Coastal Bend Regional Water Planning Area

Regional Water Plan

Volume II
Water Management Strategies

Prepared for

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Section 5A
Water Management Strategies

5A Summary of Water Management Strategies

A total of 17 water management strategies were investigated during the development of the Coastal Bend Regional Water Plan. Many of these strategies include several water supply options within the main strategy. Strategies are summarized in Tables 5A-1 and 5A-2.

Table 5A-1 shows potential strategies for the Corpus Christi service area and Table 5A-2 shows potential strategies for other service areas. All strategies are compared with respect to four areas of concern: (1) additional water supply; (2) unit cost of treated water; (3) degree of water quality improvement; and (4) environmental issues and special concerns. A graphical comparison of how each significant strategy compares to the others with respect to unit cost and water supply quantity is shown in Figure 5A-1. A detailed description of the analysis of each strategy is included in the following sections (Sections 5A.1 through 5A.17). In these detailed descriptions, each strategy was evaluated with respect to 10 impact categories, as required by TWDB rules. These categories are listed in Table 5A-3.

Recommended plans to meet the specific needs of the cities and other water user groups during the planning period – 2000 through 2050 – are presented in the following sections. In addition, proposed plans to meet long-term needs – 2030 through 2050 – are presented for the projected shortages in Nueces and San Patricio Counties. The water management strategies summarized in Tables 5A-1 and 5A-2 and discussed in detail in Sections 5A.1 through 5A.17 provide the options for building each plan to meet the specific shortages. The plans are organized by county and water user group in Sections 5.2 through 5.12 of Volume I of this report. A summary of the plans for the Region's two Major Water Providers is presented in Section 5.13 of Volume I of this report.

Table 5A-3.
Listing of Impact Categories for
Evaluation of Water Management Strategies

a.	Quantity, reliability and cost of treated water
b.	Environmental factors
c.	State water resources
d.	Threats to agriculture and natural resources in region
e.	Recreational
f.	Comparison and consistency equities
g.	Interbasin transfers
h.	Third party social and economic impacts from voluntary redistribution of water
i.	Efficient use of existing water supplies and regional opportunities
j.	Effect on navigation

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5A.1 Municipal Water Conservation

5A.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 non-capital intensive alternative that any water supply entity can and should pursue. All water supply entities and some major water right holders are required by Senate Bill 1 regulations to submit for approval to the Texas Natural Resource Conservation Commission (TNRCC) a Drought Contingency and Water Conservation Plan before September 2000. These plans must detail the entities' plans for the water supply entity to reduce water demand at times when the demand threatens the total capacity of the water supply delivery system or overall supplies are low.

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. A reduction in this per capita water use can be achieved in a variety of ways, including: retrofit plumbing fixtures, incentive programs, conservation pricing, leak detection, conservation landscaping and lawn watering, including the use of gray water, and public information and education on conservation practices. This last method is often the most effective manner to reduce water use, and deserves further elaboration.

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 *A Guidebook for Reducing Unaccounted-for Water*.

Additionally a document entitled *Strategies to Enhance Water Conservation in the Coastal Bend* has been specifically prepared to assist communities in the Coastal Bend Area with water conservation. A copy of this document is included as Appendix E. Both the TWDB and Appendix E documents include a water audit to assist each community in assessing their system.

5A.1.2 Available Yield

The water demand projections utilized in this study assume a certain level of conservation. Conservation activities that were assumed to be in place for all the projections included:

- Water-efficient plumbing fixtures consistent with the State Water Efficient Plumbing Act of 1991;
- More efficient outdoor irrigation techniques, including the use of xeriscape landscaping;
- More thorough use of leak detection processes;
- More widespread use of water efficient appliances; and
- Use of education programs for water conservation practices.

Additionally, projections for some cities reflect 'advanced' conservation. These activities may include:

- More stringent requirements and enforcement on any of the items listed;
- Financial incentives for more efficient practices; and
- Water rate structures that would provide incentives for increased conservation.

The water demand projections for 17 of the 31 cities have advanced conservation built into them. Projections for the other 14 cities and the county-other in each county were computed with 'expected' conservation, and therefore are potential candidates for additional conservation. As can be seen in Table 5A.1-1 the average per capita water use for cities with advanced conservation is approximately 25 percent lower than the cities and county-others with expected conservation.

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

Type of Conservation	*2030*	*2050*
Expected	158	157
Advanced	127	125
Region Average	145	144

Table 5A.1-2 lists those cities and county-others that could undertake additional conservation. As can be seen, many of the cities already have relatively low per capita water use. For this reason the additional conservation represents a 15 percent reduction in the per capita water use, and not the 25 percent difference between the expected and advanced conservation scenarios. A 15 percent reduction in per capita water use for those cities and county-others would result in savings – less water used – of 4,466 acft in 2030 and 4,310 acft in 2050.

5A.1.3 Engineering and Costing

Of all the water conservation activities, plumbing retrofitting is the most costly. For the 14 cites and county-others that could potentially undertake a plumbing retrofit program, it was calculated that the cost of such a program would be $446 per acft of reduced water use.[1] Although there are costs associated with other water conservation activities such as public outreach, meter replacement and leak detection programs, improved irrigation systems, and conservation oriented rate structures, such costs were not studied for this effort. For example, a city's cost of a meter replacement and leak detection program, generally part of the utilities' operation and maintenance budget, would increase the cost per acft of water conservation activities.

[1] Assumes 2.5 persons per household, 1.5 commodes per household, 11 gpcd reduction, and $75 per commode replacement cost.

5A.1.4 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 along 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 TNRCC, is the curtailment of water use during drought phases. 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.

5A.1.5 Evaluation Summary

An evaluation summary of this water management option is provided in Table 5A.1-3.

Table 5A.1-3.
Evaluation Summary of Municipal Water Conservation

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	• Firm Yield: 4,466 per acft/yr • Cost: $446 per acft/yr (Max.)
b. Environmental factors	• Negligible • No cultural resources affected
c. State water resources	• No apparent negative impacts on water resources
d. Threats to agriculture and natural resources in region	• None
e. Recreational	• None
f. Comparison and consistency equities	• 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
j. Effect on navigation	• None

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5A.2 Irrigation Water Conservation

5A.2.1 Description of Strategy

These alternatives consider the potentials of irrigation water conservation methods and their effectiveness. Irrigated agriculture accounts for almost 65 percent of the total water used in the state. Approximately 10 million acft of water are 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 70 percent of the water used for irrigation purposes, with surface water supplies accounting for the remaining 30 percent. Although irrigated agriculture accounts for only 30 percent of all harvested cropland acres in Texas, the value of irrigated crops account for more than 50 percent of the total value of crop production in the State.

In Texas, irrigated acreage development peaked in 1974 with 8.6 million acres of irrigated cropland. Since that time, irrigated acreage has declined statewide by more than 2.5 million acres, with a corresponding decline in on-farm water use of more than 3.0 million acft. 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 during the last ten years, 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.

Although the statewide trend in irrigated acreage is downward, irrigated acreage in the Coastal Bend Region does not reflect this trend. Data collected for the Region by the TWDB in 1994 indicates that irrigated acreage totaled 11,028 acres. However, recent data obtained in 2000 from local County Agents[1] indicates that irrigated acreage totals about 25,535 acres. This discrepancy is quite large, and future planning efforts need to reevaluate these totals.

There are four main methods used today to irrigate: flood, furrow, sprinkler, and drip. Flood irrigation is used for close-grown crops where fields are level and the water “floods” the field. Furrow irrigation employs parallel furrows to spread water of the fields that are too irregular to flood (row crops). Sprinkler irrigation, typically using center pivot or side roll irrigators, consists of sprinklers spaced along a pipe that moves slowly across the field.

[1] Data collected and furnished by Mr. Bobby Nedbalek.

Sprinkler irrigation uses less water and provides better distribution of water. Drip irrigation delivers small amounts of moisture to the root area of the plant through narrow plastic lines.

5A.2.2 Available Yield

The objective of irrigation conservation is to reduce the quantity of water that is lost to deep percolation, evaporation, and evapotranspiration between the water source (well or diversion point) and the irrigated crop. Thus, the reduction in the volume of water consumed is the yield made available for other uses. Costs to accomplish this include investments in irrigation application equipment, measuring instruments, and conveyance improvements to reduce seepage losses, deep percolation and evaporation of water.

Principal methods of irrigation water conservation are the following:

1. Low-pressure sprinklers;
2. Low-energy precision application systems (LEPA);
3. Surge irrigation; and
4. Furrow diking.

Sprinkler systems were initially high-pressure, above-line discharge center pivots. These systems had an irrigation application efficiency of about 60 percent. Wind drift and evaporative losses equaled approximately 40 percent. Low-pressure sprinkler systems may have partial droplines but spray water into the atmosphere above the crops. The irrigation efficiency of this type of system is approximately 80 percent while wind drift and evaporative losses are only about 20 percent of the water pumped.

A center pivot sprinkler equipped with full droplines (within 1 to 2 feet above the ground) is known as a LEPA system. This system can achieve irrigation application efficiencies of up to 95 percent.[2] Since the water is applied at low pressure, wind drift and evaporation losses are very limited. Most irrigators use furrow dikes and/or chiseling in the furrow beneath the LEPA system to maximize the uniform water application. Frequently, the pivot is run at a greater travel speed to compensate for the additional water reaching the ground.

Surge irrigation consists of a time-controlled surge valve added to conventional furrow irrigation. The surge valves allow the flow of water into the furrows for a period of time, usually 30 minutes to an hour, and then switch the water stream into the adjoining furrows for a period

[2] Guy Fipps and L. Leon New, "Improving the Efficiency of Center Pivot Irrigation With LEPA," Department of Agricultural Engineering, Texas A&M University System, College Station, Texas 77843, publication date unknown.

of time. This allows the water to soak into the furrow length that has just been wetted while the neighboring furrow is being watered. On the next cycle, the water stream is switched back to the original furrow where it is discharged into the previously wetted furrow section. On the second, third, and subsequent cycles, the water stream flows over the previously wetted sections much faster and with less deep percolation than if the stream of water has been continuously discharged into the furrow until the entire length has been wetted. The alternating between rows reduces soil intake rates and increases the advance rate across the field. Although surge valves and furrow dikes cannot be used within the same row or furrow, furrow dikes and surge valves are sometimes used in alternate furrows. Surge irrigation can eliminate irrigation tailwater losses, minimize deep percolation losses, and reduce the length of time that water in the furrow is exposed to evaporation. Water savings from 10 to 40 percent have been measured after the addition of surge valves to conventional furrow irrigation systems.[3]

Furrow diking is one of the most effective methods of reducing field runoff. Furrow diking is a mechanical tillage practice that places mounds of soil at intervals across the furrow to form storage basins. Rainfall or irrigation water is trapped and stored in the basins until it soaks into the soil.

Low-pressure sprinklers and surge valves improve irrigation application efficiency, in comparison to furrow irrigation, by reducing water requirements per acre in the 10 to 15 percent range. The LEPA system, combined with furrow diking, can reduce water requirements per acre by 30 to 40 percent.

5A.2.3 Engineering and Costing

In the 11-county area of the Coastal Bend Regional Water Planning Area, irrigation varies from county to county along with the crops irrigated. The Texas Water Development Board (TWDB) maintains records of land irrigated through the compilation of responses to annual questionnaires mailed to all known irrigators. The TWDB database for 1994 indicates that Aransas, Kenedy, and McMullen Counties have no irrigated land. In addition, the TWDB database did not have any irrigation data for Nueces County after 1992. However, information provided by County Extension Agents for the year 2000 indicates Kenedy County does irrigate some land and that Nueces County data is available for year 2000.

[3] "Ground Water Management Practices Used Within the High Plains Water District," High Plains Underground Water Conservation District No. 1, Lubbock, Texas, 1998.

In 1996, the irrigators in the Coastal Bend Region used 13,315 acft of water, of which 85 percent was from groundwater sources (Table 5A.2-1). Compared to 1990 irrigation water use, the Coastal Bend Region used 6.5 percent less water in 1996. The TWDB, in the most recent Consensus State Water Plan, "Water for Texas," August 1997, provided the "most likely" series of water demands for irrigation (Table 5A.2-1). In the Coastal Bend Region, the TWDB projects that water use for irrigation will decrease 40 percent, from an estimated use of 14,237 acft in 1990 to a projected use of 8,496 acft in 2050. This is an irrigation water use reduction of 5,741 acft by 2050. The projections represent the approximate same number of acres irrigated, but incorporate decreases in water usage through advanced conservation, as described in Section 5A.2.2.

To assess the potential for additional conservation in the Coastal Bend Region, County Agents in each of the counties were contacted to aid in the determination of irrigated acreage that is already using advanced conservation and that acreage that is also suitable for application of the LEPA system. In 1994, crops grown on irrigated acres in the Coastal Bend Region included cotton, sorghum, corn, forage crops, peanuts and other oil crops, pecans, other orchard, and vegetables. According to the TWDB estimates, the entire Coastal Bend Region had 11,028 irrigated acres in 1994 with approximately 80 percent of the acreage planted to vegetables, hay or pasture, cotton, or corn. Table 5A.2-2 summarizes the variety of crops grown in the Coastal Bend Region and the number of irrigated acres by crop for each county in 1994. However, in 2000 County Agents reported that approximately 25,535 acres are irrigated. The disparity between the 1994 and 2000 acreages will need to be reevaluated in future planning efforts.

Table 5A.2-1.
Irrigation Water Demand Projections
Coastal Bend Region

County	Use in 1990 (acft)	Use in 1996 (acft)	Projections (acft)					
			2000	2010	2020	2030	2040	2050
Aransas	—	—	—	—	—	—	—	—
Bee	3,474	2,454	3,048	2,674	2,345	2,058	1,805	1,583
Brooks	350	465	340	329	320	310	301	292
Duval	2,586	6,560	2,540	2,495	2,451	2,408	2,365	2,323
Jim Wells	1,189	851	1,045	918	806	708	622	547
Kenedy	—	—	—	—	—	—	—	—
Kleberg	461	449	397	343	295	255	220	189
Live Oak	3,333	1,034	3,097	2,878	2,674	2,485	2,309	2,145
McMullen	—	—	—	—	—	—	—	—
Nueces[1]	1,734	1,200	1,495	1,289	1,112	958	826	713
San Patricio	1,110	302	1,047	954	925	844	771	704
Total	14,237	13,315	13,009	11,880	10,928	10,026	9,219	8,496
Reductions from 1990	—	922	1,228	2,357	3,309	4,211	5,018	5,741
Percent Reductions from 1990	—	6.48	6.63	16.56	23.24	29.58	35.25	40.32
Additional Potential (acft)	—	4,773	4,467	3,338	2,386	1,484	677	—
Additional Potential (%)	—	33.52	31.37	23.44	16.76	10.42	4.75	—
Gulf Coast Aquifer								
Bee	3,300	2,454	2,895	2,540	2,228	1,955	1,715	1,504
Brooks	350	465	340	329	320	310	301	292
Duval	2,586	6,560	2,540	2,495	2,451	2,408	2,365	2,323
Jim Wells	1,189	851	1,045	918	806	708	622	547
Kleberg	429	211	369	319	275	237	205	176
Live Oak	1,500	486	1,394	1,295	1,203	1,118	1,039	965
Nueces	87	—	75	65	56	48	41	36
San Patricio	1,110	302	1,047	954	925	844	771	704
Total	10,551	11,329	9,705	8,915	8,264	7,628	7,059	6,547
Reductions from 1990	—	(778)	846	1,636	2,287	2,923	3,492	4,004
Percent Reductions from 1990	—	(7.37)	8.01	15.50	21.68	27.70	33.10	37.95
Additional Potential (acft)	—	4,998	3,375	2,585	1,933	1,298	728	216
Additional Potential (%)	—	47.37	31.99	24.50	18.32	12.30	6.90	2.05

[1] Data for 1996 for entire County not available from TWDB. Acre-feet used in 1996 is estimate from Nueces County Water Conservation and Improvement District No. 3 for that District only.

Assumptions:

Additional Potential is based on the estimate that the maximum water conservation potential is 40 percent modifying irrigation delivery systems.

Used TWDB 1996 Consensus Water Plan, Most Likely Case – below normal rainfall, aggressive adoption of irrigation technology, and reduction in federal farm programs by one-half, as revised January 21, 1999.

Source: Water Demand Projections are from TWDB database.

Table 5A.2-2.
Irrigated Acres by Crop (1994)
Coastal Bend Region

County	Cotton	Grain Sorghum	Corn	Forage Crops	Peanuts & Other Oil Crops	Pecans	Other Orchard	Hay-Pasture	Vegetables	Total
Aransas										-
Bee	900		200	116				38	18	1,272
Brooks						20		240	480	740
Duval		650	775		905			125	1,750	4,205
Jim Wells				320			185	760	640	1,905
Kenedy								200	200	400
Kleberg								440	488	928
Live Oak							14	825	4	843
McMullen										-
Nueces										-
San Patricio	465	150	100					20		735
Total	1,365	800	1,075	436	905	20	199	2,648	3,580	11,028
Percent	12.4	7.3	9.7	4.0	8.2	0.2	1.8	24.0	32.4	100.0
TWDB data indicates that Aransas County, Kenedy County, and McMullen County have no agricultural irrigation. No data is available for Nueces County for 1994. Data was available for 1992 for Nueces County, but available data was believed to be flawed and was therefore not included. Kenedy County irrigated acres by crop is for the year 2000.										

Source: TWDB database.

In telephone conversations with County Agents, irrigation practices, including crops and type of irrigation (flood, furrow or center pivot) were discussed. Estimates were then made of the acres in the County that are suitable for application of water conservation measures and those acres that may already have some type of conservation measure in use. In the Coastal Bend Region, furrow and center pivot irrigation are the major types utilized.

The maximum water conservation potential can be realized by using the LEPA system. Based on the information from the County Agents, the conservation potential for the LEPA system was assessed (Table 5A.2-3). The capital cost to install LEPA irrigation systems and furrow diking is approximately $360 per acre (Second Quarter 1999 prices).[4] It is estimated that it would take a total investment of $2.4 million to equip the estimated 6,700 acres in the Coastal

[4] "Estimates of Costs of Irrigation Conservation Equipment," High Plains Underground Water Conservation District No. 1, Lubbock, Texas, February 1994.

Bend Region. This investment, at an annual cost of $176,800 (30 years at 6 percent), would save an estimated 2,119 acft/yr at an average unit cost of $83 per acft of water saved.

Again, based on the information from County Agents, the conservation potential for surge irrigation was accessed (Table 5A.2-4). To retrofit existing furrow irrigation systems with the equipment necessary for surge irrigation, the capital costs range from $13.90 to $20.80 per acre (Second Quarter 1999 prices).[5] The water use conservation potential for surge irrigation, when compared to furrow irrigation, is 10 percent to 20 percent, per acre. It is estimated that it would take a total investment of $85,130 to equip the estimated 4,093 acres in the Coastal Bend Region. This investment, at an annual cost of $6,190 (30 years at 6 percent), would save an estimated 653 acft/yr at an average unit cost of $9 per acft of water saved.

In Nueces County, there are approximately 13 miles (5 miles of main ditch and 8 miles of secondary ditches) of unlined surface water conveyance ditches for irrigation within the Nueces County Water Conservation and Improvement District (WCID) No. 3. Water conveyance losses, caused by deep percolation and evaporation, from unlined earthen ditches can have water losses of 10 to 30 percent per each 1,000 feet of ditch. The total water loss per foot of ditch in a 2,000-hour irrigation season averages about 5,000 gallons of water.[6] The Nueces County WCID No. 3 studied the cost to construct a pipeline to replace the 5 miles of main ditches in 1991. The cost for the project, at that time, was approximately $3.0 million (approximately $3.7 million in 2nd Quarter 1999 prices). The WCID has not pursued the project.

5A.2.4 Implementation Issues

Many irrigators in the Coastal Bend Region have implemented water conservation measures. LEPA systems, furrow diking, and drip irrigation are being utilized in the Region. Additional water conservation on irrigated acres is possible with an estimated savings potential of up to 2,772 acft/yr (i.e., 2,119 acft/yr from LEPA systems and 653 acft/yr from surge systems). However, additional detailed analyses of local irrigation operations are necessary to fully evaluate the cost effectiveness in relation to water conservation. Future planning efforts should consider the use of detailed studies to fully determine the maximum potential benefits of additional irrigation conservation.

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[5] Ibid.

[6] "Ground Water Management Practices Used Within the High Plains Water District," High Plains Underground Water Conservation District No. 1, Lubbock, Texas, 1998.

5A.2.5 Evaluation Summary

An evaluation summary of this water management option is provided in Table 5A.2-5.

Table 5A.2-5.
Evaluation Summary of Irrigation Water Conservation

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	• Firm Yield: Up to ~2,772 per acft/yr • Cost: $66 per acft/yr
b. Environmental factors	• Negligible • No cultural resources affected
c. State water resources	• No apparent negative impacts on water resources
d. Threats to agriculture and natural resources in region	• Improvement to agriculture and conservation of natural resources
e. Recreational	• None
f. Comparison and consistency equities	• 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
j. Effect on navigation	• None

5A.3 Manufacturing Water Conservation and Nueces River Water Quality Issues

5A.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 1996, Nueces and San Patricio Counties accounted for 96.4 percent of the total manufacturing water use in Coastal Bend Region of 51,815 acft. Manufacturing use for the entire planning region is projected to increase to 67,785 acft in 2000 and 118,641 acft by 2050. In 2050, Nueces and San Patricio Counties will account for 98.2 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 about 60 percent of the industrial demand in the region. The industrial demand for cooling water in Nueces and San Patricio Counties is expected to grow from about 39,207 acft/yr in 2000 to 69,903 acft/yr in 2050. 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 5A.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 5A.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 the increase in chlorides occurs upstream of the Calallen Pool and about 40 percent of the

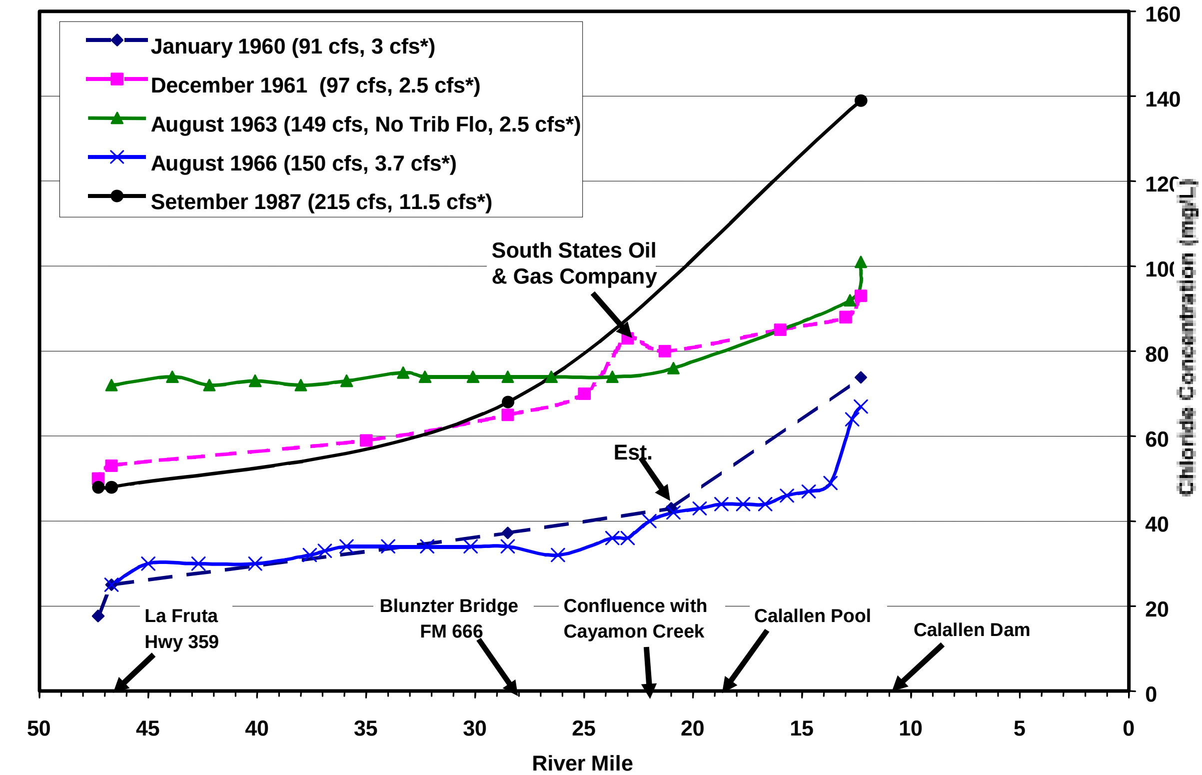


Figure 5A.3-1. Summary of Historical Data — Chloride Content of the Lower Nueces River, Segment 2102

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.

5A.3.1.1 Surface Water - Ground Water 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 5A.3-1 and shown in Figures 5A.3-2 and 5A.3-3.

Table 5A.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 5).

The most compelling observations to date of the stream monitoring and lab analysis are summarized in Figures 5A.3-4, 5A.3-5, and 5A.3-6. 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.

