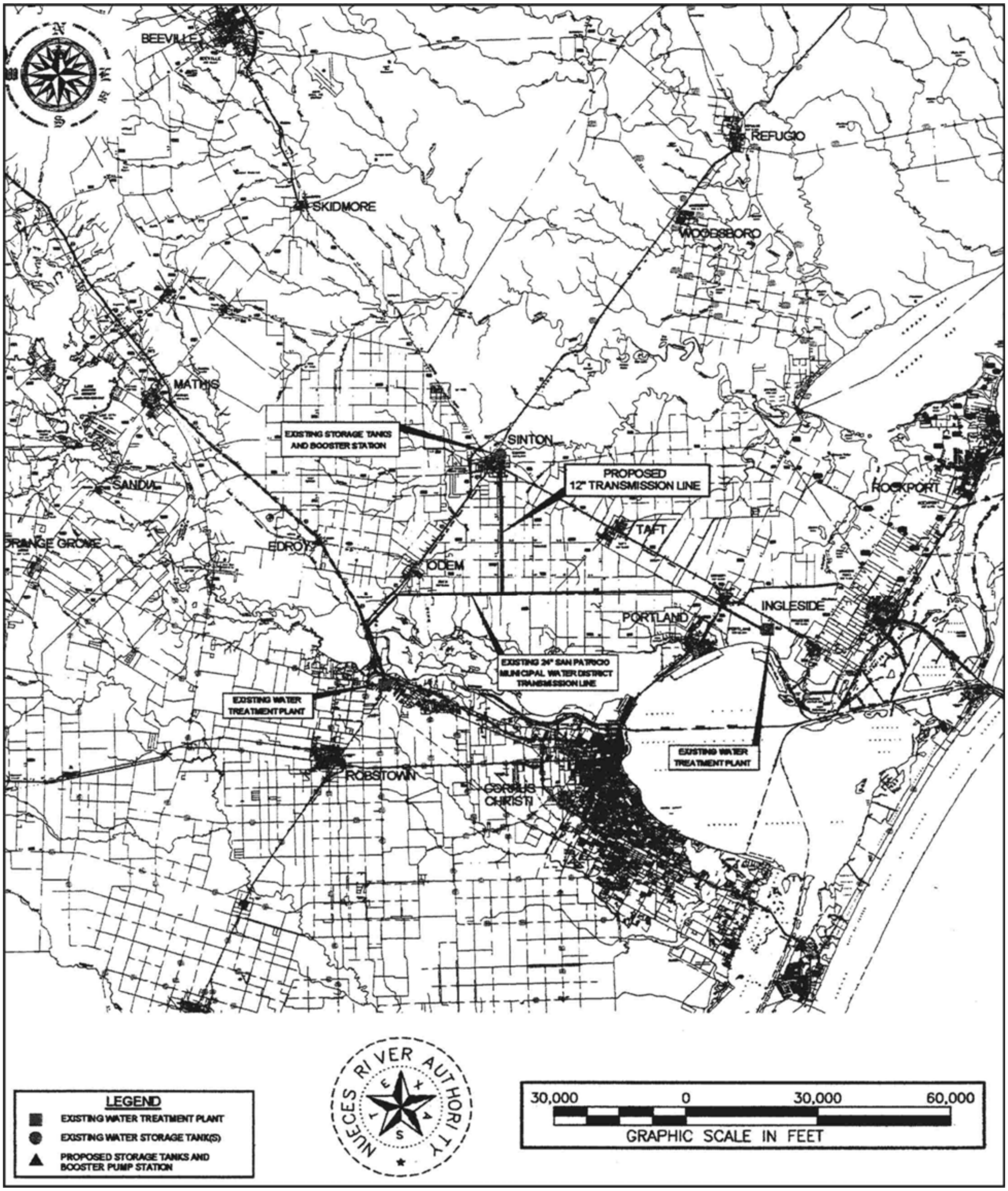

Figure 4C.18-9. San Patricio County Interconnection Alternative 1

Table 4C.18-10.
Cost Estimate Summary
Regional Surface Water Supply
San Patricio County Interconnection Alternative 1[1]
(Second Quarter 2002 Prices)