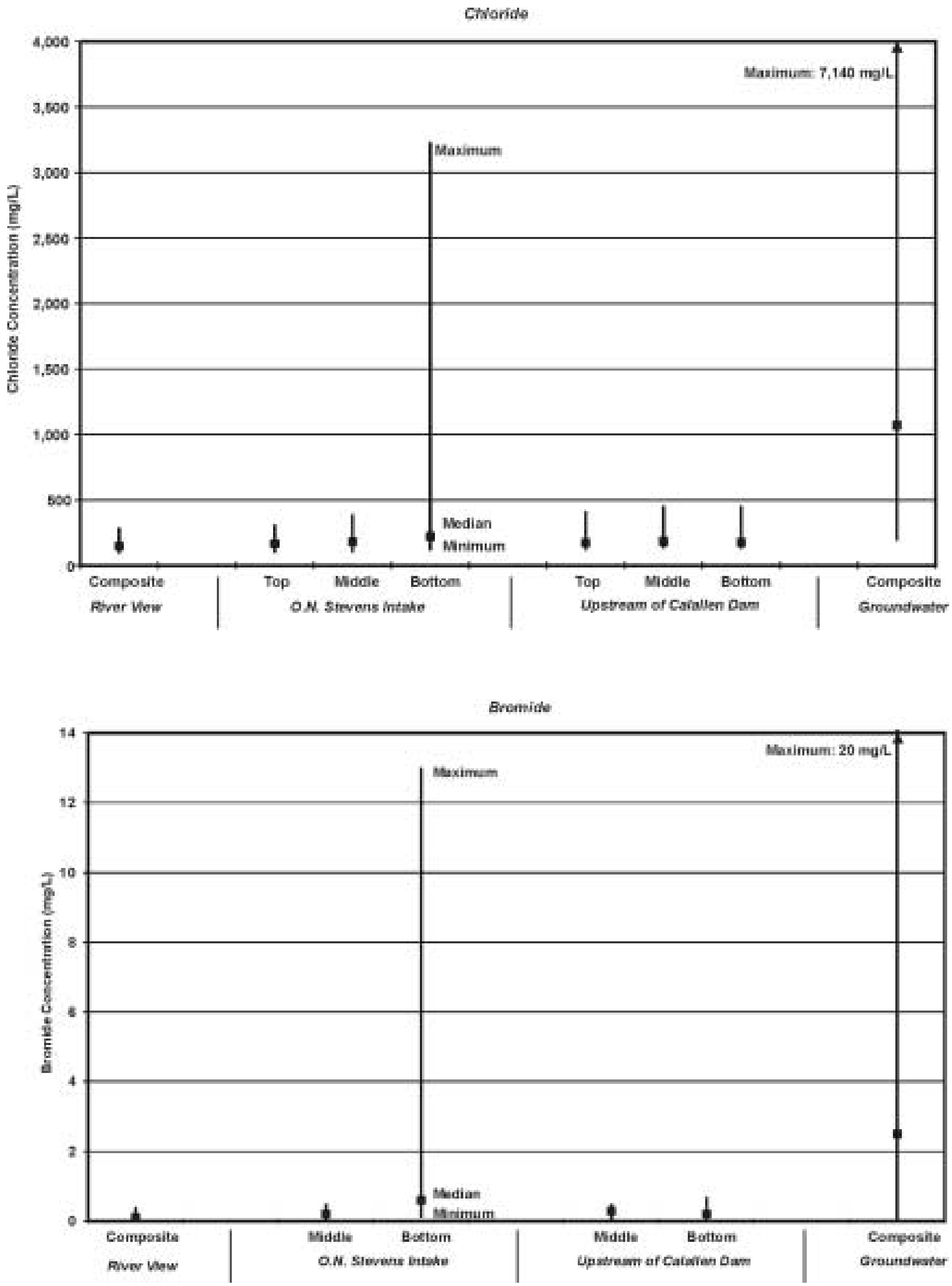
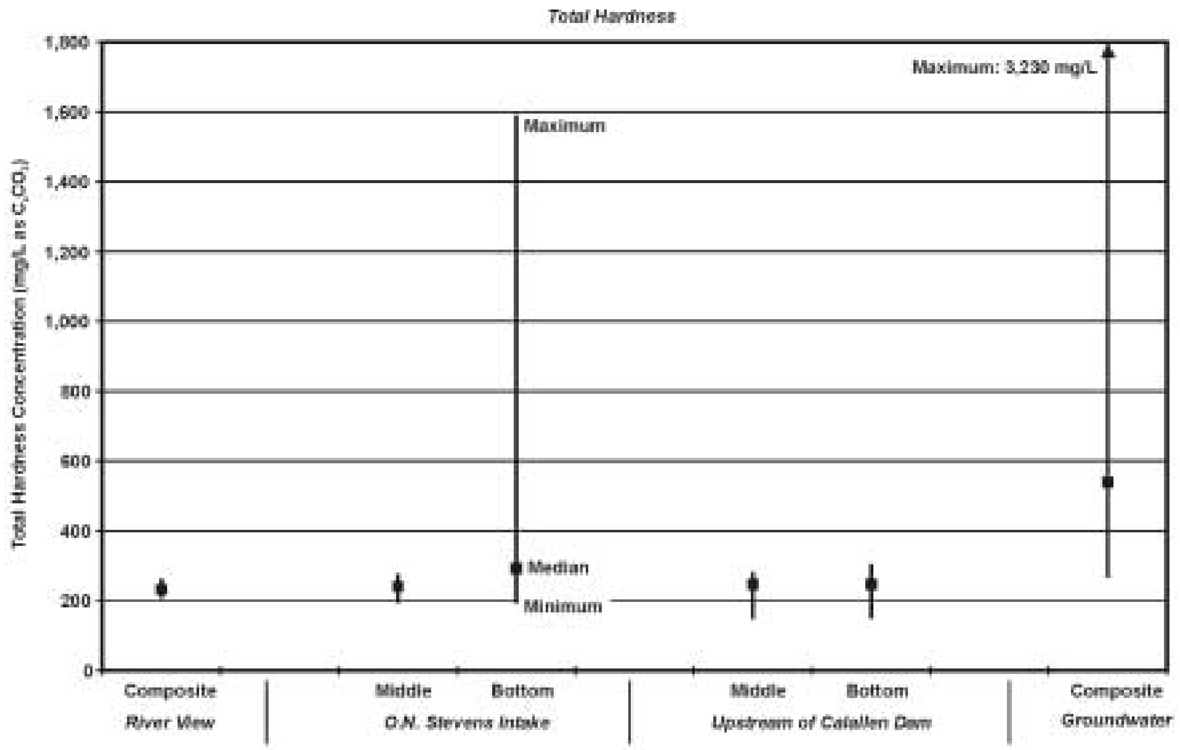


Figure 5A.3-4. Chloride and Bromide Concentrations from the Nueces River Dissolved Minerals Study



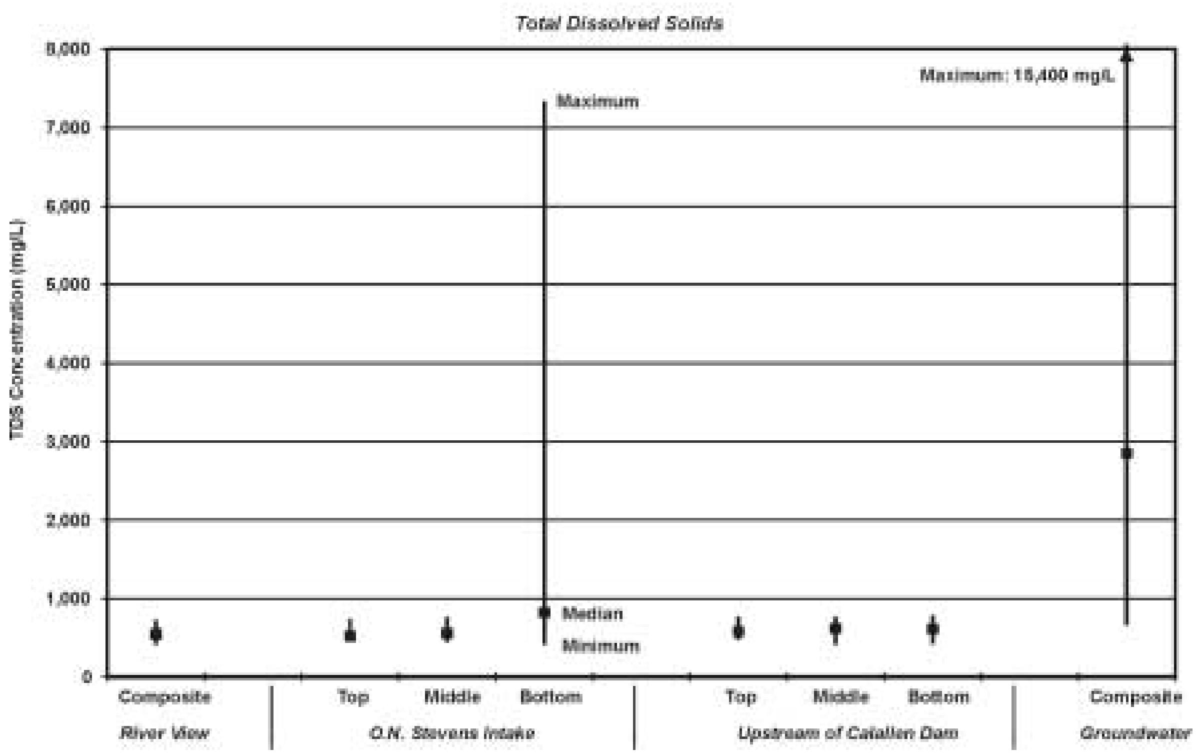


Figure 5A.3-5. Total Hardness and Total Dissolved Solids from the Nueces River Dissolved Minerals Study

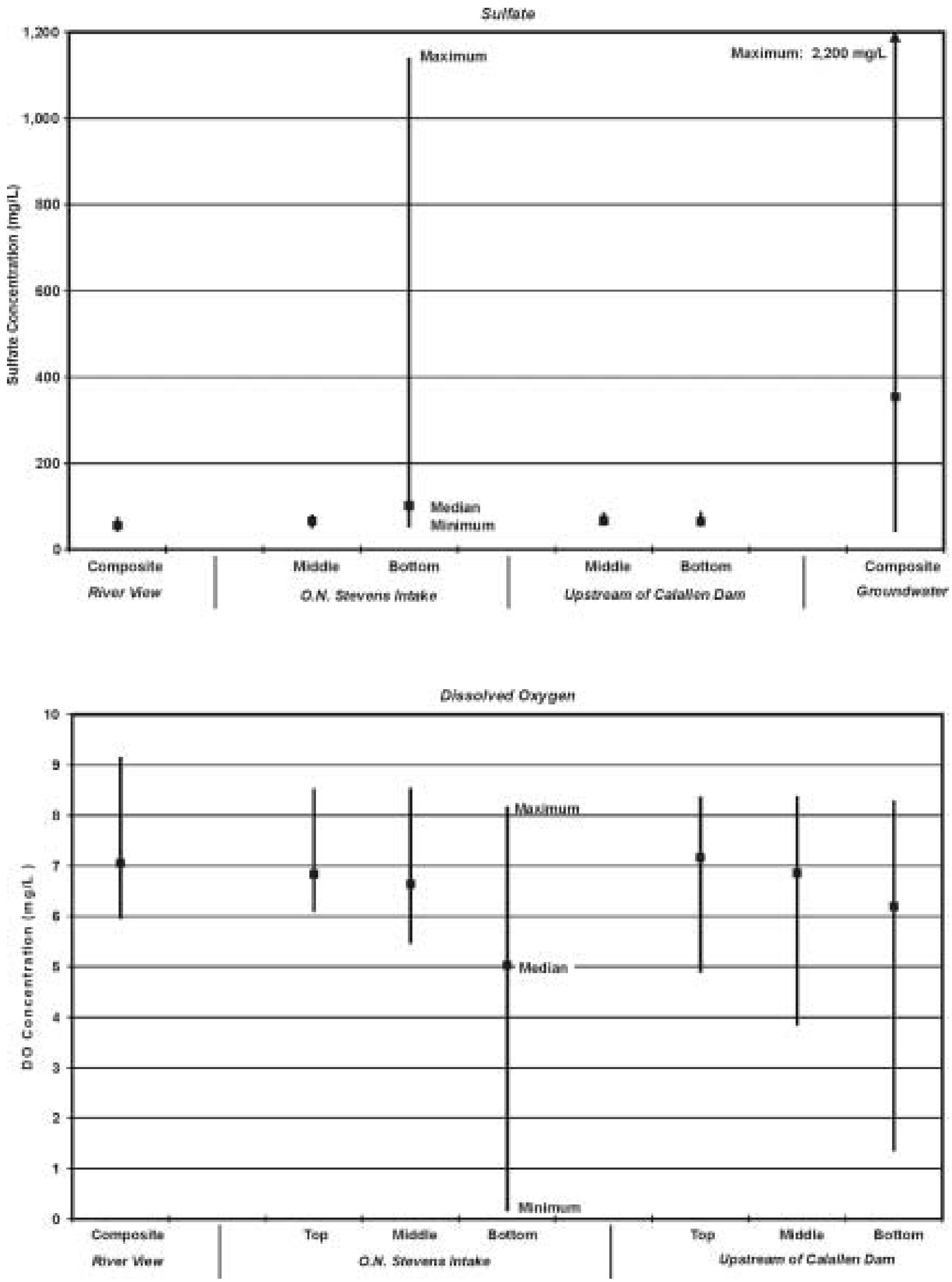


Figure 5A.3.6. Sulfate and Dissolved Oxygen Concentrations from the Nueces River Dissolved Minerals Study

Figure 5A.3-4 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. Figure 5A.3-4 presents the range of bromide within the pool. The median bromide concentration at the bottom of the river is 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 5A.3-5 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 5A.3-6 represents the concentration ranges of sulfate and dissolved oxygen. The variation is 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 G1. 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 5A.3-7) plots the major ion

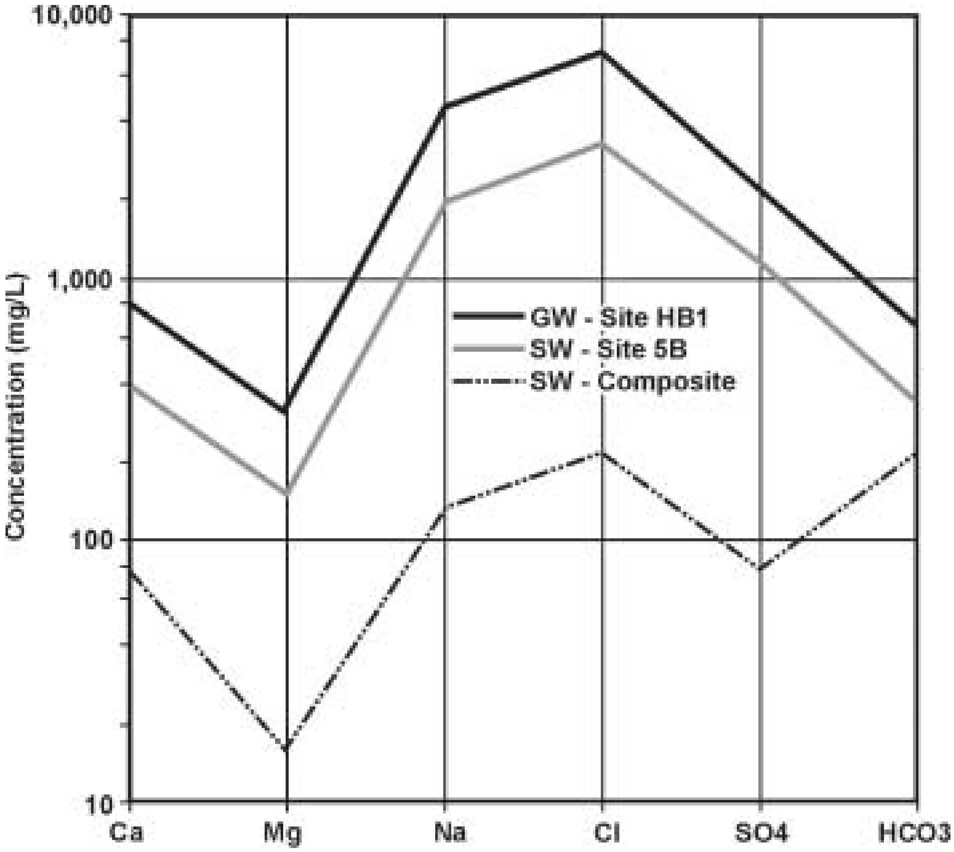


Figure 5A.3-7. Schoeller Diagram of Surface Water and Groundwater Geochemical Analysis

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.

5A.3.1.2 Surface Water – Ground Water 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 G2 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 G2.)

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 No. 3 (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 San Patricio Municipal Water District (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 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), total dissolved solids (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 5A.3-8.

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.

5A.3.1.3 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

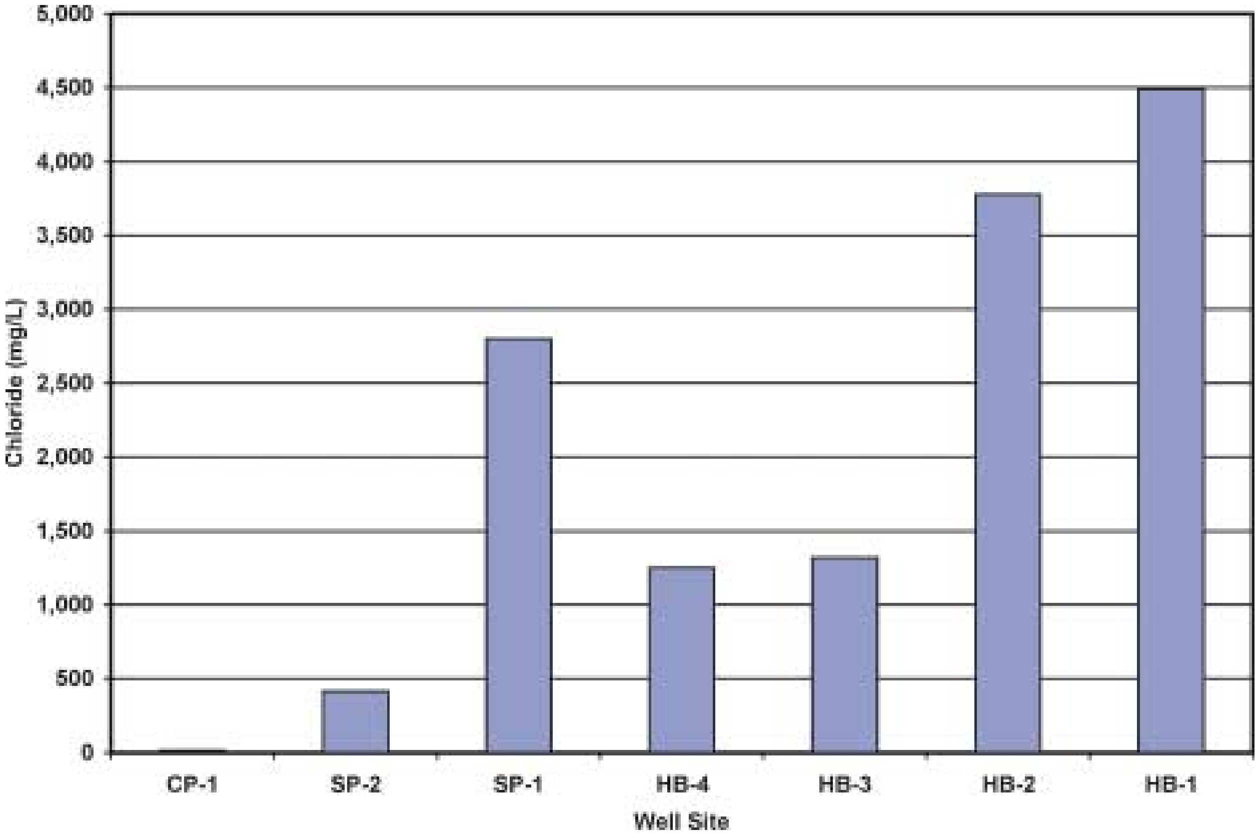


Figure 5A.3-8. Chloride Concentrations of Well Samples along the Lower Nueces River

The potential for manufacturing water use savings is based on the reduction in chloride concentration of the water supply achieved by each option. Figure 5A.3-9 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.

5A.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.

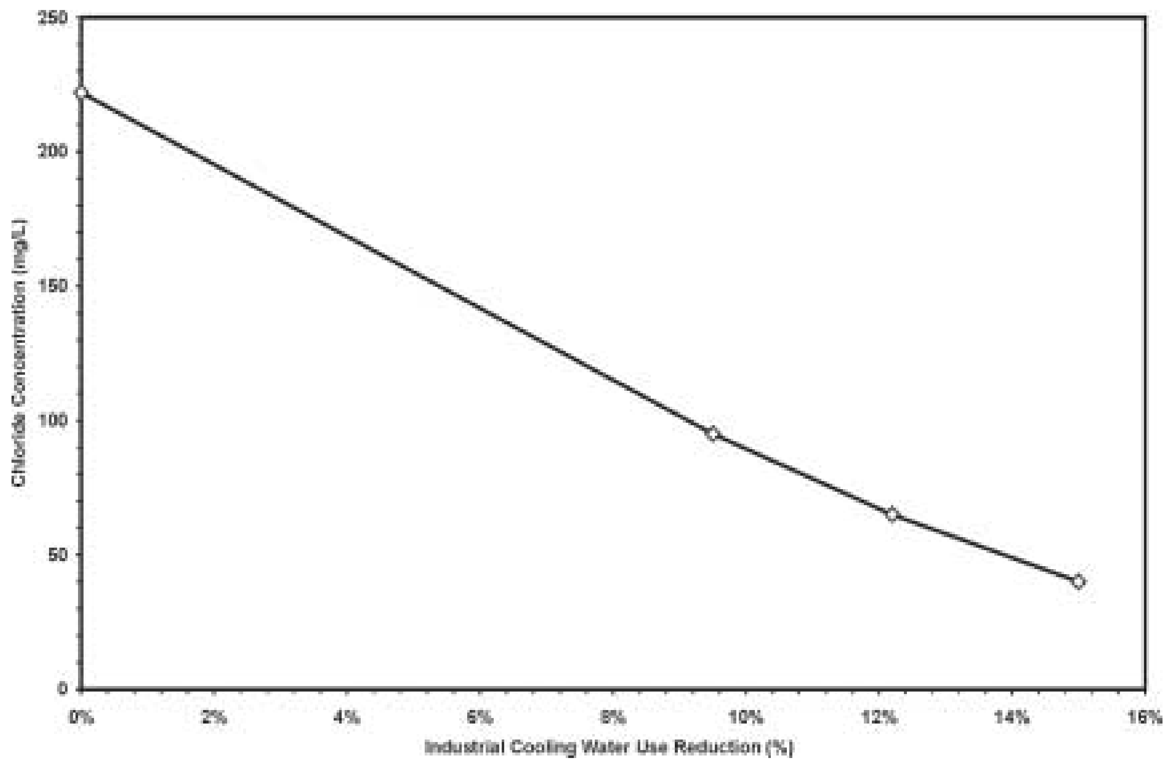


Figure 5A.3-9. Potential for Manufacturing Water Use Savings Based on Reduction in Chlorides

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 by-products (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 5A.3-9.

5A.3.2.1 Blending of Texana Water

Corpus Christi currently contracts for about 42,000 acft/yr of water from Lake Texana. As part of a plan for future supplies, the pipeline was upsized and is capable of delivering up to 108,000 acft/yr. Additional Lake Texana water is a potential surface water supply that could be transported via this pipeline and blended with Nueces River water for industrial use.

Blending Nueces River water with better quality supplies will decrease the mean mineral concentration and the natural variability. 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 5A.3-10 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. 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.

These reductions in chloride levels are expected to result in a 3 to 4 percent savings in cooling water use in the region. Using the assumptions noted above, the ranges that follow approximate the industrial water conservation associated with reducing the mean chloride concentration by about 21 percent:

- Year 2000 – 1,200 to 1,600 acft/yr
- Year 2050 – 2,100 to 2,800 acft/yr

5A.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 5A.3-11. The pipe system discharges into an inlet/outlet structure that bypasses the Calallen Dam and will allow for accurate measurement of pass-through for monthly estuary releases. 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 5A.3-12. The outlet works are estimated to reduce hardness levels by 3.8 percent to an average concentration of 232 mg/L. Figure 5A.3-12 also shows a 39.7 percent reduction in bromide from an average concentration of 0.3 mg/L to 0.18 mg/L.

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 – 200 to 600 acft/yr; and
- Year 2050 – 400 to 1,000 acft/yr.

5A.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

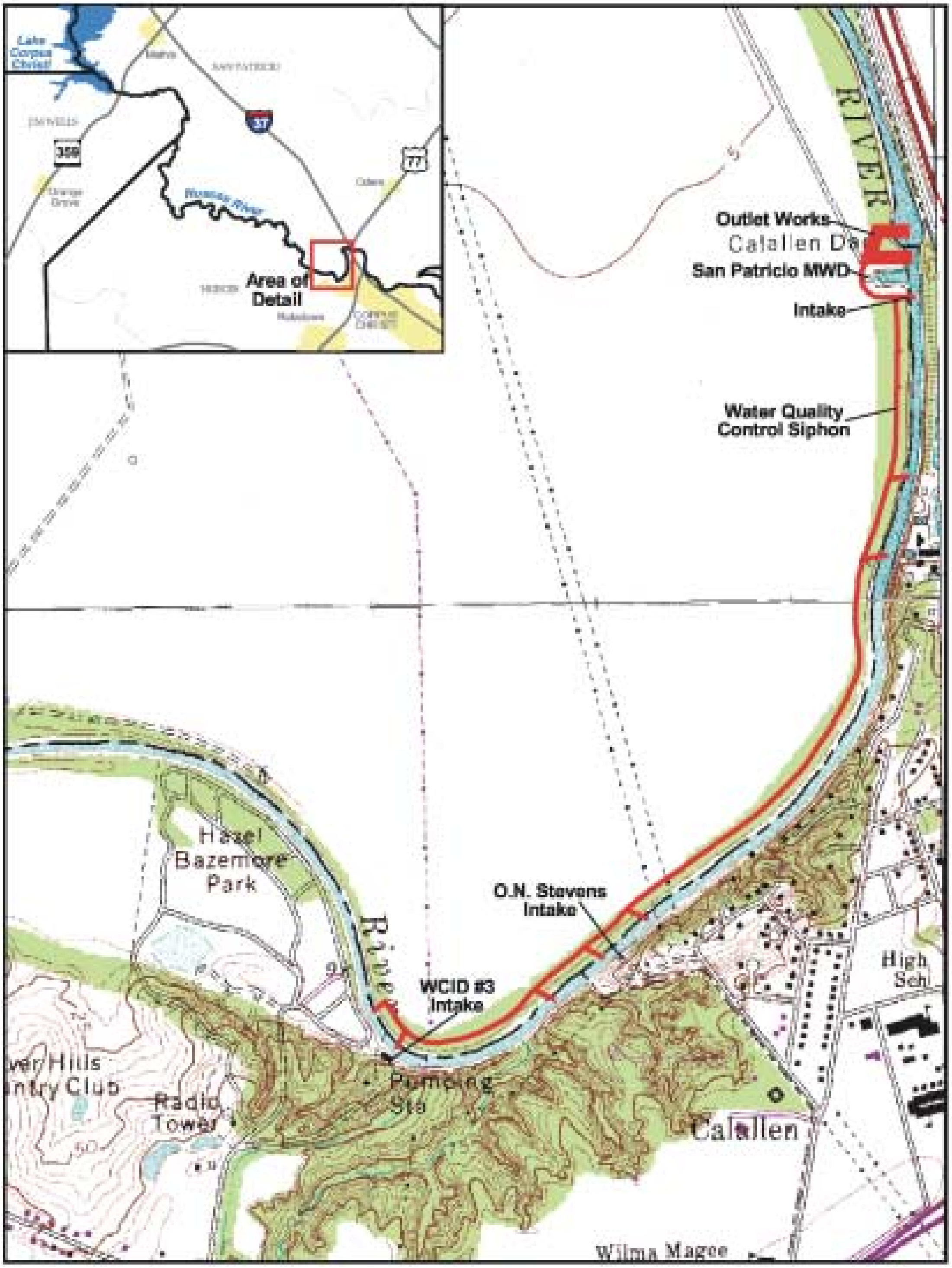


Figure 5A.3-11. Location of Water Quality Control Siphon and Outlet Works

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 determined 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 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 reductions are increased by 1 percent, as shown in Figure 5A.3-13. It is estimated that the additional water savings due to this option are 200 acft/yr for year 2000 and 400 acft/yr for 2050.

5A.3.2.4 Pipeline from Lake Corpus Christi to the O.N. Stevens Water Treatment Plant

A pipeline to deliver the total system yield of 168,600 acft/yr from Lake Corpus Christi to 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.

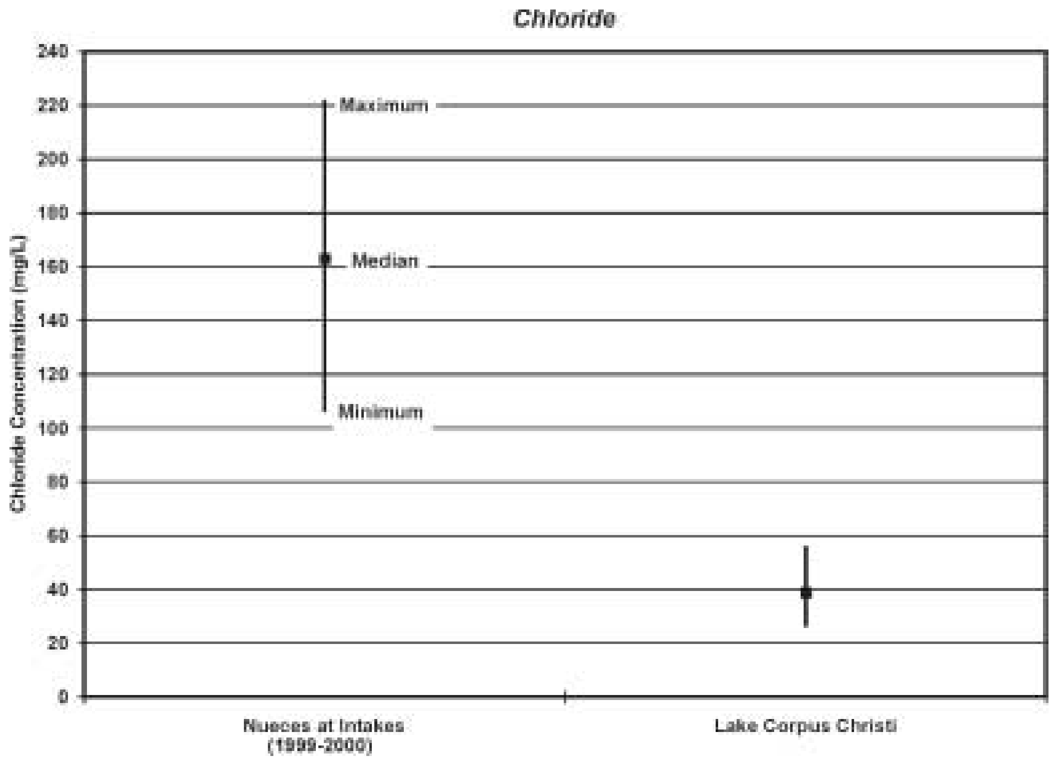
The quality of the water would improve from an average chloride concentration of 163 mg/L to an average chloride concentration of 39 mg/L as shown in Figure 5A.3-14. The hardness levels of Lake Corpus Christi are 27 percent lower than the Nueces River. The average improvement in hardness is from 185 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 3,800 acft/yr to 5,100 acft/yr savings in 2000 and 6,800 acft/yr to 9,100 acft/yr savings in 2050. 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).

As shown in Figure 5A.3-15, 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 Christi. The total yield for this option includes reduced channel losses and increased manufacturing water conservation. Reduced channel losses are estimated to be 11,800 acft/yr resulting in range of total savings between 15,600 to 20,900 acft/yr.

5A.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.



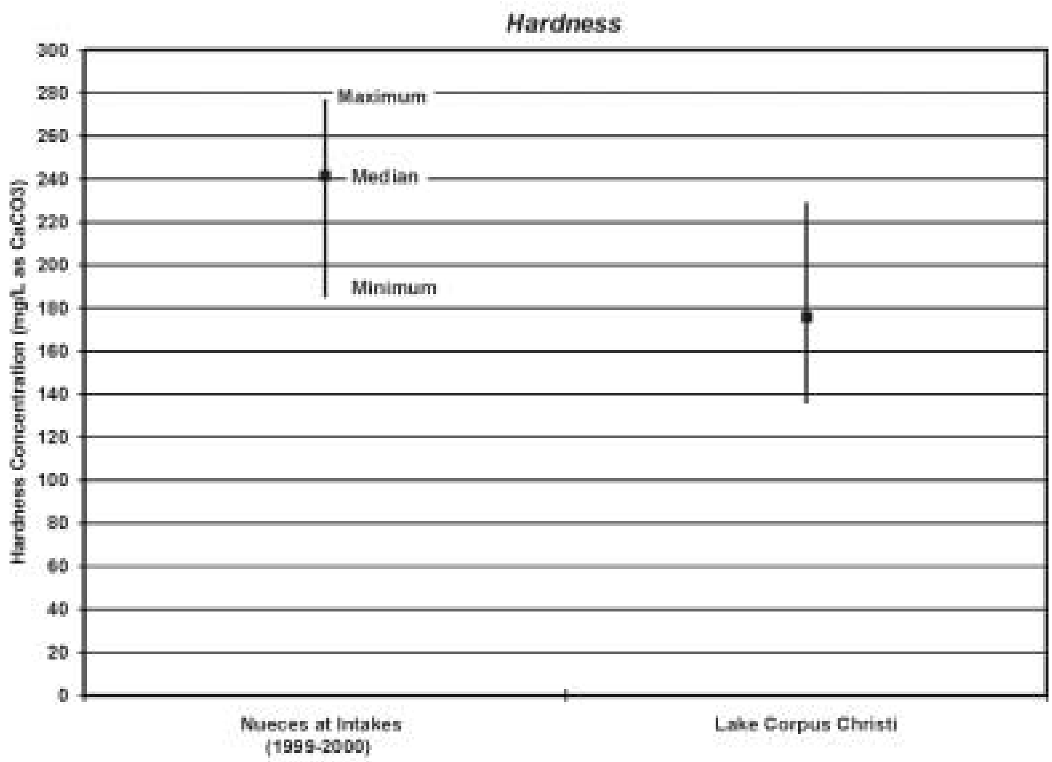


Figure 5A.3-14. Comparison of Chloride and Hardness Concentrations in the Nueces River and Lake Corpus Christi

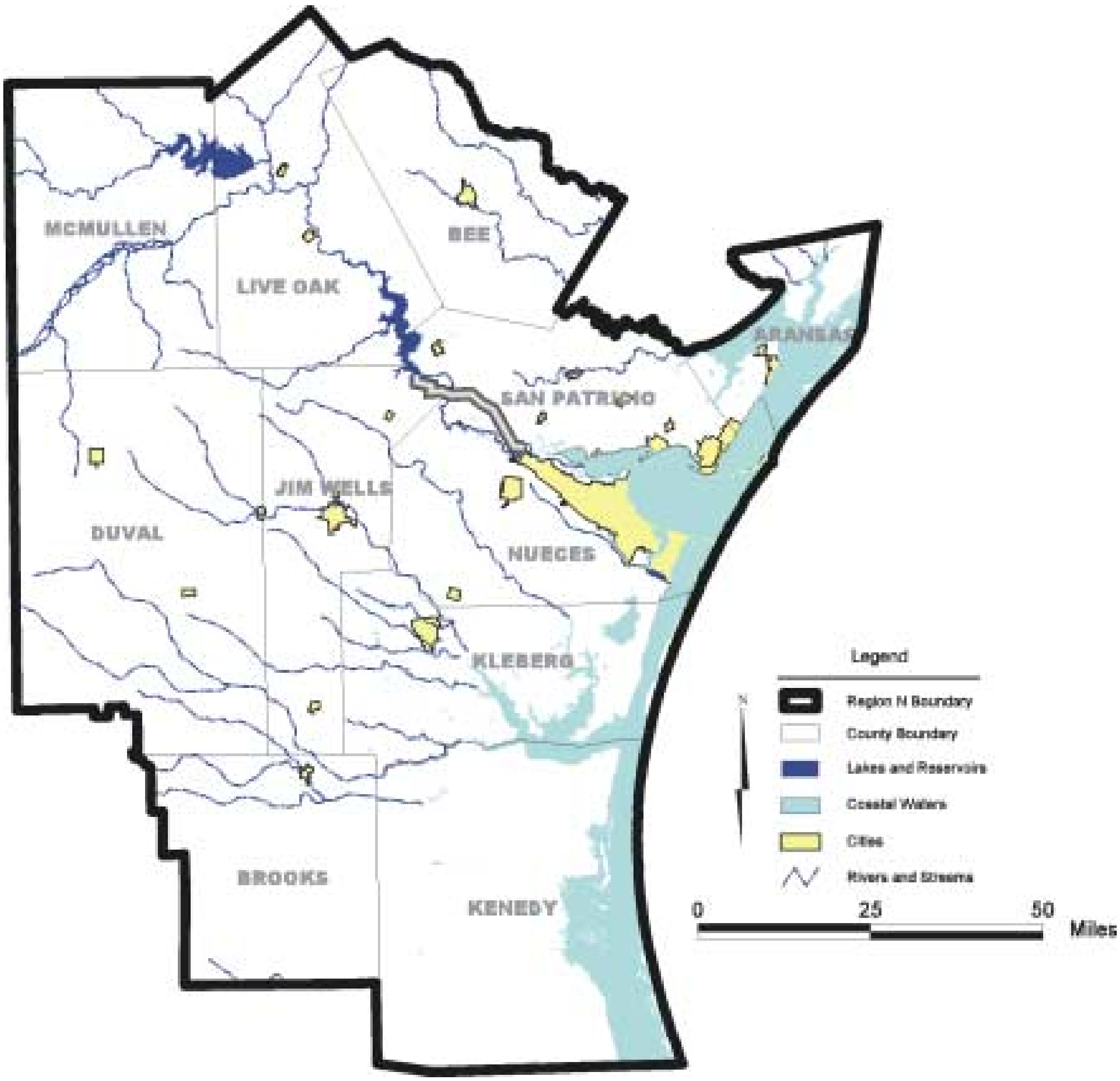


Figure 5A.3-15. Lake Corpus Christi to O.N. Stevens Pipeline Alignment

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 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 plugged wells are leaking and are in need of repair. Within San Patricio and Nueces Counties, there are 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.

5A.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 or a pipeline, will have some, though minor, environmental impacts. 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.

The proposed Lake Corpus Christi to Calallen pipeline corridor would be within Live Oak and Nueces 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.

5A.3.4 Engineering and Costing

5A.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. The current water supply available to the manufacturing industry is 41,840 acft/yr. An additional 4,500 acft/yr of interruptible water is currently available from Lake Texana by contract with the Lavaca-Navidad River Authority. A study to determine how this water could add to the firm yield of the CCR/LCC/Texana System has not been undertaken, but it would not be unreasonable for this volume of water to develop 1,600 acft/yr of firm yield when operated in conjunction with the CCR/LCC/Texana System. The only costs associated with this option are the cost to purchase additional Lake Texana water and the costs to pump it to the Coastal Bend Region.

5A.3.4.2 Outlet Works to Remove High TDS from Calallen Pool

Sampling data from the Nueces River study has shown that within the Calallen channel there are sites where saline groundwater entering the system settles to the bottom of the deepest parts of the pool. This option includes a gravity line to siphon up to 6 MGD from the bottom of the Calallen Pool at up to eight of these locations. The alignment of the pipe system is shown in Figure 5A.3-11. The pipe system discharges into an inlet/outlet structure that circumvents the Calallen Dam. This intake is comprised of three pipelines with intake screens and could handle flows of up to 250 cfs.

Table 5A.3-2.
Cost Estimate Summary for Outlet Works and Siphon to Remove High TDS from Calallen Pool (Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Siphons (8) , Control Valves and Vaults	$159,000
Intake (250 cfs) and Outlet Structure at Dam, Valves and Flow Meters	665,000
Gravity Pipeline (12", 14", 18" and 24" telescopic line)	630,000
Total Capital Cost	**$1,454,000**
Engineering, Contingencies and Legal Costs	$437,000
Environmental & Archaeology Studies, Mitigation, and Permitting	43,000
Pipeline Land Acquisition and Surveying (107 acres)	59,000
Interest During Construction (1 year)	80,000
Total Project Cost	**$2,073,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$151,000
Operation and Maintenance	14,000
Total Annual Cost*	**$165,000**
Available Project Yield (acft/yr)	**200 to 1,000**
Total Annual Cost of Water ($ per acft)	**$825 to $165**
Annual Cost of Water ($ per 1,000 gallons)	**$2.53 to $0.51**
*Does not include reduction in chemical costs due to reductions in bromide concentrations.	

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 5A.3-2. The total capital cost is estimated at $1,454,000. The project cost is $2,073,000. The total annual cost is estimated to be $165,000. 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 200 to 1,000 acft/yr results in a unit cost ranging from $165 to $825 per acft/yr.

5A.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 $2,400,000. The four intakes include one operated by the Celanese Bishop Plant Facility, two by the City of Corpus Christi and one operated by WCID #3. Intake modification with the outlet works is estimated to save an additional 200 to 400 acft/yr for the 2000 to 2050 timeframe. The cost estimate for this control strategy is shown in Table 5A.3-3. The total capital cost is estimated at $3,854,000. The project cost is $5,442,000. The total annual cost is estimated to be $469,000. Therefore the unit cost of water saved is estimated to be about $2,349 to $1,174 per acft/yr.

5A.3.4.4 Pipeline from Lake Corpus Christi to O.N. Stevens Water Treatment Plant

As shown in Figure 5A.3-15, the major facilities needed to deliver 168,600 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 297 MGD. The cost for the facilities is shown in Table 5A.3-4. The total capital cost is estimated at $74,113,000. The total project cost is $106,222,000. The total annual cost is estimated to be $11,810,000. Increases in yield include reduced channel losses (11,800 acft/yr) and increased manufacturing water conservation (3,800 to 9,100 acft/yr), resulting in total savings of between 15,600 and 20,900 acft/yr and a unit cost of $757 to $565 per acft/yr.

5A.3.4.5 Plugging Leaky and Abandoned Oil Wells

Within San Patricio and Nueces Counties, there are 16 total 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 are leaking and are in need of repair. Additional study is needed to determine the impact of the leaking wells on the lower Nueces River.

Table 5A.3-3.
Cost Estimate Summary for Intake Modifications and Outlet Works to Remove High TDS from Calallen Pool (Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Intake Modifications	$2,400,000
Siphons (8) , Control Valves and Vaults	$159,000
Intake (250 cfs) and Outlet Structure at Dam, Valves and Flow Meters	665,000
Gravity Pipeline (12”, 14”, 18” and 24” telescopic line)	630,000
Total Capital Cost	**$3,854,000**
Engineering, Contingencies and Legal Costs	$1,277,000
Environmental & Archaeology Studies, Mitigation, and Permitting	43,000
Pipeline Land Acquisition and Surveying (107 acres)	59,000
Interest During Construction (1 year)	209,000
Total Project Cost	**$5,442,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$395,000
Operation and Maintenance	74,000
Total Annual Cost	**$469,000**
Available Project Yield (acft/yr)	**200 to 400**
Total Annual Cost of Water ($ per acft)	**$ 2,349 to $1,174**
Annual Cost of Water ($ per 1,000 gallons)	**$7.21 to $3.60**

Table 5A.3-4.
Cost Estimate Summary for
Pipeline from Lake Corpus Christi to Calallen Dam
(Second Quarter 1999 Prices)

Item	*Estimated Costs*
Capital Costs	
Intake and Pump Station (296.7 MGD)	$9,676,000
Transmission Pipeline (120 in dia., 21 miles)	64,437,000
Total Capital Cost	**$74,113,000**
Engineering, Contingencies and Legal Costs	$22,718,000
Environmental & Archaeology Studies, Mitigation, and Permitting	531,000
Pipeline Land Acquisition and Surveying (107 acres)	991,000
Interest During Construction (2 years)	7,869,000
Total Project Cost	**$106,222,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$7,717,000
O&M: Intake, Pipeline, Pump Station	886,000
Pumping Energy Costs (53,453,629 kWh @ $0.06 per kWh)	3,207,000
Total Annual Cost	**$11,810,000**
Available Project Yield (acft/yr)	**15,600 to 20,900**
Total Annual Cost of Water ($ per acft)	**$757 to $565**
Annual Cost of Water ($ per 1,000 gallons)	**$2.32 to $1.74**

5A.3.5 Implementation Issues

5A.3.5.1 Blending of Texana Water

In order to make additional water available from Lake Texana, a contract amendment with LNRA would be required for the additional water needed.

5A.3.5.2 Outlet Works to Remove High TDS from Calallen Pool

Releases of water from Calallen channel 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 U.S. Army Corps of Engineers Section 404 Permit and would require cultural resource studies along the pipeline route.

5A.3.5.3 Intake Modifications

Intake modifications within the Nueces River channel may require an U.S. Army Corps of Engineers 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.

5A.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. A detailed 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 TNRCC 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:

- U.S. Army Corps of Engineers Sections 10 and 404 dredge and fill permits for the pipelines.

- General Land Office (GLO) Sand and Gravel Removal permit for pipeline stream crossings.
- GLO Easement for use of State-owned land (if any).
- Texas Parks and Wildlife Department (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.

5A.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.

5A.3.6 Evaluation Summary

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

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

Impact Category	Comment(s)
a. Quantity, reliability and cost of treated water	• Firm yield and unit costs are shown in Table 5A.3-6
b. Environmental Factors	• Minor environmental impacts from construction of facilities • Pipeline to Lake Corpus Christi would require detailed studies of lower Nueces River to determine impacts and a cultural resource investigation along pipeline route
c. State Water Resources	• No significant impacts
d. Threats to agriculture and natural resources in region	• None
e. Recreational	• None, except pipeline to Lake Corpus Christi would reduce flows in Lower Nueces River
f. Comparison and consistency equities	• 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 5A.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	1,200 to 2,800	None*
2. Outlet Works to Remove High TDS from the Calallen Pool	200 to 1,000	$825 to $165
3. Modification to Existing Intakes	200 to 400	$2,730 to $1,365
4. Pipeline from Lake Corpus Christi to Calallen	15,600 to 20,900	$757 to $565

* No additional costs to be incurred unless additional water is purchased from LNRA from Lake Texana.

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5A.4 Reclaimed Wastewater Supplies

5A.4.1 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 Natural Resource Conservation Commission (TNRCC) 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 TNRCC 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 Texas Natural Resource Conservation Commission), Austin, Texas, March 9, 1992.

On April 28, 1995, the TNRCC 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.

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.

5A.4.2 Inventory and Location of Existing Wastewater Sources

There are about 78 active, permitted domestic and industrial wastewater treatment plant discharges that discharge to the Nueces Estuary System in the 11-county Coastal Bend Regional Water Planning Area (CBRWPA). These domestic and industrial wastewater treatment plant discharges total about 85,277 acft/yr, based on the 1999 annual discharge from each wastewater treatment plant (Table 5A.4-1). The City of Corpus Christi and TNRCC compiled this list. Figure 5A.4-1 shows the location of the City of Corpus Christi wastewater treatment plants, which are the major municipal discharges into the system. Of the 85,277 acft, major municipal/domestic discharges generate about 42,168 acft/yr (49.5 percent), while industrial discharges generate about 43,059 acft/yr (50.5 percent).

In addition to the list of wastewater treatment plant discharges to Nueces Estuary System, there are a few other effluent dischargers in the CBRWPA. These dischargers are summarized in Table 5A.4-2. These wastewater treatment plants discharged a total of 3,881 acft/yr. Of the effluent discharges by the permit holders in Table 5A.4-2, the majority of the effluent is from municipal/domestic users. Only 1.1 acft was discharged by an industry. These discharges

[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.

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

Facility	***Acre-Feet Discharged***
City of Woodsboro	176.95
City of Odem	133.31
City of Sinton	588.98
Texas Department of Transportation	0.02
AEP-Central Power and Light (Lon Hill Power Station)	611.82[3]
City of Corpus Christi – Allison Plant	3,335.76
San Patricio Co. Municipal Utility District #1	13.90
City of Orange Grove	102.65
Bishop Consolidated Independent School District	3.35
City of Agua Dulce	38.36
City of Driscoll	61.19
Coastal Bend Youth City	12.03
Nueces Co. Water Conservation & Improvement District #5	33.91
City of Rockport	1,007.39
Town of Bayside	9.82
City of Taft	533.31
Nueces Co. Water Conservation & Improvement District #4	1,068.77
U.S. Dept of Navy	815.25
City of Gregory	423.02
City of Ingleside	594.60
E.I. Dupont de Nemours & Co	10,927.23
Occidental Chemical Corp.	1,556.88
City of Portland	1,426.88
Sublight Enterprises	9.70
Liberty Seafood, Inc.	0.77
Aker Gulf Marine, Partnership	3.71
City of Aransas Pass	984.99
Williams Terminals Holdings, L.L.C.	40.54
Elementis Chromium, L.P.	9,555.29
Citgo Refining & Chemicals,	2,427.77
City of Corpus Christi – Broadway	4,895.80
Coastal Refining & Marketing	1,941.38
Coastal Refining & Marketing	20.56

Table 5A.4-1 (continued)

Facility	***Acre-Feet Discharged***
Diamond Shamrock	44.50
Encycle Texas, Inc.	313.92
Javelina Company	101.00
Koch Refining Co.	2,045.41
Koch Refining Co.	2,700.80
Neste Trifinery	26.21
Equistar Chemicals, L.P.	922.61
Qualitech Steel Corp.	2,538.58
Valero Refining Company	3,364.79
City of C.C. Peoples Baptist Church	7.58
City of Corpus Christi – Oso Plant	13,646.51
City of Corpus Christi – Westside	3,870.39
City of Robstown	1,241.98
Tennessee Pipeline Co	47.35
Texas A & M University System	0.56
Texas A & M University System	11.78
City of Corpus Christi - Flour Bluff	1,952.43
City of Corpus Christi – White Cap	1,050.39
City of Alice	927.23
City of Alice	729.38
City of Kingsville	1,821.72
Kleberg County	4.57
Kleberg County	13.38
Rivera Water Conservation & Improvement District	43.64
U.S. Dept. of Navy	89.59
Ticoma Polymers, Inc.	2,339.93
City of Bishop	96.42
City of Kingsville	400.61
Texas Ecologists	1,518.33
Total Discharges	85,227.48

[1] These wastewater dischargers are recognized by the City of Corpus Christi and the TNRCC as contributors to freshwater inflows to the Nueces Estuary System.

[2] Annual wastewater discharged, in acft, for 1999. Total Municipal/Domestic discharges – 43,168.38 acft. Total Industrial Discharges – 43,059.10 acft.

[3] Source: AEP-CPL.

Source: Texas Natural Resource Conservation Commission, 2000.

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

Facility	*Acre-Feet Discharged*[1]
City of Beeville	2,565.7
Pettus Municipal Utility District	61.0
City of San Diego	495.7
City of George West	89.5
City of Three Rivers	166.9
McMullen Co. Water Conservation & Improvement District #1	0.0[2]
Applied Industrial Materials	0.0[2]
Tesoro Marine Services	1.1
City of Mathis	501.5
Total Discharges	3,881.4

[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: Texas Natural Resource Conservation Commission, 2000.

combined with those into the Nueces Estuary System bring the combined effluent discharge in the CBRWPA to 89,108 acft in 1999 (about 46,048 acft/yr (51.7 percent) municipal/domestic discharges and 43,060 acft/yr (48.3 percent) industrial discharges).