Item	Estimated Costs
Capital Costs	
Transmission Pipelines (8.1miles)	$827,000
Storage and Pump Station Modifications	215,000
Total Capital Costs	**$1,042,000**
Engineering, Legal Costs and Contingencies	323,000
Environmental & Archaeology Studies and Mitigation	203,000
Land Acquisition and Surveying	238,000
Interest During Construction (1.5 years)	109,000
Total Project Cost	**$1,915,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$139,000
Operation and Maintenance:	
Pipelines and Pump Stations	14,000
Pumping Energy Costs	39,000
Treated Water Cost	549,000
Total Annual Cost	**$741,000**
Available Project Yield[2] **(acft/yr)**	**1,120**
Annual Cost of Water ($ per ac ft)	**$662**
Annual Cost of Water ($ per 1,000 gallons)	**$2.03**

[1] Interconnection between San Patricio Municipal Water District transmission main and Sinton.
[2] Average Day Demand in Year 2030, based on 2001 Plan.

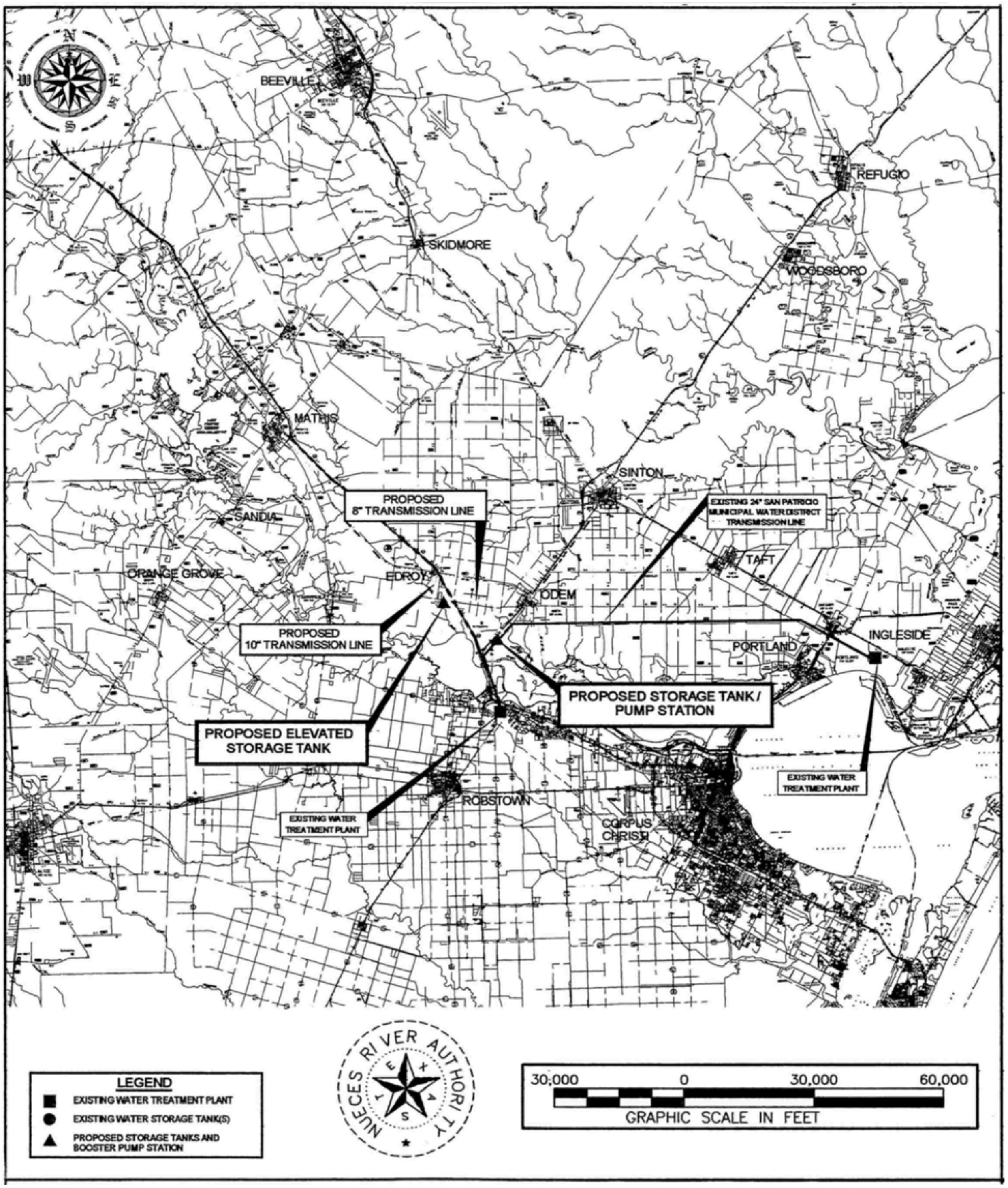

Figure 4C.18-10. San Patricio County Interconnection Alternative 2

Table 4C.18-11.
Cost Estimate Summary
Regional Surface Water Supply
San Patricio County Interconnection Alternative 2[1]
(Second Quarter 2002 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (8.5 miles)	$714,000
Storage and Pump Station	683,000
Total Capital Costs	**$1,397,000**
Engineering, Legal Costs and Contingencies	$453,000
Environmental & Archaeology Studies and Mitigation	213,000
Land Acquisition and Surveying	145,000
Interest During Construction (2 years)	177,000
Total Project Cost	**$2,385,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$173,000
Operation and Maintenance:	
Pipelines and Pump Stations	24,000
Pumping Energy Costs	11,000
Treated Water Cost	61,000
Total Annual Cost	**$269,000**
Available Project Yield[2] (acft/yr)	**125**
Annual Cost of Water ($ per ac ft)	**$2,152**
Annual Cost of Water ($ per 1,000 gallons)	**$6.60**

[1] Interconnection between San Patricio Municipal Water District transmission main and Edroy.
[2] Average Day Demand in Year 2030, based on 2001 Plan.

4C.18.3 Environmental Issues

Environmental issues related to the potential water system interconnections in the Coastal Bend Region can be categorized as follows:

- Effects related to pipeline construction and maintenance; and
- Effects resulting from changes in Nueces River flows, including inflows to the Nueces Estuary.