5A.4.3 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.[3] 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

[3] 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.

flows directly into the Nueces River. Except during periods of high flow, the Nueces River bypasses the Nueces Delta and flows directly into Nueces Bay (Figure 5A.4-2). 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.[4]

In a study[5] performed in 1993, estimates were made of the increase in yield of the CCR/LCC System for each river and wastewater diversion alternative 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 wastewater treatment plants and a 70 MGD capacity river diversion from Calallen Reservoir to the Nueces Delta.

This alternative was re-evaluated 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.[6] Under this plan, the Allison and Broadway WWTP plus river diversion would produce an average annual yield increase over the year 2000 to 2050 time period of 5,500 acft/yr as indicated in Table 5A.4-3. Two additional alternatives were analyzed to determine the potential increases in system yield for the same year 2000 to 2050 timeframe. In one alternative, the 70 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 5A.4-3. 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

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[4] 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.
[5] Ibid.

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

alternative to the productivity factor. The yield increase provided by this option averaged only 1,100 acft/yr as shown in Table 5A.4-3. Recent information indicates that the third alternative, which has the lowest yield increase, presents the most realistic productivity factor scenario.

Table 5A.4-3.
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 & Broadway WWTP (MGD)*	*River Water*	*Wastewater*	
70	8.8	3	5	5,500
0	8.8	—	5	3,000
0	8.8	—	1	1,100

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 closing the Broadway WWTP and pumping 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. While the 1995 Agreed Order allows credit for additional wastewater diversions to Nueces Bay, the new proposal, referred to as the “Agreement in Principal”, with the TNRCC and other parties, would have allowed the City relief from inflow requirements when the reservoir system is below 50 percent and Drought Condition I had been implemented. The changes in the operating plan would have increased the freshwater availability for Nueces Bay during drought conditions and increased the amount of dependable water supply available from the CCR/LCC System for municipal and industrial use. However, industries involved with the industrial diversion allocation addressed in the plan expressed concerns about the potential for increased administrative penalties and liabilities resulting from diverting their current wastewater discharges to a different location (i.e., the Nueces Estuary). As a result, the diversion of industrial effluent was determined to not be feasible at that time. In addition, certain agencies and conservation groups objected to the plan. The City attempted to reach agreement with the various agencies and groups regarding the freshwater inflows to the Nueces Estuary, but with no success and the Agreement in Principal was discontinued.

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 has been completed and diversion began in 1999. Data is still being collected on the benefits of this diversion to the productivity of the bay system. The City also has moved forward with a plan to eliminate the Broadway WWTP due to its age. All wastewater flows from the Broadway WWTP service area will be diverted to the Greenwood (also called the Westside) WWTP. Final design of the pipeline from the Broadway WWTP to the Greenwood WWTP should begin in 2000.

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 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.

5A.4.4 Wastewater Reuse for Municipal and Industrial Purposes

5A.4.4.1 Texas Administrative Code, Chapter 210 – Use of Reclaimed Water

There are two general qualities of treated wastewater allowed for reclaimed water use under TNRCC 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.

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 TNRCC requires that the reclaimed water will be of the quality specified in the rules (Table 5A.4-4).

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

Table 5A.4-4.
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

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

County	*Entity*	*Use*	*Flow (MGD)*
Aransas	City of Rockport	Golf course irrigation	0.2611[1]
Bee	City of Beeville	WWTP, irrigation, construction	0.0018[1]
Jim Wells	City of Alice	Golf course irrigation, Coastal Bermuda turf irrigation	0.0885[1]
Kleberg	City of Kingsville	Irrigation	0.137[1]
Live Oak	City of George West	Local landowner irrigation	0.0165[1]
Nueces	City of Corpus Christi	Pharoah Valley Golf Course irrigation	0.082[2]
		Oso Golf Course irrigation	0.1462[2]
		Gabe Lozano Golf Course irrigation	0.2021[2]
		Baseball field irrigation	0.0104[2]
		Padre Isles Golf Course irrigation	0.2601[2]
San Patricio	City of Mathis	Local Landowner irrigation	0.0446[1]
	City of Aransas Pass	Wetlands enhancement (proposed)	0.0936[3]
		Irrigation of industrial land (proposed)	0.8424[3]

Sources:
[1]Historical self-reporting reuse data compiled by TWDB (1998 data).
[2]Wastwater Reuse Study prepared for City of Corpus Christi by HDR Engineering, Inc., Draft December 2000
[3]Engineering Feasibility Report for Northshore Resource Conservation Project prepared for San Patricio Municipal Water District by Naismith Engineering, Inc., October 1999. Reuse is scheduled to start in first quarter 2001.

5A.4.4.2 City of Corpus Christi Wastewater Reuse

In the recent past, operators of many of the municipal and industrial facilities in the CBRWPA area have been contacted to determine past, present and planned water reuse plans. The 1984 drought forced Corpus Christi and its water customers to adopt strict water conservation and reuse measures. The water reuse plans of interest were those in use during the 1984 drought period, current reuse plans, and future plans.

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 wastewater treatment plant effluent to some public facilities for irrigation purpose; i.e., for golf course and park irrigation. For example, in 1999, wastewater reuse for golf course and baseball park irrigation was about 256 million gallons or 785 acft/yr. This practice has some limitations, as the need for wastewater for irrigation is not continuous. Thus, the wastewater is not reused in 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.

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 5A.4-3 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.

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 wastewater treatment plants 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.[7]

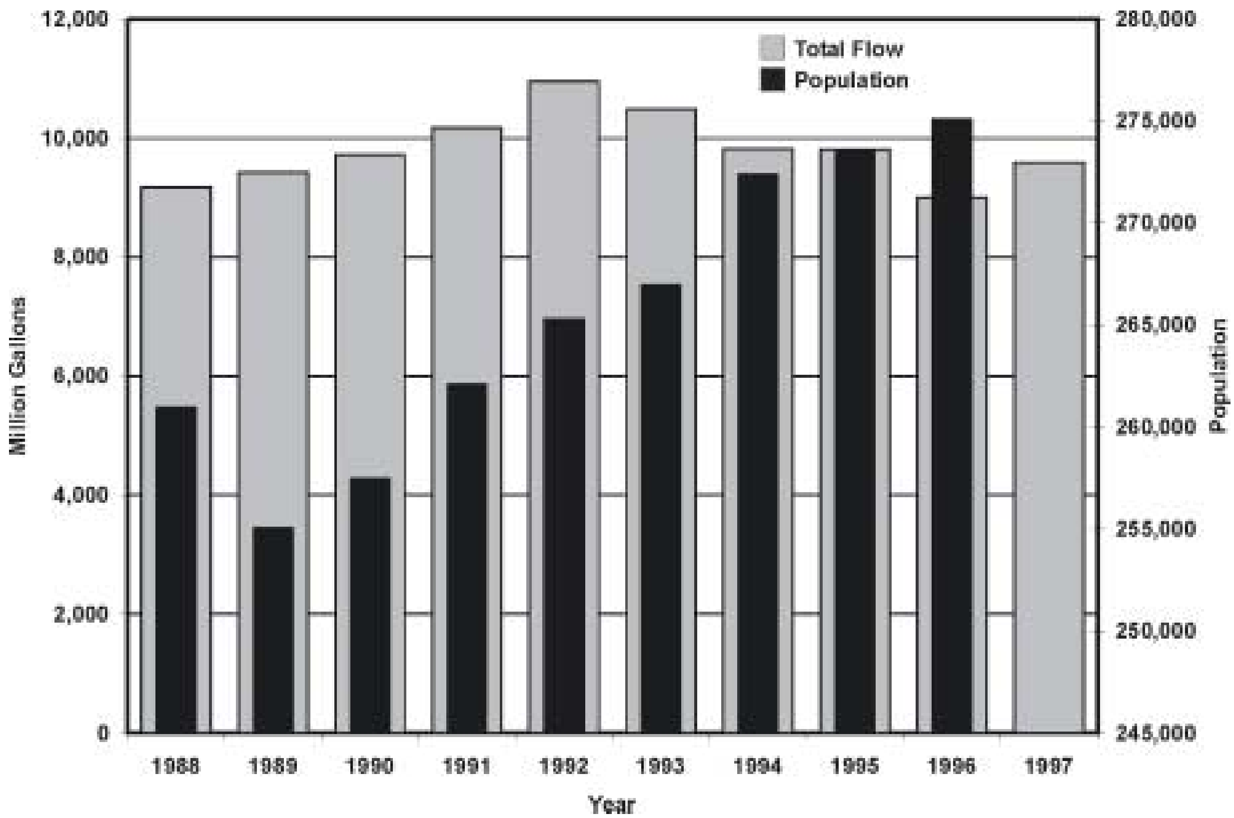

Figure 5A.4-3. City of Corpus Christi Wastewater Flows versus Population

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.

[7] 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 eight hours of chlorination to control viruses and lime softening to control hardness.

5A.4.4.3 Industrial Wastewater Reuse

5A.4.4.3.1 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 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.

5A.4.4.3.2 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 35 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 5A.4-6 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."[8]

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

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

Table 5A.4-6.
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

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.

5A.4.4.4 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[9] 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 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 items 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.

5A.4.4.5 City of Corpus Christi Broadway Wastewater Treatment Plant Diversion Project

In 1997, an additional study[10] was undertaken regarding the City of Corpus Christi Broadway WWTP. This plant is the City's oldest wastewater treatment plant. The plant service

[9] 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.
[10] "City of Corpus Christi Wastewater Facilities Implementation Plan, Oso & Greenwood Service Areas and Broadway Plant Diversion," City of Corpus Christi, February 1997.

area has experienced an approximate 39 percent reduction in population due to an out-migration starting in 1960. The City's latest plan includes the 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. It is anticipated that final design of the selected alternative will begin in 2000.

With the diversion of wastewater flow from the Broadway WWTP to the Greenwood WWTP, and the future elimination of the Broadway 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.[11]

5A.4.4.6 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[12] to assess the reuse of the City of Robstown WWTP effluent to supplement their industrial water supply.

Oxy Petrochemicals 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.

[11] Ibid.

[12] "Municipal Wastewater Reuse Feasibility Study, Oxy Petrochemicals, Corpus Christi, Texas," Oxy Petrochemicals, August 1996.

Although the feasibility study concluded the project was feasible, the Oxy Petrochemicals project has not been implemented.

5A.4.4.7 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. A major industrial complex is located between the cities of Portland and Ingleside. Reynolds Metals Company, a major area industry, is interested in obtaining and using municipal wastewater for non-potable purposes that are now met with raw water from the CCR/LCC System. The San Patricio Municipal Water District (SPMWD), who obtains both treated water and raw water from the CCR/LCC System, supplies municipal and industrial water to the area.

SPMWD and TWDB, in cooperation with area cities and industries, funded a regional wastewater reuse planning study that was completed in October 1994. The study recommended a regional wastewater collection, treatment and reuse system, which includes the Cities of Portland, Gregory, Aransas Pass, and Ingleside, with delivery of treated effluent to Reynolds Metals Company for reuse.[13] The project would increase the available water supply to the SPMWD service area by about 3,237 acft/yr, at an estimated cost of $461 per acft (1993 price). However, since 1,400 acft of the municipal wastewater effluent (about 43 percent) is now being discharged to Nueces Bay and is credited toward freshwater inflow requirements for Nueces Bay (specified in both the 1992 Interim Order and 1995 Agreed Order), it is necessary to evaluate the effects on yields from CCR/LCC System when eliminating 1,400 acft of wastewater flows to Nueces Bay. Under the 1995 Agreed Order, CCR/LCC releases to Nueces Bay would have to be increased to offset the loss of the wastewater effluent and thus water made available for other purposes would be less than the full 3,237 acft mentioned above. Reuse of 1,400 acft of wastewater by industry would reduce the demand upon the CCR/LCC System by 1,400 acft; however, the reduction of wastewater discharges to Nueces Bay would cause additional releases from the CCR/LCC System under the 1992 Interim Order and reduce the system yield by 340 acft. This results in a net increase of 1,060 acft/yr in regional water supply.[14] Since

[13] Naismith Engineering, Inc. (NEI), et al., "Northshore Regional Wastewater Reuse, Water Supply, and Flood Control Planning Study," San Patricio Municipal Water District, et al., October 1994.

[14] Ibid. Note: Of the total potential wastewater available for reuse (i.e., 3,237 acft), only 1,400 acft is diverted from discharges to the Nueces Bay.

Reynolds Metals Company is a no discharge facility, there are no return flows from its water use. The regional wastewater collection and treatment system described above may be implemented as a future project.

As described above, 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[15] 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 requirements for area industries. The City of Aransas Pass WWTP currently discharges to Redfish Bay and the effluent and sludge to Reynolds Metals Company reuse project does not impact the Agreed Order for the CCR/LCC System.

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 Reynolds Metals Company uses with reclaimed municipal wastewater. To implement the project, a pipeline will be constructed from the City's wastewater treatment plant to the Reynolds Metals Company tailing beds. Figure 5A.4-4 shows the pipeline route and the North Shore area in the vicinity of this project. The pipeline will be capable of delivering either wet sludge or a slurry of sludge and reclaimed water. When completed, the pipeline will replace the current use of tanker trucks to transport the sludge. The sludge will serve as a soil amendment for the tailings. The reclaimed water will be used to establish vegetation on barren areas and irrigate areas where vegetation has previously been established. The project is currently in the construction phase.

In addition, a small portion of the Aransas Pass WWTP effluent will be utilized at the Aransas Pass Nature Area for wetlands enhancement. This project has been completed and is being funded by a Coastal Management Program grant and is not a part of the Northshore

[15] "Engineering Feasibility Report and Environmental Assessment for the Northshore Resource Conservation Project – Phase I," San Patricio Municipal Water District, June 1997 (Updated October 1999).

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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.

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 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.

5A.4.5 Wastewater Reuse for Landscape and Agricultural Use

The City of Corpus Christi has initiated studies on the feasibility of irrigating City-owned landscape with reclaimed wastewater. Within the City, various categories of public facilities and recreation areas/undeveloped areas have been identified where landscape irrigation could be applied (Table 5A.4-7).

Table 5A.4-7.
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

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 5A.4.4.1);
- 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 City has not completed their analysis of landscape irrigation with reclaimed wastewater, thus no costs are currently available. However, the City has used wastewater treatment plant effluent to irrigate local golf courses and a baseball field for a number of years.

The quantity of wastewater reused for golf course and/or public park irrigation in the CBRWPA cannot be accurately calculated based on the limited data available; however, it is estimated to be a small percentage (less than 4 to 5 percent) of the total municipal wastewater flow. In 1999, the City of Corpus Christi diverted approximately 785 acft of treated effluent (from various WWTPs) to area golf courses and a baseball park. This represents approximately 3 percent of the City's wastewater discharge from its six wastewater treatment plants.

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.

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 wastewater treatment plant (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 ground water 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.

5A.4.6 Analyses and Discussion of Consumptive Wastewater Reuse and Advanced Conservation as Related to Estuaries Inflow Requirements

5A.4.6.1 Introduction

Under the 1995 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.

5A.4.6.2 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.[16,17] 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 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

[16] HDR, et al., Op. Cit., September 1995.
[17] 1999 survey results, as reported in Table 5A.4-1.

discharged into the Nueces River.[18,19] 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 new 1995 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.

5A.4.6.3. Impact Assessment

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.[20,21] 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 species diversity of emergent vegetation.[22] 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. Comprehensive, long-term studies are now under way with the Allison Diversion demonstration project to assess the potential effects of wastewater on the relative abundance and diversity of species in the Nueces Estuary.

[18] HDR et al., "Regional Wastewater Planning Study, Nueces Estuary, Phase I," City of Corpus Christi, et al., November 1991.
[19] HDR et al., "Regional Wastewater Planning Study, Nueces Estuary, Phase II," City of Corpus Christi, et al., March 1993.
[20] 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.
[21] 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.
[22] Ibid.

5A.4.6.4 Implementation Issues

Major implementation issues include wastewater treatment levels required by regulatory agencies (TNRCC), 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 has been conducting water quality and biological studies of the Nueces Delta and Estuary since October 1994. Those studies ended in 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.

Excerpts from the plan's Abstract and Executive Summary[23] are included below and the main features of the Demonstration Project are shown in Figure 5A.4-5.

> *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.*

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

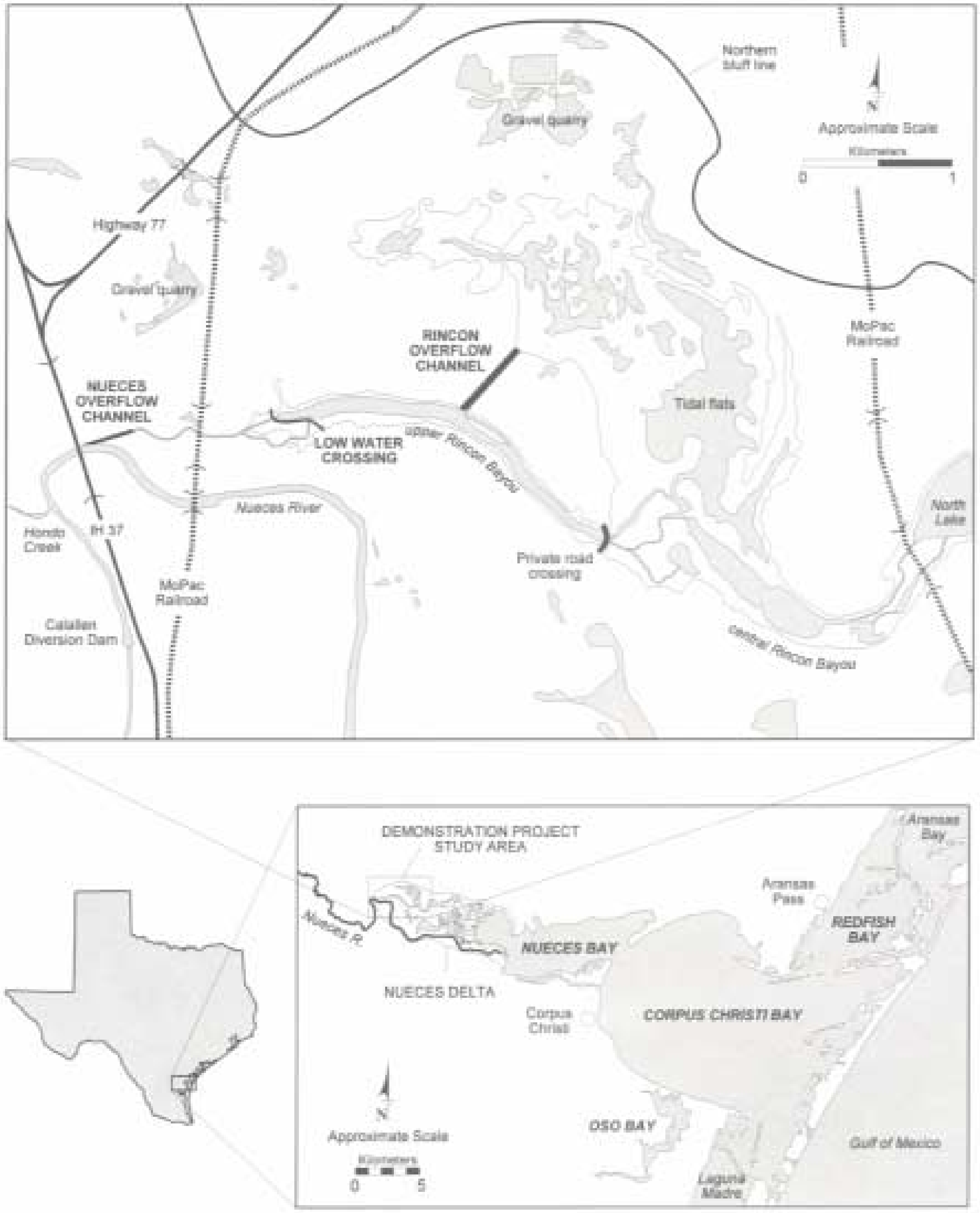

Figure 5A.4-5. Location of the Nueces Delta (below) and of the Rincon Bayou Demonstration Project Features (above)

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

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, 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.

5A.4.7 Evaluation Summary

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

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

Impact Category	Comment(s)
a. Quantity, reliability, and cost of treated water	• Firm yield: Highly variable • Cost: Highly variable
b. Environmental factors	• Environmental impact to estuary in potential reduction of freshwater inflows • Cultural resource investigations will be required for all pipeline routes • Construction and maintenance of transmission pipeline corridor(s)
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	• 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 reuse opportunities of water supplies
j. Effect on navigation	• None.

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5A.5 Carrizo-Wilcox Aquifer Supplies

5A.5.1 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 5A.5-1). 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 Underground Water Conservation District (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. 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 the 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 re-developed 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. 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.

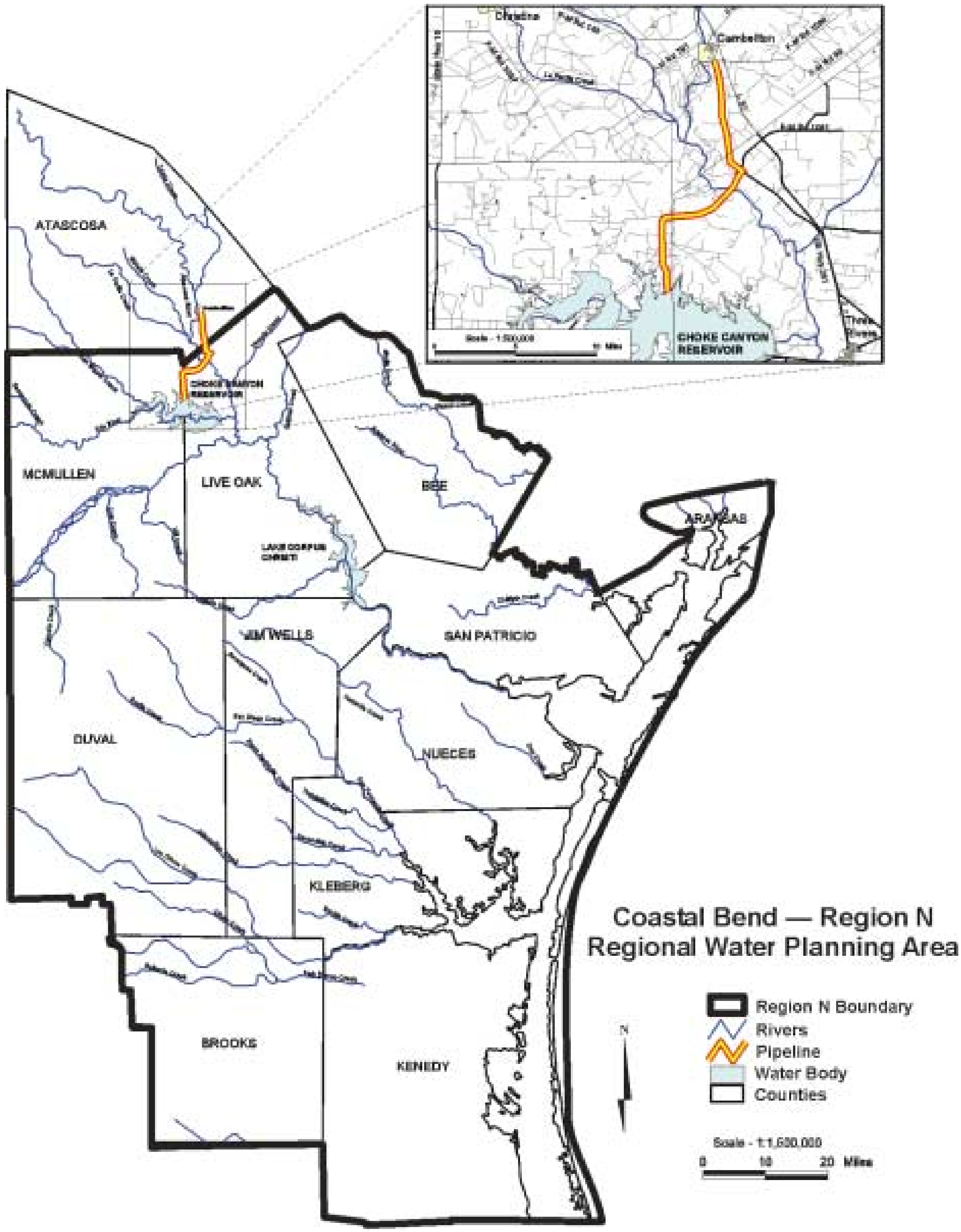

Figure 5A.5-1. Carrizo-Wilcox Supply Option

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 (RWPG Region L) 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.

5A.5.2 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 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 3,615 acft/yr both for year 2010 conditions and year 2050 conditions. This represents approximately 54 percent of the 6,720 acft/yr of water pumped annually into Choke Canyon Reservoir from the well field in Campbellton. However, these losses would be significantly reduced if a pipeline between Choke Canyon Reservoir and Lake Corpus Christi were constructed, as discussed in Section 5A.9. In this case, the yield is estimated to be approximately 5,700 acft/yr.

5A.5.3 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 (TPWD, 1984). 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 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.

5A.5.4 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. Costs are summarized in Table 5A.5-1.

In addition to capital costs detailed in the Table 5A.5-1, Evergreen UWCD mandates export fees of $0.17 per 1,000 gallons exported. In addition, water rights for exported water are conveyed with property ownership. In order to export 6,720 acft of water from the district, an entity would need to purchase 6,720 acres of land within the district.

Results of the cost estimate indicate that total capital costs for infrastructure associated with the project would be approximately $7,411,000, as detailed in Table 5A.5-1. Annual costs would be on the order of $2,369,000. For the proposed project yield of 3,720 acft/yr, this is equivalent to a unit cost of water of $655 per acft (or $2.01 per 1,000 gallons). If a pipeline between Choke Canyon Reservoir and Lake Corpus Christi were constructed to minimize channel losses the project is estimated to have a yield of about 5,700 acft/yr and a unit price of $405 per acre-foot as shown in Table 5A.5-1.

Table 5A.5-1.
Cost Estimate Summary
Campbellton Well Water Supply Project Option
Second Quarter 1999 Prices

Item	***Estimated Costs for Facilities***
Capital Costs	
Terminal Storage, and Pump Station (6 MGD)	$1,965,000
Well Field and Transmission Pipeline (12", 16", 18", 20", 106,420 ft total)	5,446,000
Total Capital Cost	**$7,411,000**
Engineering, Legal Costs and Contingencies	$2,525,000
Environmental & Archaeology Studies and Mitigation	571,000
Land Acquisition and Surveying (6,685 acres)	7,220,000
Interest During Construction (2 years)	1,419,000
Total Project Cost	**$19,146,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$1,331,000
Operation and Maintenance:	
Wells, Pipeline, Pump Station	97,000
Pumping Energy Costs (8,493,000 kWh @ $.06 per kWh)	510,000
Water Export Fee ($0.17/1,000 gal)	372,000
Total Annual Cost	**$2,369,000**
Without pipeline between CCR and LCC	
Available Project Yield (acft/yr)	**3,720**
Annual Cost of Water ($ per acft)	**$655**
Annual Cost of Water ($ per 1,000 gallons)	**$2.01**
With pipeline between CCR and LCC	
Available Project Yield (acft/yr)	**5,700**
Annual Cost of Water ($ per acft)	**$405**
Annual Cost of Water ($ per 1,000 gallons)	**$1.24**

5A.5.5 Implementation Issues

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

- Land Acquisition/Water Rights – Evergreen UWCD mandates that water rights for export of groundwater outside the district be limited to an amount in acft no greater than the acreage of land owned by any entity. Since Lake Corpus Christi is located outside of the Evergreen UWCD, an entity would need to purchase 6,720 acres of land surrounding Campbellton to justify the export of 6,720 acft/yr of Carrizo groundwater.
- Installation of pumps into the dormant well field will require permitting from the Evergreen UWCD.
- Environmental/Water Quality Issues – TNRCC 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.

5A.5.6 Evaluation Summary

An evaluation summary of this water management option is provided in Table 5A.5-2.

Table 5A.5-2.
Evaluation Summary of
Campbellton Well Option to Enhance Water Supply Yield

Impact Category	Comment(s)
a. Quantity, reliability, and cost of treated water	• Firm Yield: Between 3,615 and 5,700 acft/yr • Cost: Between $405 and $639 per acft/yr
b. Environmental factors	• Pipeline construction may temporarily disrupt local wildlife • Mixing relatively hot water into Choke Canyon may locally affect aquatic life • Cultural resources will need to be avoided when facilities are constructed
c. 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	• None
f. Comparison and consistency equities	• 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

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5A.6 Gulf Coast Aquifer Supplies

5A.6.1 Conjunctive Use of Groundwater Supplies from Refugio County

5A.6.1.1 Description of Strategy

The existing regional water system operated by the City of Corpus Christi has two supplies of water. One is the Nueces River Basin (Lake Corpus Christi and Choke Canyon Reservoir) and the second is 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 5A.6-1) 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's currently contracts for about 42,000 acft/yr of water from Lake Texana. 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, but requires ratification or authorization in the next legislative session before becoming permanent. Regulations on the development of groundwater and the export of groundwater from the new district have not been established, and are therefore not considered.

[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.

5A.6.1.2 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. It's 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.[2] 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.[3] 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.

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[2] Mason, Curtis C., "Ground-water Resources of Refugio County, Texas," Texas Water Commission Bulletin 6312, 48p., 1963.

[3] Muller, D. A. and Robert D Price, "Ground-water Availability in Texas, Estimates and Projections through 2030," Texas Department of Water Resources Report 238, 77p., 1979.

A 1991 large-scale regional aquifer system analysis of the Texas Gulf Coast Aquifer System included the development of a groundwater model.[4] 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.

As part of the development of the Coastal Bend Regional Water Plan, a more 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.

For this option, a second test with the Coastal Bend groundwater model was conducted. In this case, the pumping rates outside the proposed well field (Figure 5A.6-1) were set at the projected year 2050 rates. In the proposed well field, the pumping was adjusted until water level declines from predevelopment are just less than 200 feet of drawdown. These tests indicate about 18,900 acft/yr is available from the well field in southwestern Refugio County and about 32,700 acft/yr is available in the northwest part of the county. It is important to note that the combined availability of groundwater to the proposed well field under this second test is nearly twice the groundwater availability adopted by the Coastal Bend RWPG (about 29,300 acft/yr). This is attributed to the year 2050 pumpage estimates for Bee, Goliad, and Victoria Counties being less than the availability estimates.

The availability of groundwater for this option, after considering local demands, is about 28,100 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 the year 2050 (1,179 acft/yr).

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[4] 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.

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 the balance between the supply and demand of 28,100 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.

5A.6.1.3 Environmental Issues

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 5A.6-1). 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 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.

5A.6.1.4 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 5A.6-1). 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 5A.6-1. 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 $6,267,000 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 $224 per acft (Table 5A.6-1).

Table 5A.6-1.
Cost Estimate Summary
Conjunctive Use of Groundwater Supplies from Refugio County
(Second Quarter 1999 Prices)

Item	***Estimated Costs for Facilities***
Capital Costs	
Well Field (28 wells; 1,200 gpm)	47,619,000
Well Field Collection Pipeline (12 to 36-in. dia.; 33 miles)	10,374,000
Transmission Pump Station	4,947,000
Transmission Pipeline (48-in. dia.; 3.5 miles)	2,036,000
Total Capital Cost	**$24,976,000**
Engineering, Legal Costs and Contingencies	$8,121,000
Environmental & Archaeology Studies and Mitigation	973,000
Land Acquisition and Surveying (141 acres)	1,321,000
Interest During Construction (2 years)	2,832,000
Total Project Cost	**$38,223,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$2,777,000
Operation and Maintenance:	
Intake, Pipeline, Pump Station, and Well Field	274,000
Pumping Energy Costs to Texana Pipeline (27,753,990 kWh @ $0.06 per kWh)	1,665,000
Purchase of Water (28,000 acft/yr @ $55.40 per acft)[1]	1,551,000
Total Annual Cost	**$6,267,000**
Available Project Yield (acft/yr)	**28,000**
Annual Cost of Water ($ per acft)	**$224**
Annual Cost of Water ($ per 1,000 gallons)	**$0.69**

[1] Includes assumed payment to landowner for use of water and any potential export fees for transfer of groundwater out of the county.

5A.6.1.5 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.

5A.6.1.6 Evaluation Summary

An evaluation summary of this regional water management option is provided in Table 5A.6-2.

Table 5A.6-2.
Evaluation Summary of the Refugio County Groundwater

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	• Firm yield: 28,000 acft/yr • Water Quality: Fair • Low cost: $224 per acft
b. Environmental factors	• Negligible impacts • Cultural resources will have to be surveyed and avoided
c. 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	• Insignificant, as very little of water is suitable for use by agriculture

e. Recreational	• None
f. Comparison and consistency equities	• 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

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5A.6.2 Groundwater Alternative for Small Municipal and Rural Water Systems, Coastal Bend Water Planning Region

5A.6.2.1 Description of Strategy

Relatively small municipal and rural water systems of the Coastal Bend Water Planning Region commonly use the Carrizo-Wilcox and Gulf Coast Aquifers for their supply. The use of groundwater sources is a strong preference because the water is usually readily available and inexpensive. However, the water's salinity often exceeds public drinking water standards.

The purposes of this water supply alternative are to:

- Evaluate groundwater availability and water treatment requirements of small municipalities and 'county-other' water users until the year 2050;
- Determine if a water system expansion is required;
- Determine which entities need to develop additional water supplies and/or treat local groundwater for elevated concentrations of total dissolved solids (salinity) or other water quality constituents; and
- If additional supplies are needed, estimate the cost of installing additional wells. If treatment of local groundwater supplies is needed, estimate the cost of these treatment facilities.

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

- An engineering analysis of the water system as to the condition or adequacy of the wells, transmission system, and storage facilities;
- A projection of maintenance 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;
- 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. Compile information prepared for the Coastal Bend Regional Water Planning Group on current (1996) and TWDB's projected populations and water demands for each of the municipalities;
2. Estimate the required system capacity through the year 2050;

3. Compile and summarize publicly available information for each municipal water system from TNRCC and TWDB; and
4. Analyze aquifer information from TWDB and USGS databases and reports as to availability and salinity of groundwater from the Gulf Coast Aquifer in the Coastal Bend Water Planning Region.

5A.6.2.2 Evaluation of Municipal Water Systems

A summary description of each municipal water system with a population in excess of about 500 (Figure 5A.6-2) that totally relies on local groundwater for a supply is presented in this section. If the system's well capacity does not meet the projected peak day demand, an estimate is provided on the number of additional wells that will be required, when the wells are needed, and the total capital cost for the well(s) and a pipeline to tie into the existing distribution system. If the local groundwater does not currently meet public drinking water standards, an estimate is given on water treatment plant requirements and the estimated cost. Only the cost of a water treatment plant is estimated. A detailed analysis to collect and transport the water from existing and new wells as well as the disposal of the saline concentrate is beyond the scope of this reconnaissance level evaluation. For drinking water supplies, the public drinking water standard for salinity is 1,000 mg/L of total dissolved solids.

5A.6.2.2.1 Sinton and Tilden

The municipal systems servicing the communities of Sinton and Tilden appear to have a local groundwater supply and well capacity that is suitable and sufficient to meet their requirements through the year 2050.

5A.6.2.2.2 Falfurrias, Premont, and San Diego

The municipal systems servicing the communities of Falfurrias, Premont, and San Diego are in counties where the groundwater quality commonly meets the drinking water standards for salinity, but where the water demands exceed groundwater availability before year 2050. The water availability is based on the supply that can be developed on a sustained basis with an allowable decline of about 250 feet in groundwater levels. Considering the current water levels are at least 150 feet above the critical levels and modest shortages in projected groundwater supplies for these municipalities, sufficient groundwater is available to cover this shortage from a depletion of storage, at least until the year 2050. In other words, the allocation of groundwater from the county supply is sufficient to meet the projected demands.

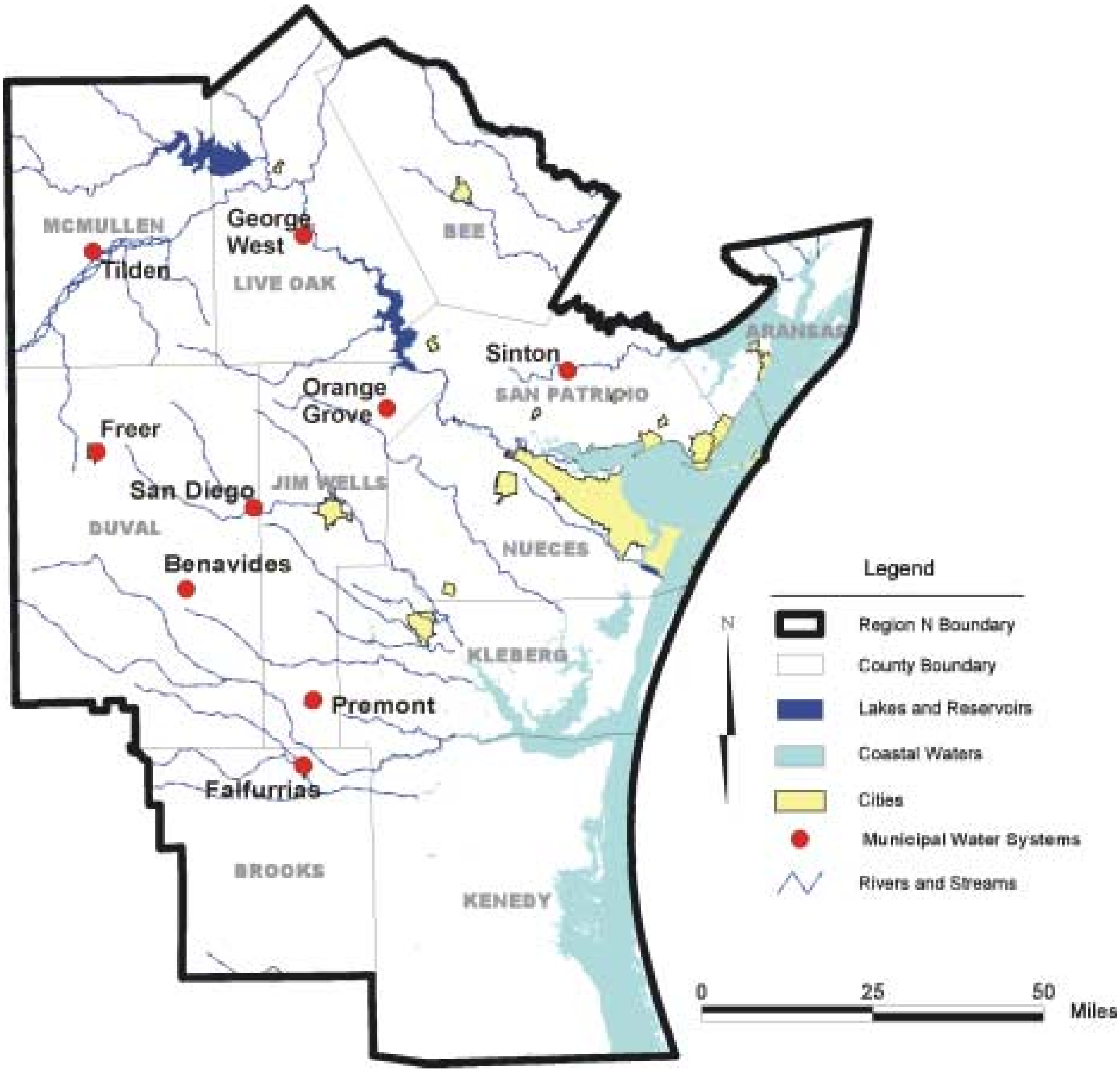

Figure 5A.6-2. Small Municipal Water Systems Relying on Groundwater

Current well capacities for the communities of Falfurrias and Premont are estimated to be sufficient to meet the peak day demands through the year 2050. However, the well capacity for San Diego appears to be insufficient by the year 2030 on the basis of reported total well capacity, estimated peak day demand, and typical well yields. The analysis indicates one additional well is needed to provide a sufficient water supply. The estimated capital cost for the well and a half-mile of pipeline is $290,000.

5A.6.2.2.3 George West and Orange Grove

George West and Orange Grove are located where sufficient groundwater is estimated to be availability to meet the demands through the year 2050; however, the salinity of local groundwater commonly exceeds drinking water standards. For both cities, information suggests that existing wells will be able to meet peak day demands through year 2050.

For George West, the maximum peak day demands through year 2050 indicate that a 1.0-MGD water treatment plant could be required. The cost of constructing a brackish water treatment plant of this size is estimated to cost about $2,570,000. This does not include site specific cost of connecting the existing wells to the water plant or the cost of concentrate disposal. Considering debt service and operation and maintenance, the annual cost is estimated to be about $354 per acft based on 100-percent utilization of the water plant and $521 per acft based on an average 50-percent utilization of the water plant (Table 5A.6-3).

For Orange Grove, the maximum peak day demands through year 2050 indicate that a 0.5-MGD water treatment plant is required. The cost of constructing a desalination water treatment plant of this size is estimated to cost about $1,519,000. This does not include site-specific cost of connecting the existing wells to the water plant or the cost of concentrate disposal. Considering debt service and operation and maintenance, the annual cost is estimated to be about $397 per acft based on 100-percent utilization of the water plant and $593 per acft based on an average 50-percent utilization of the water plant.

5A.6.2.2.4 Benavides and Freer

Benavides and Freer are located where groundwater salinity is commonly in the 1,000 to 1,500 mg/L; and, where the total water demands on aquifers exceeds availability. Also, the cities are located in a county where mining and irrigation demands have had a recent and dramatic increase.

Benavides is in an area of Duval County where groundwater is available from the Oakville Sandstone and the Goliad Sands. Although the estimates of groundwater availability indicates groundwater supplies are insufficient for Benavides' future demands, considering current water levels are at least 150 feet above the critical levels and that only modest shortages are projected for these municipalities, sufficient groundwater is available to cover this shortage by moderately overdrafting the aquifer, at least until the year 2050. An analysis based on reported total well capacity, the estimated peak day demand, and typical well yields in the area suggests that one new well will be needed by year 2010. The estimated capital cost for the well and a half-mile of pipeline is $290,000. To treat the slightly saline groundwater to drinking water standards, a water treatment plant with a capacity of 1.0 MGD is required. The cost of constructing this size brackish water treatment plant to remove the excessive salt content from local groundwater is estimated to cost about $2,570,000. Considering debt service and operation and maintenance, the annual cost for the water treatment plant is estimated to be about $354 per acft based on 100-percent and $521 per acft based on 50-percent utilization of the water plant. This does not include site specific cost of connecting the existing and new wells to the water treatment plant or the cost of concentrate disposal.

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 gallons per minute to large wells. Considering the severe water level declines in the existing well field, the distance to potential well fields in the Carrizo-Wilcox and Gulf Coast Aquifers, and well yield and water quality characteristics of the Catahoula Tuff in the aquifer, the groundwater alternative for Freer includes (1) reducing the water production in the current well field to two wells, (2) adding a new well field in the Catahoula Tuff Aquifer that extends southeast of the city with three wells, (3) adding a new well field in the Catahoula Tuff Aquifer that extends northeast of the city with four wells, (4) constructing and operating a 2.0-MGD desalination water treatment plant, and (5) connecting the wells to the water treatment plant. The total capital cost for well field facilities is estimated to be $2,566,000; and the total project cost for the brackish water treatment plant is estimated to be $5,140,000. This does not include the cost of disposing of the concentration from the desalination process. Considering debt service and operation and maintenance, the annual costs for the water treatment plant are estimated at $354 per acft and $521 per acft, based on the 100-percent and 50-percent utilization of the new facilities, respectively.

5A.6.2.3 Evaluation of Rural Water Systems

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 5A.6-3 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.

5A.6.2.3.1 Aransas, Bee, Jim Wells, Kenedy, Kleberg, McMullen, and San Patricio Counties

For Aransas, Bee, Jim Wells, Kenedy, Kleberg, McMullen, and San Patricio Counties, the groundwater availability, overall, is sufficient to meet the demands of rural water suppliers. However, 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 5A.6-3.

5A.6.2.3.2 Brooks, Duval, Live Oak, and Nueces Counties

For Brooks, Duval, Live Oak, and Nueces Counties, the long-term groundwater availability is insufficient to meet the demands on rural water systems. Also, locally, the salinity groundwater in these counties can vary from fresh (less than 1,000 mg/L) to slightly saline (up to 3,000 mg/L).

In Brooks, Duval, and Live Oak Counties, the greatest water shortages in the county-other category are 567 acft/yr in year 2000 in Brooks, 372 acft/yr in year 2000 acft/yr in Duval, and 361 acft/yr in year 2050 in Live Oak. Considering the current water levels are estimated to be more than 100 feet above critical levels in these counties and only modest projected shortages, groundwater is considered to be sufficient to cover this shortage from a depletion of storage, at least until the year 2050.

In Nueces County, the demands far exceed the supplies and the salinity commonly exceeds public drinking water standards. As a result, the groundwater alternative plan is to not rely on groundwater and, instead, reduce demands and seek surface water supply contracts with the City of Corpus Christi and the South Texas Water Authority.

5A.6.2.4 Environmental Issues

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.

5A.6.2.5 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.

5A.6.2.6 Evaluation Summary

A evaluation summary of this regional water management option is provided in Table 5A.6-4.

Table 5A.6-4.
Evaluation Summary of the Alternative for Small Municipal and Rural Water Systems

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	Firm yield: Except for Nueces County, yield of aquifers through year 2050 should be adequate Cost: Variable
b. Environmental factors	• Negligible impacts • Cultural resources will need to be surveyed and avoided
c. 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	• Insignificant, as very little of water is suitable for use by agriculture
e. Recreational	• None
f. Comparison and consistency equities	• 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

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5A.6.3 Recovery of Bank Storage from Lake Corpus Christi

5A.6.3.1 Description of Strategy

Lake Corpus Christi is approximately 35 miles northwest of Corpus Christi and is a vital component of the water supply for the Corpus Christi area (Figure 5A.6-3). Because a significant portion of Lake Corpus Christi overlies the outcrop of the Goliad Sand of the Gulf Coast Aquifer, some water in the lake flows into the aquifer and becomes bank storage when the lake fills. This is verified by monitoring wells adjacent to the lake, which show a strong correlation between water levels in wells and water levels in the lake. This water supply option evaluates the feasibility of recovering the water lost to bank storage (Figure 5A.6-4).

The two options considered for recovering water lost to bank storage are:

1. Installing a well field around Lake Corpus Christi and pumping the water back into the lake when water levels in the lake are low, and
2. Continuing to allow the water in bank storage to drain back into the lake naturally as the water levels in the lake decline, as has happened in the past.

The well field option would allow for the control of the rate and timing of the water recovery, while the natural return of the water would be gradual and would depend on water levels in the lake.

5A.6.3.2 Available Yield

A study of the water movement between Lake Corpus Christi and the Gulf Coast Aquifer was conducted by developing and using a model of the lake and surrounding aquifer. The model is based on the USGS's MODFLOW computer program, which simulates groundwater flow. The Gulf Coast Aquifer-Lake Corpus Christi model has one layer, divides the area into a grid of 100 rows and 62 columns, and has a grid spacing of 1,000 feet (Figure 5A.6-5). Based on the general geologic characteristics in the Gulf Coast Aquifer in the vicinity of Lake Corpus Christi, the hydraulic conductivity for the aquifer was set at 1 foot per day in the horizontal direction and the storage coefficient was set at 0.3. Recharge was set at a constant 0.000001 feet per day over the entire layer.