The various proposed pipelines required for the water system interconnections are within Duval, Jim Wells, Brooks, San Patricio, and Nueces Counties. The pipelines are intended to transfer water between the municipal and industrial demands of these counties. The construction of these pipelines would result in soil and vegetation disturbance within the pipeline construction corridor. Longer-term impacts would be confined to the maintained right-of-way. Several studies are required before the proposed pipelines are constructed. The studies include, but are not limited to, environmental, habitat, and cultural resources studies.

Implementation of the water system interconnections would place an increased demand on the CCR/LCC System. This will impact reservoir levels, streamflows, and inflows to the Nueces Estuary. An evaluation of these impacts may be required before the water system interconnections are implemented, although the anticipated impacts are negligible.

Implementation of water system interconnections in San Patricio County are expected to reduce chlorides for Sinton and hydrogen sulfide for Edroy and help to ensure Safe Drinking Water Act standards.

4C.18.4 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 4C.18-12.

Table 4C.18-12.
Evaluation Summary of the Potential Water System Interconnections

Impact Category	***Comment(s)***
a. Water Supply	
1. Quantity	1. Firm yield: Range from 2,554 acft/yr to 125 acft/yr depending on interconnection project
2. Reliability	2. Good reliability.
3. Cost of Treated Water	3. Generally high project cost; between $2,152 to $662 per acft.
b. Environmental factors	
1. Instream flows	1. Possible low impact.
2. Bay and Estuary Inflows	2. Possible low impact.
3. Wildlife Habitat	3. Construction and maintenance of transmission pipeline corridor(s) may impact wildlife species.
4. Wetlands	4. None or low impact.
5. Threatened and Endangered Species	5. Endangered species survey will be needed to avoid significant sites.
6. Cultural Resources	6. Cultural resource survey will be needed to avoid significant sites.
7. Water Quality a. dissolved solids b. salinity c. bacteria d. chlorides e. bromide f. sulfate g. uranium h. arsenic i. other water quality constituents	7. May potentially enhance water quality for rural communities. 7d. May improve water quality issues associated with chlorides for Sinton. 7f. May improve water quality issues associated with high hydrogen sulfide for Edroy.
c. Impacts to state water resources	• No negative impacts on other water resources
d. Threats to agriculture and natural resources in region	• Temporary damage due to construction of pipeline(s)
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Standard analyses and methods used for portions
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None