At the updip (upstream) and downdip (downstream) boundary of the model grid, the cells were designated as constant head cells and represent the regional groundwater levels in these areas. These constant head cells create a groundwater gradient toward the lower grid boundary

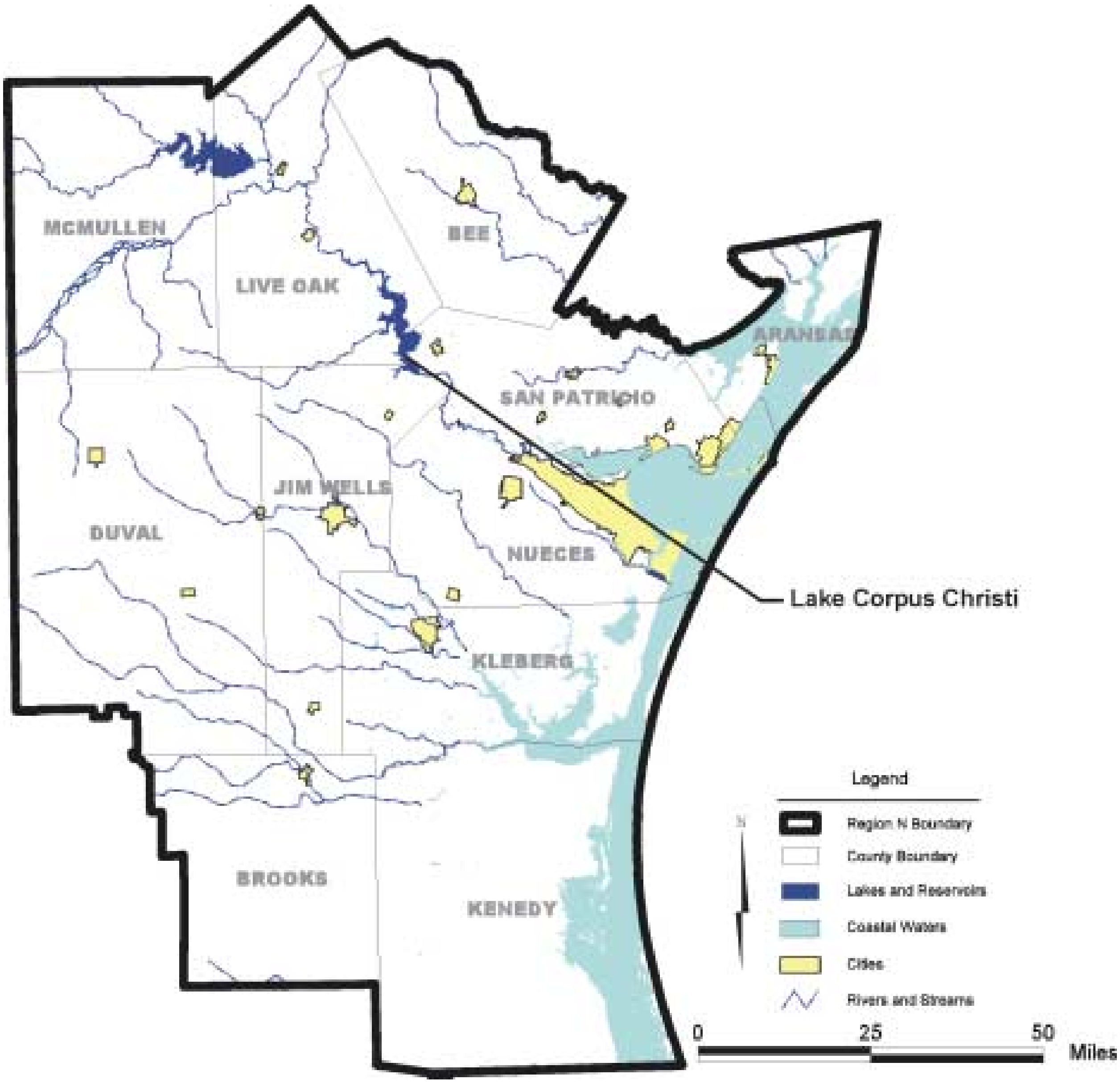

Figure 5A.6-3. Lake Corpus Christi Location Map

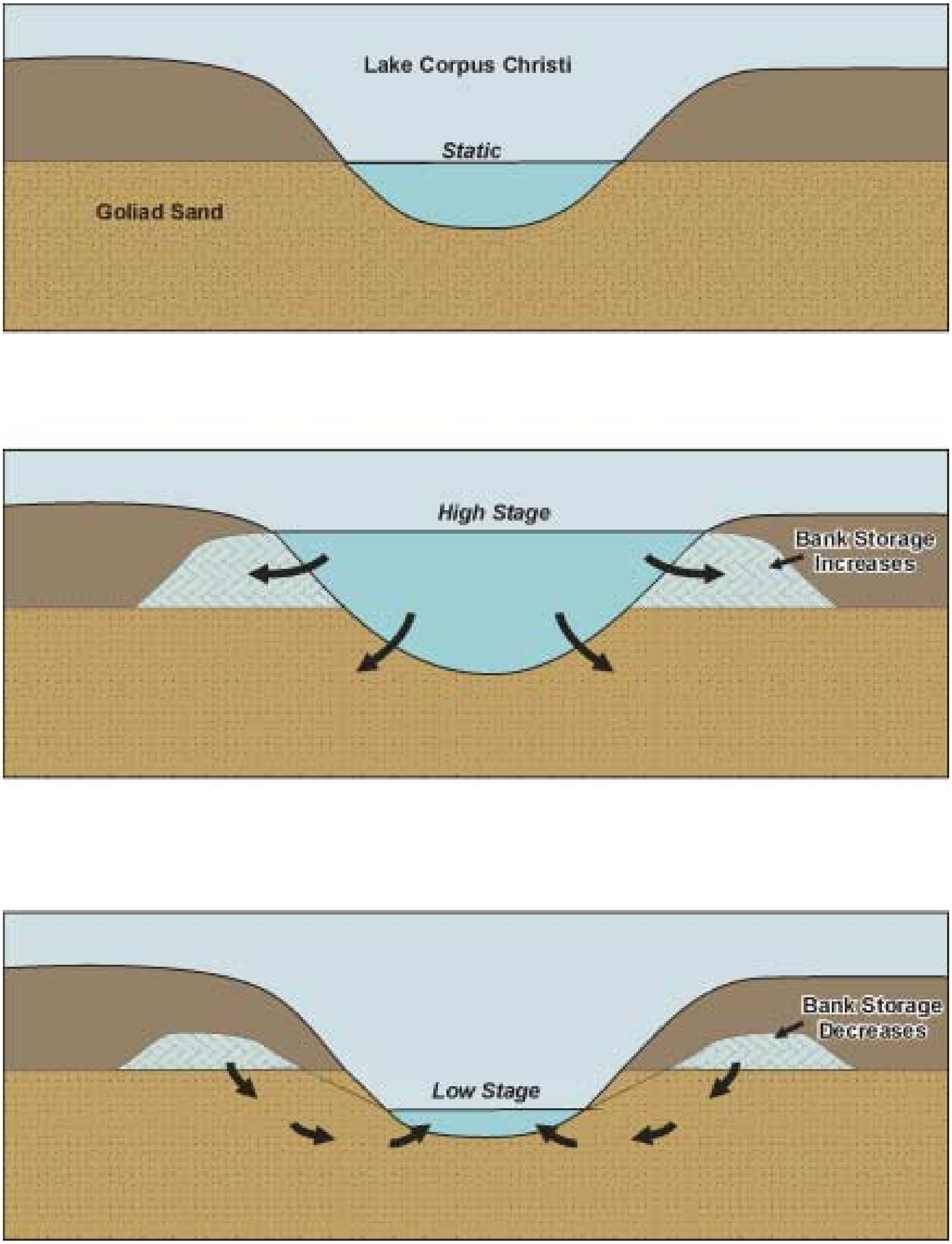

Figure 5A.6-4. Schematic Cross-Section of Lake Corpus Christi and Goliad Sand

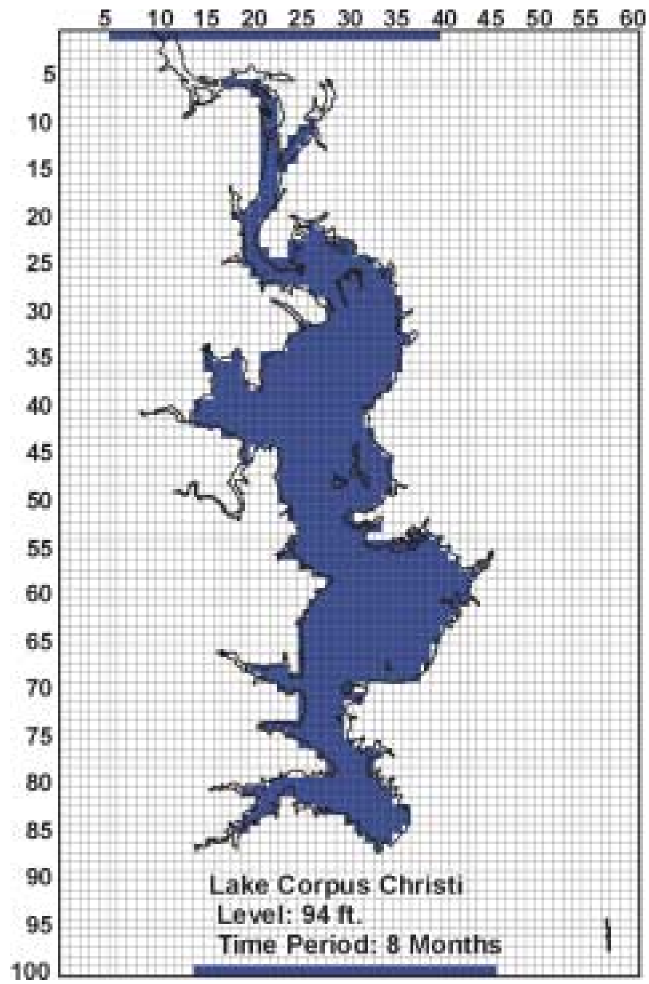

Figure 5A.6-5. Gulf Coast Aquifer-Lake Corpus Christi Model

and simulates groundwater movement beneath and adjacent to the lake. The water levels of the constant heads are based on records from existing monitoring wells located around the lake. The model layer has a top elevation of 94 feet and the bottom layer has an elevation of mean sea level. Starting water levels for the series of simulations were computed by running the model without the lake being represented. These starting heads were used for the first simulation. Model cells within Lake Corpus Christi were represented as constant heads, which allows water to enter and leave the lake as needed.

Quantifying the exchange of water between Lake Corpus Christi and the Gulf Coast Aquifer required several steps. They are summarized below.

- Records of water levels in Lake Corpus Christi were studied to select a test period for study. The selected period includes a 6-year period from 1991 to 1996 when the lake started full, drains down to a very low level, and refills.
- The 6-year period of historical data was simplified to seven steps. As shown in Figure 5A.6-6, the lake was assumed to start full at 94 feet and drop in 4-foot steps until the lake declined to 74 feet. Finally, after a 5.5-year period, the lake level rose abruptly to 94 feet.
- The model was iterated through the 6-year cycle five times to allow the aquifer to stabilize to hydrologic conditions with the lake being in place. Movement of water into and from bank storage was computed using the models' mass balance option.

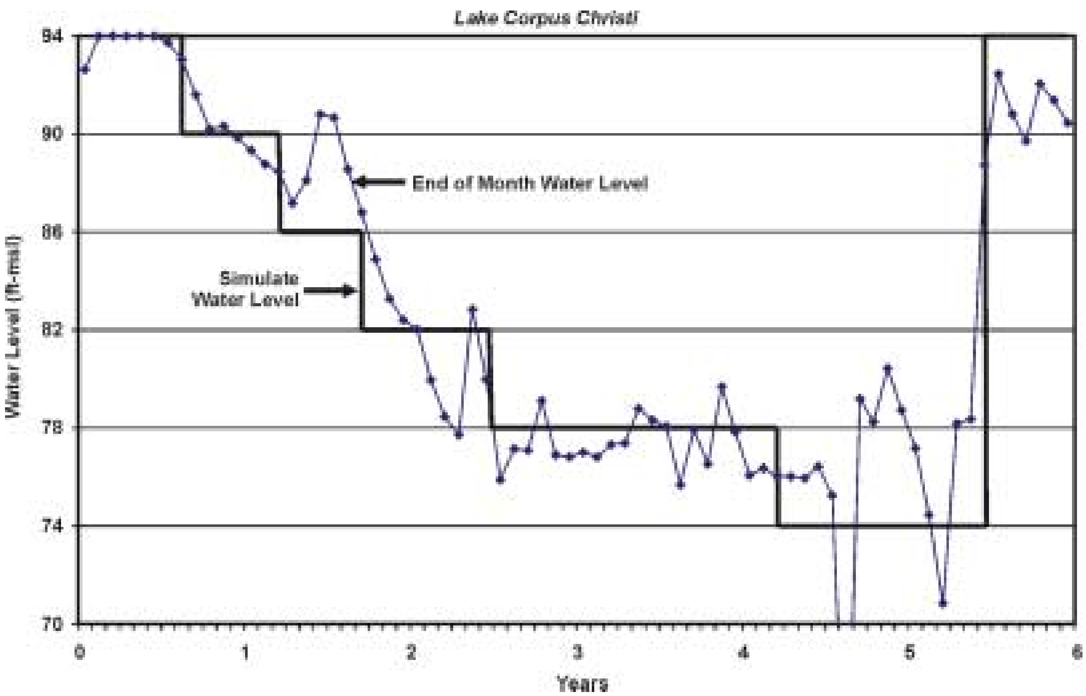

Figure 5A.6-6. 6-Year Test Period

The net exchange of water leaving and entering Lake Corpus Christi is illustrated in Figure 5A.6-7. The chart shows about 400 acft of water is lost to bank storage in the first 8 months when the lake is full. As the water level in Lake Corpus Christi declines, water returns to the lake at a rate of about 25 acft per month during the third and fourth year. At the end of the cycle, about 700 acft is lost to bank storage in the final 7 months, when the lake level rises from 74 feet to 94 feet. The net exchange after one entire 6-year cycle is 387 acft gained by the lake. Some of this flow is attributed to natural groundwater inflow from the upstream part of the lake.

In conclusion, essentially all of the water lost from Lake Corpus Christi into bank storage naturally returns to the lake.

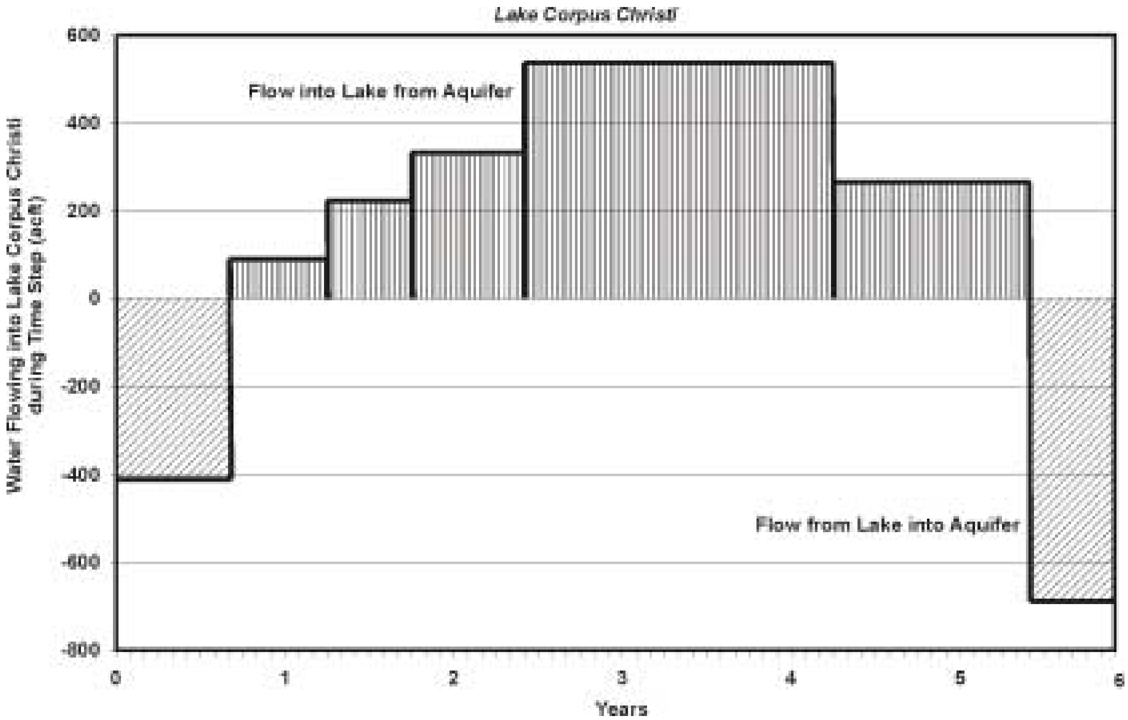

Figure 5A.6-7. Net Flow Into and Out of Bank Storage

5A.6.3.3 Environmental Issues

Water quality data from wells in the Lake Corpus Christi area indicates variable concentrations of dissolved solids and chlorides in the groundwater. Groundwater samples collected from 1984 to 1986 indicate dissolved solids concentration to run 1,350 mg/L and chloride average 500 mg/L. Long-term trends are not available due to lack of analytical data; however, groundwater quality in this area is not believed to have changed significantly. The water quality of the native groundwater is expected to be more saline than the surface water in bank storage.

5A.6.3.4 Engineering and Costing

The model results indicate a net gain to Lake Corpus Christi of 387 acft over the 6-year test period. Considering (1) the modest amount of water entering bank storage, (2) the natural return of this water, (3) the cost of installing and maintaining a well field, and (4) the relatively poor quality of water in this part of the Gulf Coast Aquifer, the recovery of bank storage using a well field does not appear to be an attractive water management strategy.

5A.6.3.5 Evaluation Summary

A evaluation summary of this regional water management option is provided in Table 5A.6-5.

Table 5A.6-5.
Evaluation Summary of Recovery of Bank Storage from Lake Corpus Christi

Impact Category	Comment(s)
a. Quantity, reliability, and cost of treated water	• Firm Yield: Negligible • Water Quality: Minor changes • Cost: Negligible
b. Environmental factors	• Negligible • Cultural resources would have to be surveyed and avoided
c. State water resources	• No significant impacts on water resources
d. Threats to agriculture and natural resources in region	• Negligible
e. Recreational	• None
f. Comparison and consistency equities	• Standard analyses and methods used
g. Interbasin transfers	• None
h. Third party social and economic impacts from voluntary redistribution of water	• Some improvements in water quality in wells near Lake Corpus Christi
i. Efficient use of existing water supplies and regional opportunities	• Maintains existing supplies
j. Effect on navigation	• None

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5A.7 Potential Aquifer Storage and Recovery (from the Gulf Coast Aquifer)

5A.7.1 Description of Strategy

For purposes of this evaluation, Aquifer Storage and Recovery (ASR) is considered as use of a dual-purpose well to inject water into an aquifer for storage and to recover the water at a later date. ASR is useful to water utilities that have a surplus of water at times but do not have sufficient storage to save the 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. 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. This strategy more fully utilizes the available capacities of the water treatment plant and, possibly, the availability of the supply. If the water supply issue were during 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 water as well as pumping water.

Two ASR options are evaluated. The first option would function as a local facility and would serve the Rockport area. It is evaluated on a concept of storing and recovering water on an annual cycle. Under this option, water would be injected to the aquifer in non-summer months and then recovered in the summer. The other option would function as a regional facility and would serve the Corpus Christi area. 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. The locations of the two ASR systems considered here are shown in Figure 5A.7-1.

5A.7.1.1 Rockport Facility

The water system serving the Rockport area imports its water from the San Patricio Municipal Water District (MWD) through a 16-inch pipeline that is about 8 miles long. This facility has served the area very well for many years; however, a projected increase in demands has caused concerns about its capacity during the summer. One means of extending the life of the pipeline is to add substantial storage in the Rockport area. This storage of water would allow the utility to import water during the winter when customer demand is low and draw water from the reservoir during the summer when the customer demand is high. Using the year 1997 as an example, the daily demands for Rockport ranged from about 1.5 MGD to 3.6 MGD and averaged

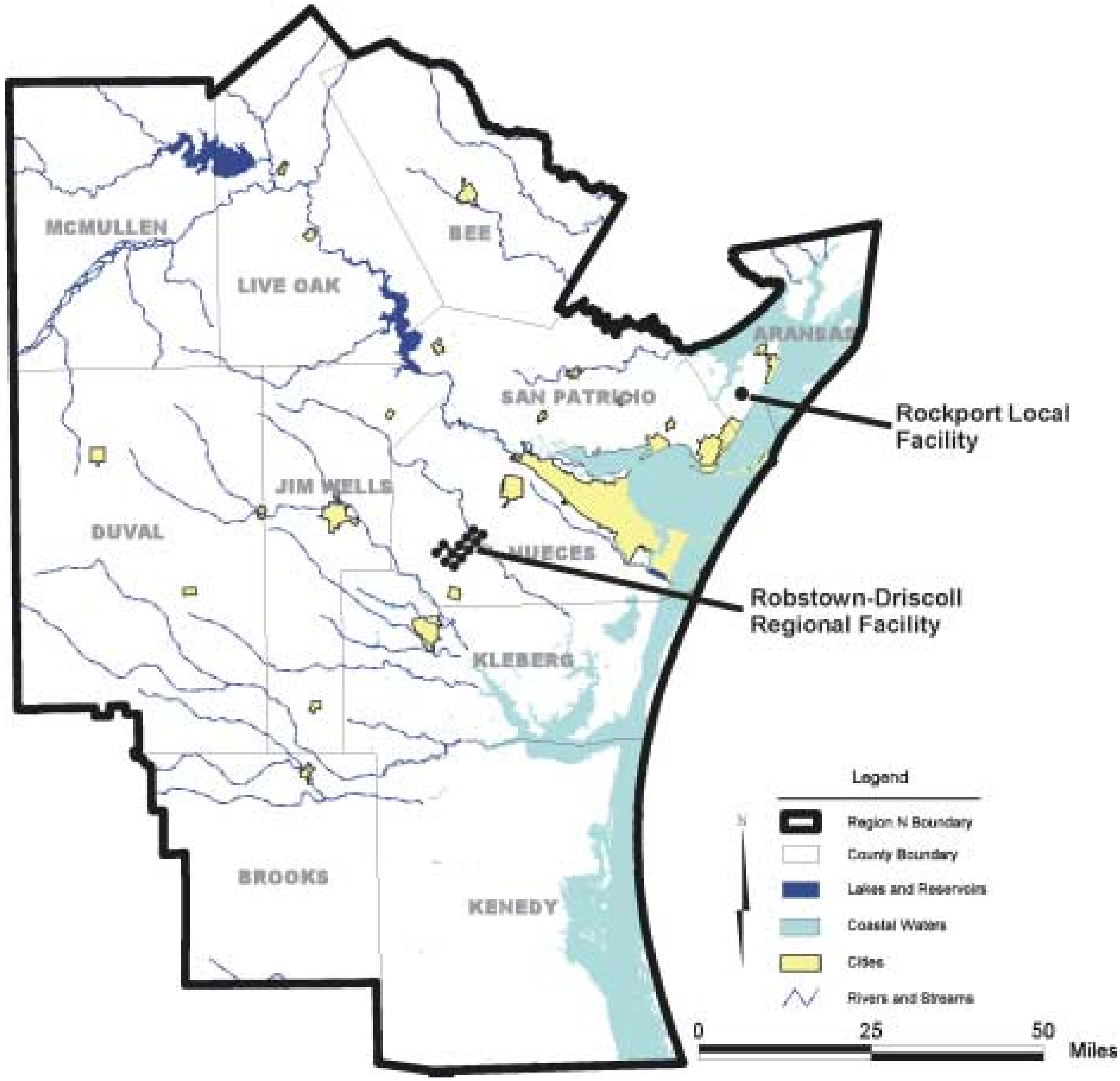

Figure 5A.7-1. Location of ASR Facilities

about 2.1 MGD, as shown in the top graph in Figure 5A.7-2. Using the local aquifer as a reservoir, an ASR system has the potential to delay the construction of a new pipeline for several years. For purposes of this analysis, an ASR facility is sized at 0.5 MGD. It would operate in the injection cycle from November through April, be idle in May, would operate in the recovery

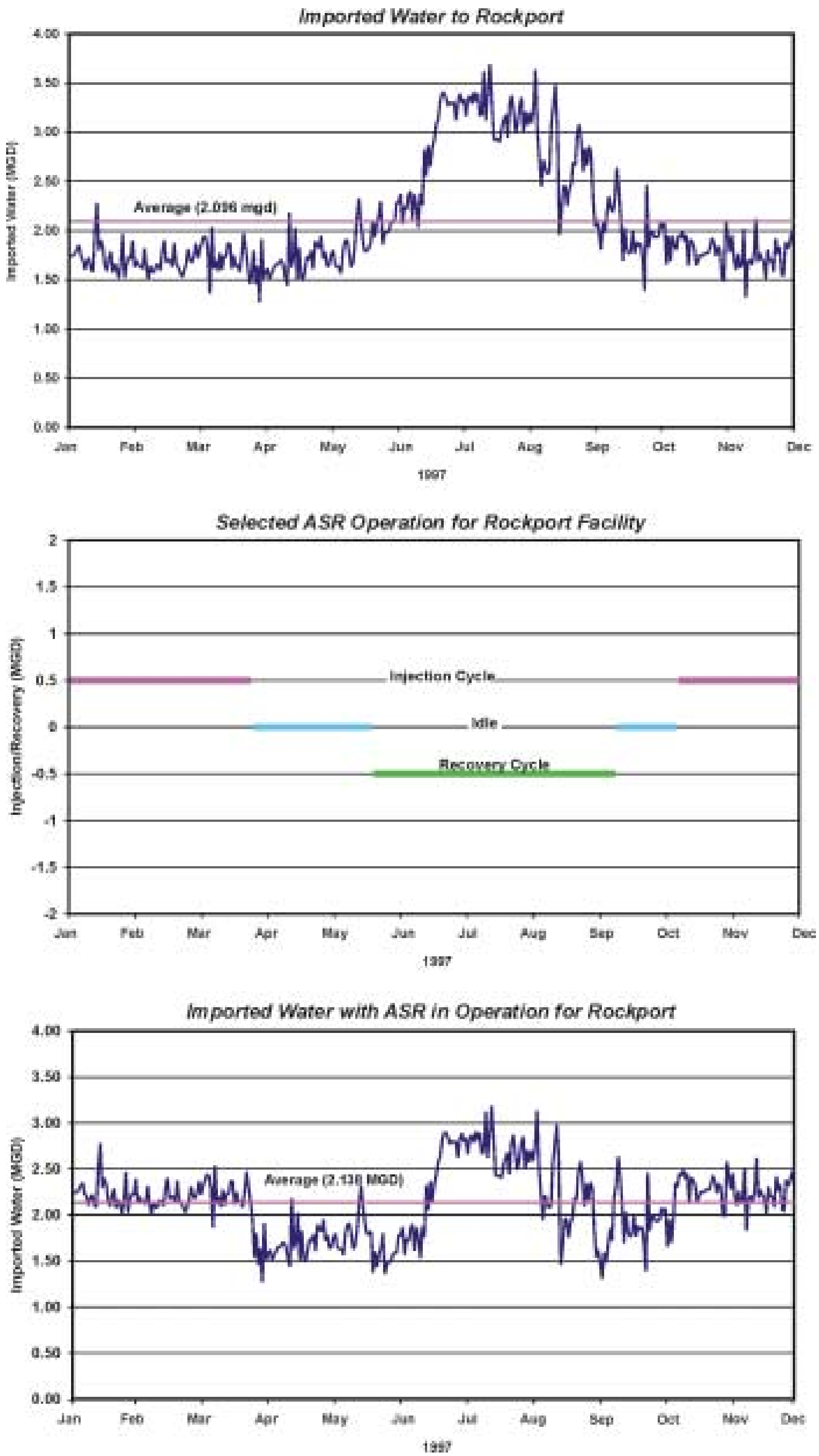

Figure 5A.7-2. Imported Water With and Without ASR

cycle from June through September, and be idle in October, as shown in the middle graph in Figure 5A.7-2. This reduces the summer peak day demand on the pipeline by about 15 percent. A graph showing the demand on the pipeline with the ASR is shown in the bottom graph in Figure 5A.7-2. To size the ASR system for larger demands, the demand pattern for other years would have to be studied along with the projected growth and seasonal demands.

Other benefits of ASR include (1) a reduction in the required capacity of the San Patricio Municipal Water District's water treatment plant and distribution system, and (2) storage of emergency water supplies in case a hurricane or other disaster damaged the water pipeline and transmission system.

5A.7.1.2 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 would come from interruptible water in Lake Texana. Interruptible water refers to that water which is available when Lake Texana's water level is higher than 1 foot below the spillway. It would be transported to the Corpus Christi region by the Lake Texana pipeline, treated by the City of Corpus Christi, and 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. The ASR system was sized to be within the constraints of unappropriated water from Lake Texana, transmission capacity of the Lake Texana pipeline, 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. Considering the high demands on the regional water system during the summer, the period for recharge is limited to an average of 6 months during each October through May period. Thus, a 10-MGD system operating 6 months out of a year could store 5,600 acft of water each year. Considering the unappropriated water supply from Lake Texana during the years 1941 to 1979 and during the injection window (October through May) as an example (Figure 5A.7-3), the full capacity would be available 22 years out of the 39-year period and at 75 percent of capacity during 26 years of the 39-year period.

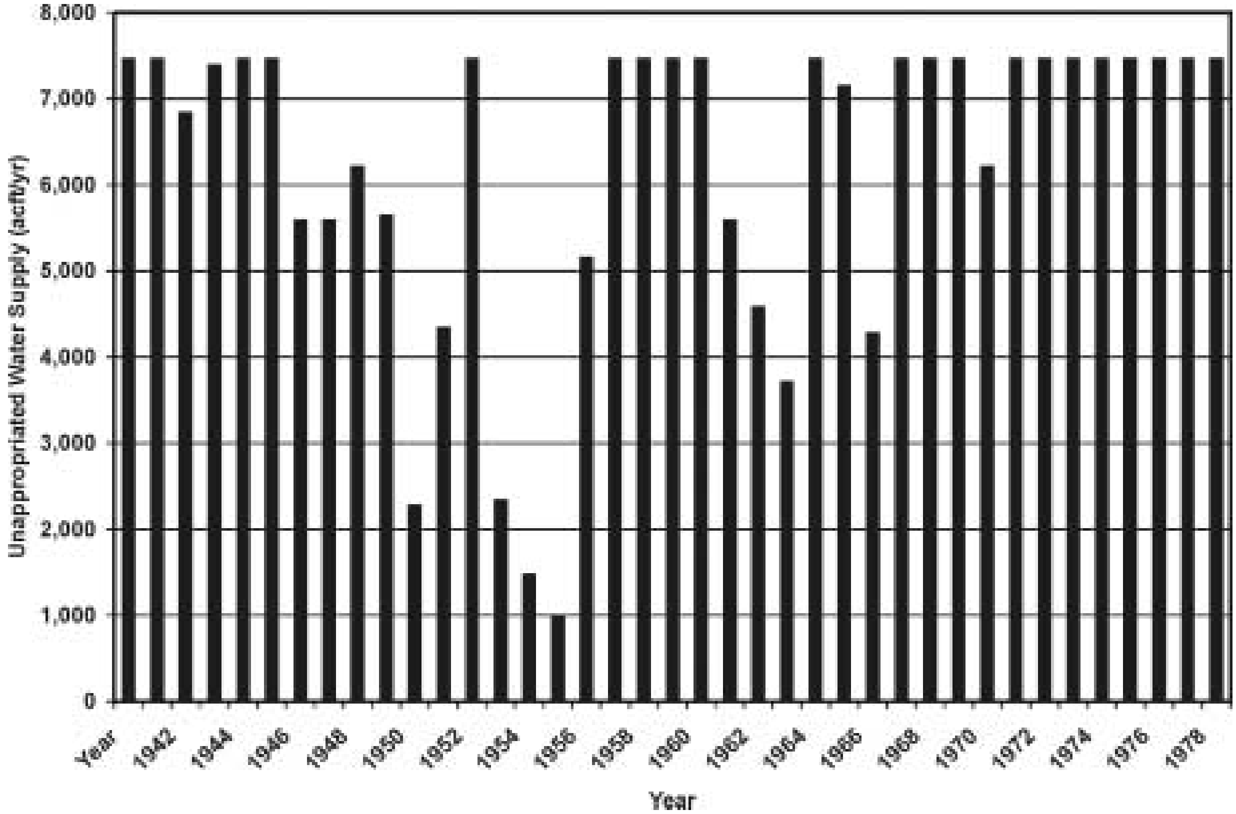

Figure 5A.7-3. Unappropriated Water from Lake Texana (1941 through 1979)

For an example in illustrating the utility of a regional ASR facility, a 10-year period is assumed to have a 7-year relatively wet period followed by a 3-year relatively dry period. Over the first 7 years, the 10-MGD ASR facility is assumed to operate on a recharge cycle 6 months of each year and at an average of 90 percent of capacity. This scenario would place about 35,000 acft of treated surface water into aquifer storage. With continuous recovery operations at 90 percent of capacity during the 3-year drought, about 30,000 acft could be recovered. This injection recovery cycle is shown in Figure 5A.7-4. Considering potential water losses, this scenario would approximately balance the long-term recharge and recovery cycles and provide about 10,000 acft/yr of water supply during a 3-year drought.

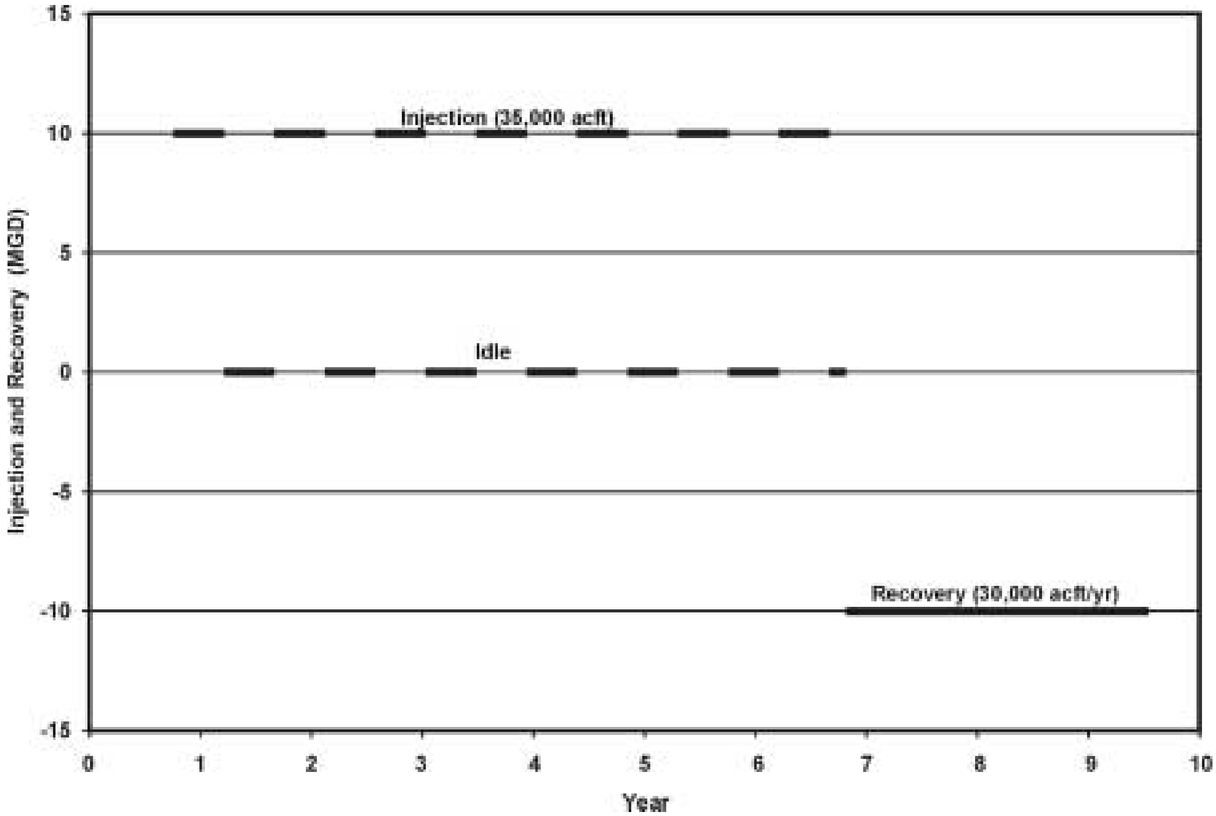

Figure 5A.7-4. Injection and Recovery Cycle for Regional ASR Facility

5A.7.2 Guidelines for an ASR System

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, TNRCC regulations require that the injected water be at least as 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 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.

5A.7.3 Available Yield

An analysis of the feasibility of the two ASR systems consisted of:

1. Studying the hydrogeologic characteristics of the subsurface,
2. Developing a groundwater model of the aquifer system,
3. Selecting a reasonable well capacity for the target water storage zone,
4. Conducting an injection and recovery test with the model,
5. Analyzing compatibility of injected water with native water and aquifer materials,
6. Analyzing the hydrogeologic and chemical data and modeling results, and
7. Comparing the findings with the guidelines.

5A.7.3.1 Rockport Facility

A study of about ten geophysical logs from oil wells in the area identified two potential target zones for storage of fresh groundwater. The upper zone has a sand thickness range between 10 and 70 feet and is 1,000 to 1,200 feet below land surface. The lower zone has a sand thickness range between 50 and nearly 200 feet and is 1,400 to 1,800 feet below land surface. Allowing for a water level of rise of about 50 to 60 feet in the ASR well during the injection cycle, the injection capacity is estimated to be about 70 gpm in the upper zone and 350 gpm (about 0.5 MGD) in the lower zone. The lower zone was selected because of the much greater well capacity at a relatively modest increase in well depth.

A digital groundwater model was developed with 13 layers, covering a 9-mile by 11.6-mile area, and having a 500-foot grid spacing. A test of the annual injection and recovery cycle describe earlier (i.e., 6 months of injection, 1 month idle, 4 months of recovery, and 1 month idle) resulted in a water level rise in the cell with ASR well to be 46 feet at the end of the injection cycle and a decline of 40 feet below starting conditions at the end of the recovery cycle. At a distance of about 1 mile, the maximum water level rise was about 12 feet and maximum decline was about 10 feet. At the end of each 6-month injection cycle, a freshwater bubble around the well would extend about 300 feet from the well. This estimate is based on an average sand thickness of 150 feet and a porosity of 0.30. Model results indicate an insignificant drift of the freshwater bubble and less than 5 percent of the injected water would leak into the layers above and below the target zone.

A preliminary geochemical analysis of the mixing of the native groundwater with the injected surface water indicates that the formation would not become plugged by precipitation from a chemical reaction. Likewise, the injected water is not expected to dislodge clay particles from the few clay beds in the target zone and plug the sands.

Based on the geophysical logs, the salinity of the water in the target zone is 10,000 to 20,000 milligrams per liter. The difference in densities of the injected water and the native water will cause a tendency for the freshwater to rise to the top of the denser, saline water. However, the layering of the formation and the relatively short storage cycle is expected to minimize the problem. Taking this and other factors in consideration, efficiency in recovery of stored water for this scenario is estimated to be about 70 percent during the early years. The efficiency of recovery is likely to be much better during the later years.

Finally, a comparison of the Rockport ASR option with the HDR guidelines is presented in Table 5A.7-1.

As shown in Table 5A.7-1, the guidelines for the Rockport facility are exceeded for the salinity of water in the target storage zone, the water levels in the well, and the depth of the well. The elevated salinity is expected to cause some extra losses of injected water to flush the saline water from the bubble around the well; the high water levels will require the injection of water under pressure and possible losses through unplugged boreholes; and the well depth will cause a relatively high capital cost.

Table 5A.7-1.
Comparison of ASR Options with HDR's Guidelines for ASR Systems

Element	*Guideline*	*Rockport Local Facility*	*Robstown-Driscoll Regional Facility*
Quality of Source Water	Treated to Drinking Water Standards	Treated water from San Patricio MUD	Treated water from Corpus Christi water treatment plant
Availability of Water	More than half the time	More than half the time	More than half the time
Location	Near water treatment and distribution facilities	Near distribution facilities	Near distribution facilities
Productivity of Aquifer, as indicated by typical well capacities	700 gallons per minute (gpm) or more	About 350 gpm	About 750 gpm
Aquifer Conditions	Confined	Confined	Confined
Aquifer Thickness	50 to 200 feet	About 50 feet	Two 100-foot zones
Depth to water-bearing zone	200 to 500 feet	About 1,600 feet	About 500 feet
Aquifer Material	Resistance to dissolution	Mostly sand	Mostly sand
Water Quality	At or near Drinking Water Standards, and Compatibility of injected water and aquifer materials	Very saline, and Appears to be compatible	Slightly saline, and Appears to be compatible
Water Levels	100 - 300 feet below land surface	Near land surface	60 to 100 feet below land surface
Data Availability	Extensive reports and data bases	Geophysical logs	Moderate detail in reports and data bases
Wells	New	New	New
Other groundwater users	Limited	None	Few in potential well field, moderate number within 20 miles

5A.7.3.2 Robstown-Driscoll Regional Facility

As study of many geophysical logs from oil wells in the Robstown/Driscoll area identified an excellent target zone for storage of fresh groundwater. The target zone is two rather massive sand layers in the Goliad Sand formation. The top layer extends from a depth below land surface about 500 to 600 feet, and the second layer extends from about 675 to 775 feet. Allowing for a water level of rise to near land surface, about 60 to 70 feet, in the vicinity of the ASR well during the injection cycle, the injection capacity is estimated to be about 700 gpm.

A digital groundwater model was developed with 4 layers, covering a 15-mile by 15-miles area, and having 500-foot grid spacing. Several tests with the model suggested a layout of five wells spaced 1 mile apart along the west side of U.S. 77 south of Robstown, a second row of four wells 2 miles farther west, and a third row of two wells an additional 2 miles farther west. A test of the 7-year injection cycle with a 6 months continuous injection each year resulted in a water level rise in the cell with ASR well to be 68 feet. At distances of 0.25, 2.0, and 5.0 miles, the water levels rose about 42, 20, and 5 feet, respectively. By the end of the 3-year recovery cycle, the water levels had declined below the starting conditions by about the same amount. After the recovery cycle was completed, the water levels would return to near the starting conditions.

At the end of 7-year injection cycle, a freshwater bubble around each well would extend about 525 feet from the well. This estimate is based on a total sand thickness of 200 feet and a porosity of 0.30. Model results indicate an insignificant drift of the freshwater bubble and less than 2.5 percent of the injected water would leak into the layers above and below the target zone.

A preliminary geochemical analysis of the mixing of the native groundwater with the injected surface water indicates that the formation would not become plugged by precipitation from a chemical reaction. Likewise, the injected water is not expected to dislodge clay particles from the few clay beds in the target zone and plug the sands.

Based on the geophysical logs, the salinity of the water in the target zone is about 1,000 mg/L. Taking this and other factors in consideration, efficiency in recovery of stored water for this scenario is estimated to be about 90 percent during the early years. The efficiency of recovery is likely to be much better during the later years.

Finally, a comparison of the Robstown-Driscoll Regional ASR option with the HDR guidelines is presented in Table 5A.7-1. 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 very manageable.

5A.7.4 Environmental Issues

The ASR options involves the construction of well fields in the Gulf Coast Aquifer System that would support the municipal water utility in the Rockport area and 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.

During construction and development of the Rockport well, considerable quantities of saline water will be produced. This water will have to be contained and properly discharged to body of saltwater.

5A.7.5 Engineering and Costing

Although there are many ASR systems in the nation, there is essentially no experience in the design and operation of ASR facilities in this region. As a result, an approach with three phases is recommended. They are summarized below:

Phase I: Feasibility Assessment and Conceptual Design

- Determine objectives
- Assess supply and demand
- Determine suitability of aquifer
- Prepare conceptual design
- Estimate economics
- Review permit and regulatory issues

Phase II: Field Test and Demonstration:

- Design testing and monitoring
- Design and construct well, facilities, and monitors
- Obtain permits
- Conduct tests
    - Well performance
    - Aquifer response
    - Geochemical
    - Recovery efficiency

- Analyze test data
- Determine economics
- Make recommendations
- Make decisions

Phase III: Place Demonstration ASR Well in Service or Construct ASR well:

- Construct permanent well(s) and surface facilities
- Obtain final permit
- Write operations plan
- Begin operations

The major facilities that will be required for these options include:

- Use of existing water treatment plant for surface water supplies
- Transmission system from the existing distribution system to the ASR wells:
    - Pipeline(s)
    - Pump Station(s)
- ASR Well Field(s):
    - ASR wells
    - Monitoring wells
    - Injection controls
    - Pumps and motors
    - Disinfection

5A.7.5.1 Rockport Local Facility

To put an ASR system in operation for the Rockport area, Phase I has to be completed and Phases II and III initiated and completed. The estimated costs include capital cost as well as project cost for contingencies, engineering, easements, permits, etc. are summarized in Table 5A.7-2. As shown, the annual costs for the 0.5-MGD facility, including debt service for a 30-year loan at 6 percent interest and operation and maintenance costs, including power, are estimated to be $209,500. The annual cost for storing and recovering the water is estimated at $374 per acft. These costs do not include the purchase of treated water.

5A.7.5.2 Robstown-Driscoll Regional Facility

To put an ASR system in operation for the Robstown-Driscoll area, Phase I has to be completed and Phases II and III initiated and completed. The estimated costs include capital cost as well as project cost for contingencies, engineering, easements, permits, etc. are summarized in Table 5A.7-3. As shown, the average annual costs for the 10-MGD facility, including debt service for a 30-year loan at 6 percent interest and operation and maintenance costs, including power, are estimated to be $1,876,000. The average annual cost for storing and recovering the water over a 10-year cycle is estimated at $167 per acft. These costs do not include the purchase of treated water.

Table 5A.7-2.
Cost Estimate Summary
Rockport Local ASR Facility
(Second Quarter 1999 Prices)

Item	*Phase 1 Feasibility & Conceptual Design*	*Phase 2 Field Test and Demonstration*	*Phase 3 Construction & Putting ASR Well in Service*	*Total Costs*
Capital Costs				
Transmission Pipeline (8 in dia., 200 feet)	$0	$0	$8,000	$8,000
Water Treatment (Disinfection) 0.5 MGD	0	0	279,000	279,000
Well Field Costs	0	278,000	382,000	660,000
Other	0	40,000	206,000	246,000
Total Capital Cost	**$0**	**$318,000**	**$875,000**	**$1,193,000**
Engineering, Legal Costs, Contingencies, Studies and Testing/Lab Fees	$20,000	$196,000	$356,000	$572,000
Environmental & Archaeology Studies and Mitigation	0	9,000	30,000	39,000
Land Acquisition and Surveying	0	9,000	41,000	50,000
Interest During Construction (1 year)	0	18,000	51,000	69,000
Total Project Cost	**$20,000**	**$550,000**	**$1,353,000**	**$1,923,000**
Annual Costs				
Debt Service (6 percent for 30 years)	$1,000	$40,000	$98,000	$139,000
Operation and Maintenance				
Intake, Pipeline, Pump Station	0	3,000	4,000	7,000
Water Treatment (Disinfection)	0	0	55,500	55,500
Pumping Energy Costs ($0.06 per kWh)	0	0	8,000	8,000
Total Annual Cost	**$1,000**	**$43,000**	**$165,500**	**$209,500**

Table 5A.7-3.
Cost Estimate Summary
Robstown-Driscoll Regional ASR Facility
(Second Quarter 1999 Prices)

Item	*Phase 1 Feasibility and Conceptual Design*	*Phase 2 Field Test and Demonstration*	*Phase 3 Construction & Putting ASR Well in Service*	*Total Costs*
Capital Costs				
Collection Transmission Pipeline (12.25 miles)	$0	$0	$1,985,000	$1,985,000
Booster Station (642 HP)	0	0	1,406,000	1,406,000
Water Treatment (Disinfection) 10MGD	0	0	2,322,000	2,322,000
Well Field Costs	0	474,000	3,260,000	3,734,000
Total Capital Cost	**$0**	**$474,000**	**$8,973,000**	**$9,447,000**
Engineering, Legal Costs, Contingencies, Studies and Testing/Lab Fees	$40,000	$301,000	$3,042,000	$3,383,000
Environmental & Archaeology Studies and Mitigation	0	1,000	314,000	315,000
Land Acquisition and Surveying	0	1,000	435,000	436,000
Interest During Construction (1 year)	0	26,000	511,000	537,000
Total Project Cost	**$40,000**	**$803,000**	**$13,275,000**	**$14,118,000**
Annual Costs				
Debt Service (6 percent for 30 years)	$3,000	$58,000	$964,000	$1,025,000
Operation and Maintenance				
Intake, Pipeline, Pump Station	0	5,000	964,000	1,025,000
Water Treatment (Disinfection)	0	0	619,000	619,000
Pumping Energy Costs ($0.06 per kWh)	0	0	145,000	145,000
Total Annual Cost	**$3,000**	**$63,000**	**$1,810,000**	**$1,876,000**

5A.7.6 Implementation Issues

Implementation of the ASR concepts includes the following issues:

- Suitable supplies of water for injection;
- Water treatment prior to injection;
- Lack of experience to develop confidence in the ability to inject and recover water from an aquifer. This includes the 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;
- Experience in operating the facilities;
- 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.

5A.7.7 Evaluation Summary

Evaluation summaries of the Rockport Local ASR Facility and the Robstown-Driscoll Regional ASR Facility are provided in Tables 5A.7-4 and 5A.7-5, respectively.

Table 5A.7-4.
Evaluation Summary of the Rockport Local ASR Facility

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	• Firm Yield: Not applicable • Water Quality: Not applicable • Cost: Not applicable
b. Environmental factors	• Minor impacts during construction of wells and pipelines • Cultural resource survey will be needed to avoid impacts to any site
c. State water resources	• No negative impacts
d. Threats to agriculture and natural resources in region	• Negligible

e. Recreational	• None
f. Comparison and consistency equities	• 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

Table 5A.7-5.
Evaluation Summary of the Robstown-Driscoll Regional ASR Facility

Impact Category	***Comment(s)***
a. Quantity, reliability, and cost of treated water	• Firm Yield: Not applicable • Water Quality: Not applicable • Cost: Not applicable
b. Environmental factors	• Minor impacts during construction of wells and pipelines • Cultural resource survey will be needed to avoid impacts to any site
c. State water resources	• No negative impacts
d. Threats to agriculture and natural resources in region	• Negligible
e. Recreational	• None
f. Comparison and consistency equities	• 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

5A.8 Modify Existing Reservoir Operating Policy

5A.8.1 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. A recent volumetric survey performed by the TWDB reported the capacity of Choke Canyon Reservoir to be 695,262 acft. Today, the City operates these three reservoirs (Calallen, Lake Corpus Christi, and Choke Canyon Reservoir) 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 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 5A.8-1. 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 5A.8-1
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	29[1] 14[2]	—
Lake Corpus Christi	239,473	25.9%	2.85	—	—	4%
River Reach between Lake Corpus Christi and Calallen	—	—	—	35	7[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 maximum percentage lost.
[2] Represents average percentage lost.

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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 5A.8-1, losses from Choke Canyon Reservoir downstream to, and including losses from, Lake Corpus Christi can be as high as 29 percent and average about 14 percent, while losses downstream of Lake Corpus Christi to the Calallen pool average about 7 percent. In addition, under a 1995 order from the TNRCC,[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. 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 TNRCC 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
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.

[6] Texas Natural Resource Conservation Commission (TNRCC), 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] TNRCC, Certificate of Adjudication No. 21-3214, Held by the City of Corpus Christi, et al.

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 new 1995 Agreed Order are as follows:

1. The water passed through from the CCR/LCC System to satisfy the TNRCC 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 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

[8] Ibid.

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.

5A.8.2 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. A summary of the firm yield of the system in 2010 and 2050, assuming Phase IV operations and the 1995 Agreed Order, and computed by the NUBAY model[9] is provided in Table 5A.8-2.

Table 5A.8-2.
CCR/LCC System Firm Yields(Phase IV Policy)

Reservoir Sedimentation Year	*CCR/LCC System Firm Yield (acft/yr)*
2010	180,000
2050	171,800

The reservoir system yields tabulated in Table 5A.8-2 are essentially the maximum yields available under the City's current reservoir operating policies and existing schedule governing

[9] 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 2050 system storage capacities. The model has been developed and updated through a series of projects since 1991 and currently operates on a 1934 to 1997 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; and HDR, "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999).

freshwater pass-throughs to the bay and estuary. Since the decision was made in the 1970's 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.

5A.8.3 CCR/LCC System Yield Recovery

5A.8.3.1 Summary of Ecological Studies of the Nueces Estuary

Beginning with the USBR's Environmental Impact Statement (EIS) for the Choke Canyon project,[10] 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),[11,12] the Texas Department of Water Resources (predecessor agency to the Texas Water Development Board),[13] Espey, Huston and Associates,[14] and unpublished research by scientists at the 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 TNRCC) to

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

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.[15] 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[16,17] 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[18] 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 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 (see Figure 5A.8-1). While the demonstration project term expired in September 2000, and the Nueces Overflow Channel was subsequently filled in, the project's Concluding Report[19] 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. It

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15 TNRCC, Certificate of Adjudication No. 21-3214, held by the City of Corpus Christi, et al.
16 HDR, et al., "Nueces Estuary Regional Wastewater Planning Study, Phase 1," City of Corpus Christi, et al., November 1991.
17 HDR, et al., "Nueces Estuary Regional Wastewater Planning Study, Phase 2," City of Corpus Christi, et al., March 1993.
18 Ibid.
19 USBR, "Rincon Bayou Demonstration Project, Concluding Report," Volumes I and II, U.S. Dept. of the Interior, et al., September 2000.

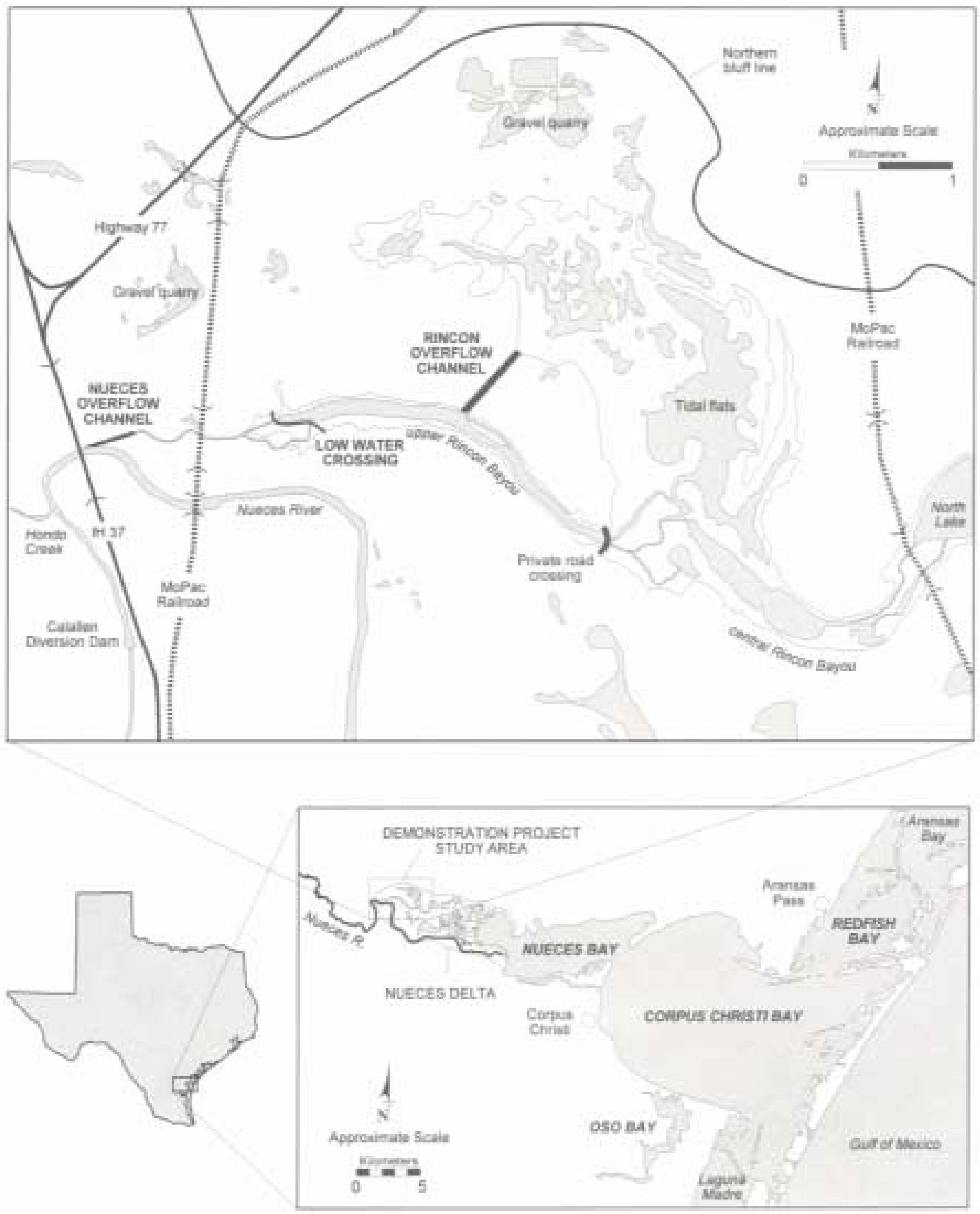

Figure 5A.8-1. Location of the Nueces Delta (below) and of the Rincon Bayou Demonstration Project Features (above)

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

recommends that the project be restored on a permanent basis and modified in certain areas to improve the hydrologic function.

The Allison Wastewater Diversion Project is ongoing, with one year of baseline data having been collected prior to the initiation of the effluent diversions, and now two years of post diversion data having been collected (see Figure 5A.8-2). The City of Corpus Christi is maintaining an extensive monitoring program designed to assess the benefits of the two million gallons per day (2 MGD) of effluent being discharged into the wetlands of the South Lake area of the Nueces Delta.

5A.8.3.2 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 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 5A.8-3.

Table 5A.8-3.
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
Notes: Diversion volumes include future expected ww 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 5A.8-3 and 5A.8-4 show the location of the WWTP's 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 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 5A.8-4 and Figure 5A.8-5, 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.

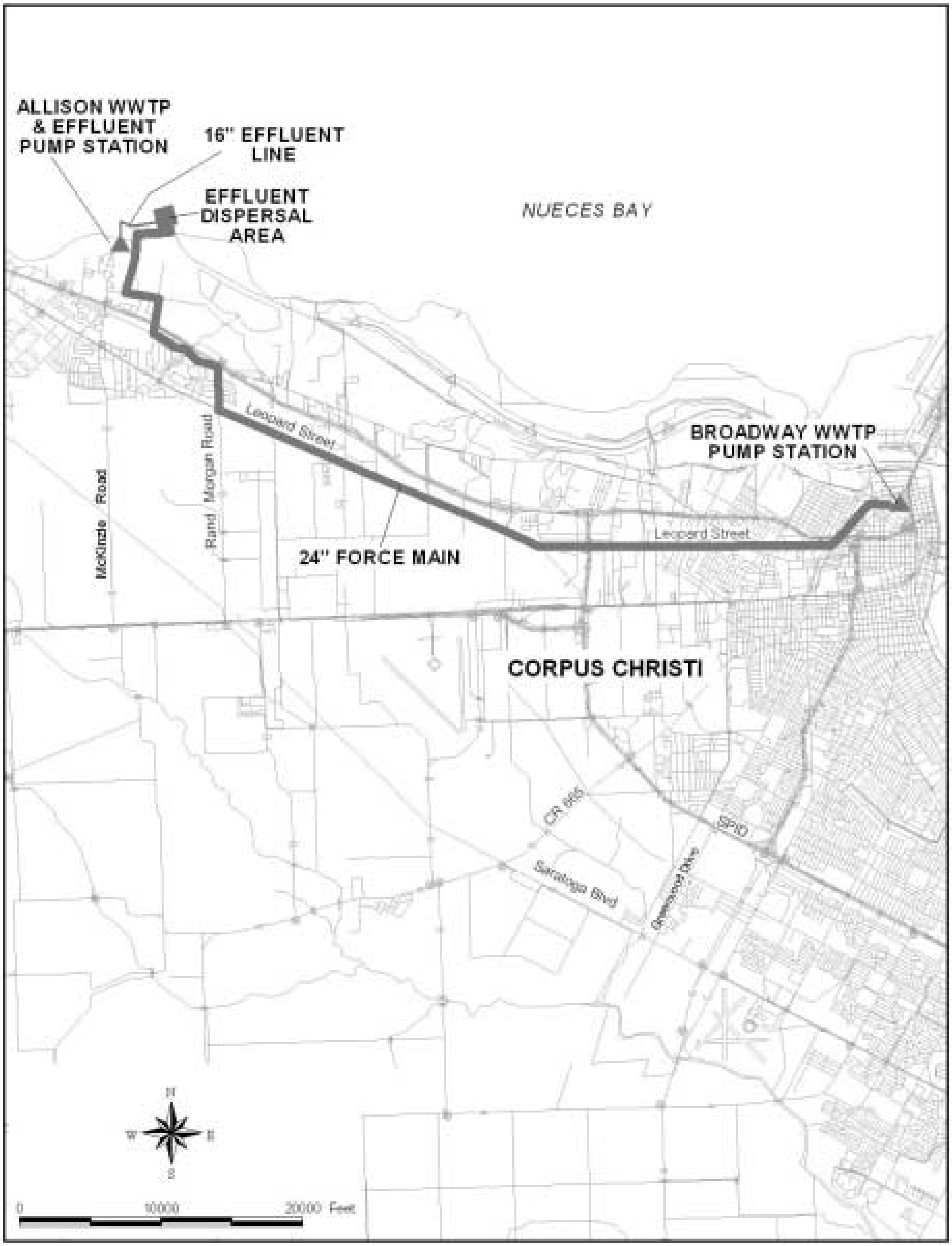

Figure 5A.8-3. Effluent Diversion Scenario 2

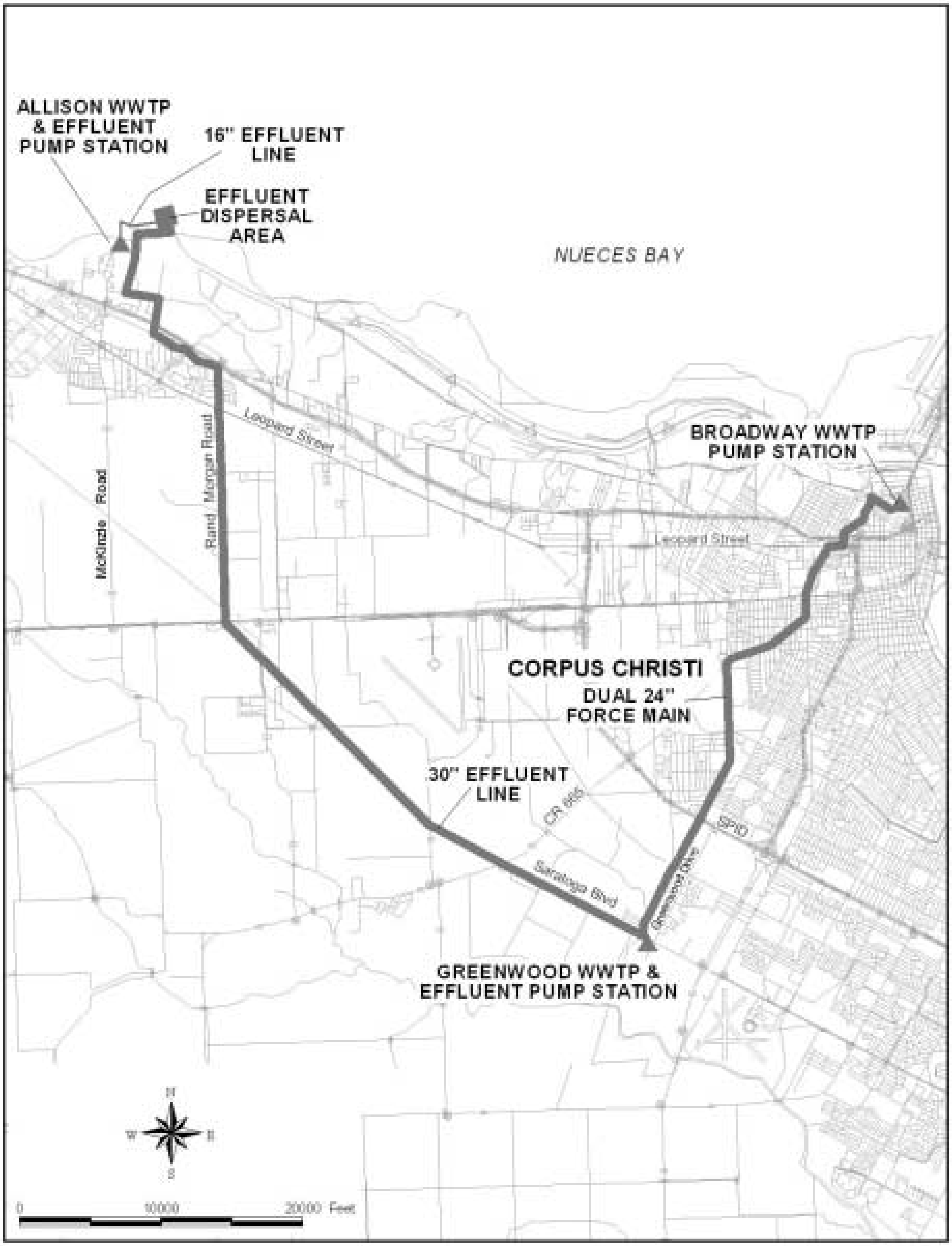

Figure 5A.8-4. Effluent Diversion Scenario 3

Table 5A.8-4.
Incremental Firm Yield Increases for
Alternative CCR/LCC Operating Scenarios (acft/yr)

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

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

5A.8.4 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.

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.[20,21] 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 1995 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.[22,23] 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.

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.[24] 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 ROW's which are located in urban areas. Less than 30 acres of delta wetlands and brushy uplands would be affected.

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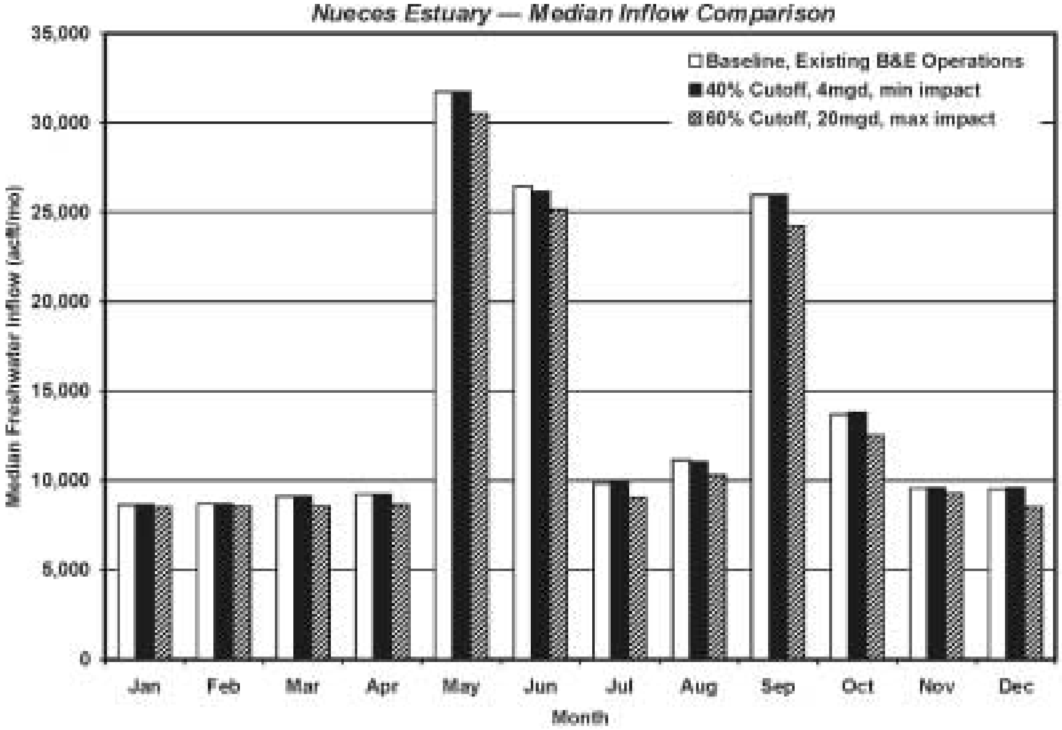
[20] HDR et al., Op. Cit., November 1991.
[21] HDR et al., Op. Cit., March 1993.
[22] Whitledge, T.E. and D.A. Stockwell, "The Effects of Mandated Freshwater Releases on the Nutrient and Pigment Environment in Nueces Bay and Rincon Delta: 1990-1994." In: Water for Texas, Research Leads the Way (Jensen, R. ed.). Proceedings of the 24th Water for Texas Conference, 1995.
[23] 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.
[24] Ibid.

Use of these pipelines to transport effluent from Broadway and Greenwood WWTP's 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 5A.8-6 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). Figure 5A.8-7 shows the potential changes in flow to the Upper Nueces Delta and Bay in particular. The existing 1995 Agreed Order regarding freshwater inflows to the Nueces Estuary targets activities in upper Nueces Bay and Delta. Each of the graphs in these two figures shows three scenarios: the baseline (existing 1995 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 5A.8-7, 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



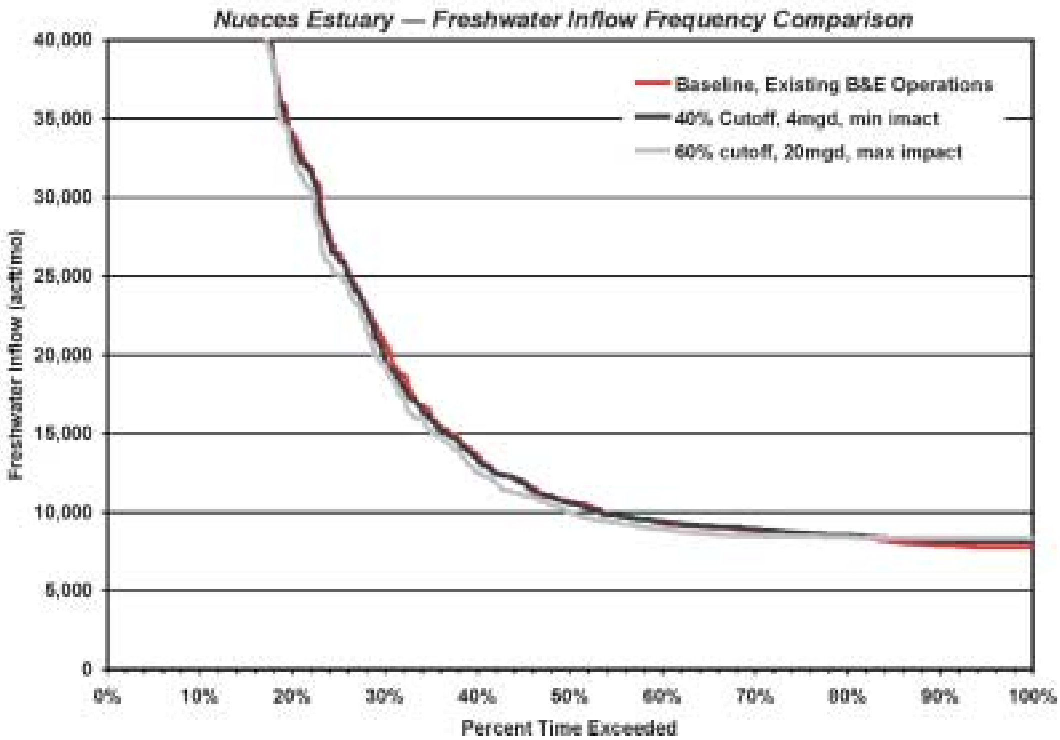
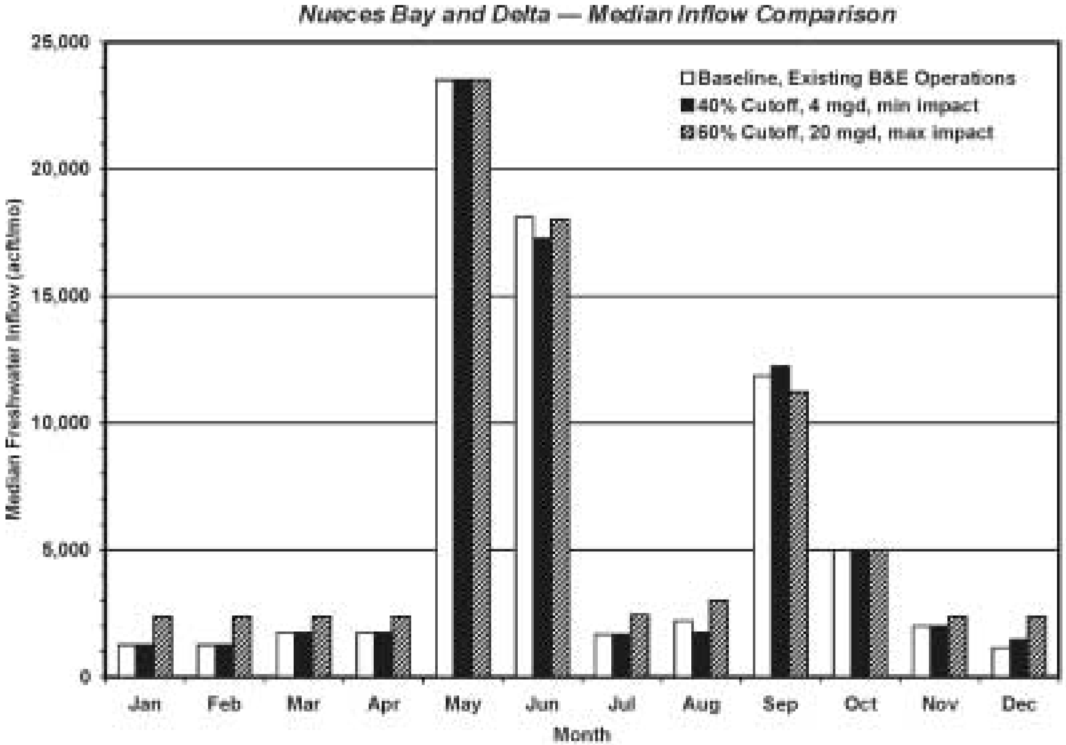


Figure 5A.8-6. Impacts to Freshwater Inflows to Nueces Estuary



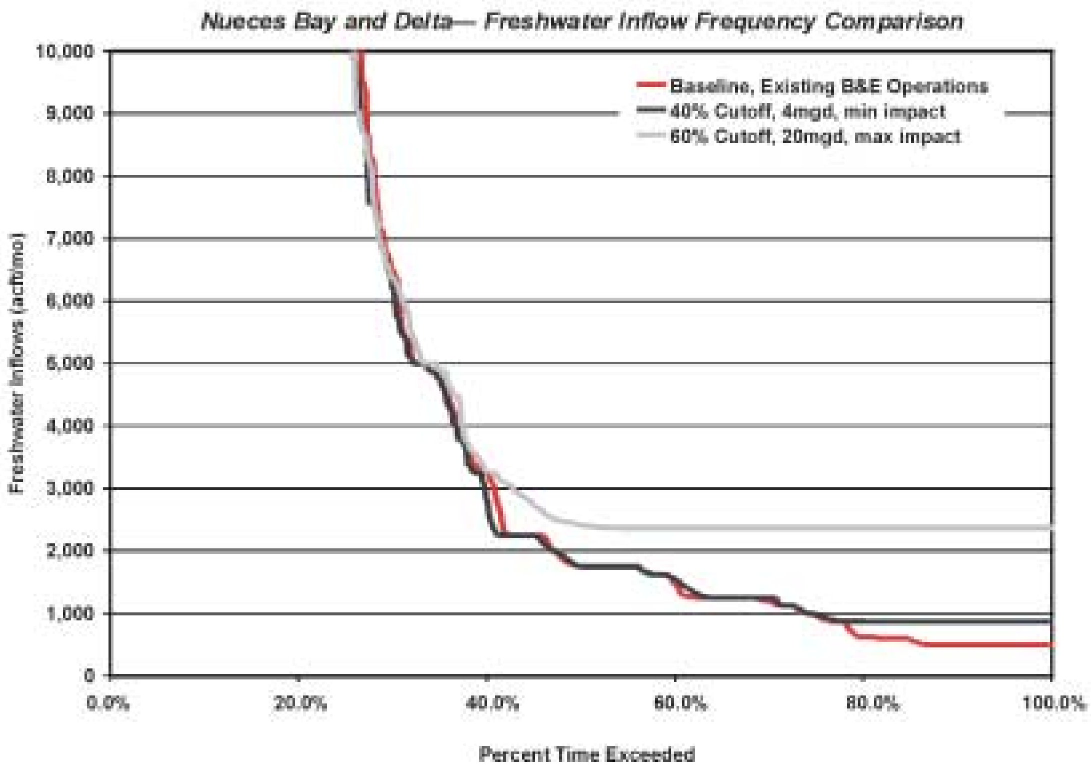


Figure 5A.8-7. Impacts to Freshwater Inflows to Nueces Bay and Delta

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 5A.8-7), 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 5A.8-6) 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 1995 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 1995 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[25] (see Section 5A.8.3.1) 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 USBR study documented significant degrees of increased ecological function returning to the Nueces Delta and Estuary as a result of the Demonstration Project, and any projects involving diversions of freshwater to the delta (i.e., the effluent diversion projects analyzed and discussed herein) should consider re-opening the Nueces and Rincon overflow channels as a part of the overall plan to enhance the Nueces Estuary ecosystem.

5A.8.5 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. Table 5A.8-5 provides a cost breakdown for Scenario 1.

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

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 5A.8-6 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.

Table 5A.8-7 provides a cost breakdown for Scenario 3.

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.

5A.8.6 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 TNRCC 1995 Agreed Order regarding freshwater pass-throughs, as currently written, does not allow operations like those presented herein, the potential amendment of the TNRCC permit would have to be considered before implementing such a project.

Table 5A.8-5.
Cost Estimate Summary for
Effluent Diversion Scenario 1[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Effluent Force Main	$0
Effluent Pump Station	0
Total Capital Costs	**$0**
Engineering, Legal Costs and Contingencies	0
Environmental & Archaeology Studies and Mitigation	0
Land Acquisition and Surveying	0
Interest During Construction (1 years)	0
Total Project Cost	**$ (See Note 2)**
Annual Costs	
Debt Service (6 percent for 30 years)	$ (See Note 2)
Operation and Maintenance**:**	
Effluent Force Main and Pump Station	13,000
Pumping Energy Costs	13,000
Total Annual Cost	**$26,000**
Available Project Yield (acft/yr)	**7,100 to 10,700 [3]**
Annual Cost of Water ($ per acft)	**$3.66 to $2.43 [3]**
Annual Cost of Water ($ 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%.

Table 5A.8-6.
Cost Estimate Summary for
Effluent Diversion Scenario 2[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Pipelines (14.4 miles)	$13,904,000
Pump Stations	2,570,000
Total Capital Costs	**$16,474,000**
Engineering, Legal Costs and Contingencies	4,942,000
Environmental & Archaeology Studies and Mitigation	325,000
Land Acquisition and Surveying	207,000
Interest During Construction (3 years)	658,000
Total Project Cost	**$22,606,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$1,642,000
Operation and Maintenance**:**	
Pipelines and Pump Stations	203,000
Pumping Energy Costs	112,000
Total Annual Cost	**$1,957,000**
Available Project Yield (acft/yr)	**7,100 to 11,400**
Annual Cost of Water ($ per acft)	**$275 to $172** [3]
Annual Cost of Water ($ per 1,000 gallons)	**$0.85 to $0.53** [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 5A.8-7.
Cost Estimate Summary for
Effluent Diversion Scenario 3[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Pipelines (20.6 miles)	$15,304,000
Pump Stations	5,770,000
Total Capital Costs	**$21,074,000**
Engineering, Legal Costs and Contingencies	6,322,000
Environmental & Archaeology Studies and Mitigation	507,000
Land Acquisition and Surveying	326,000
Interest During Construction (4 years)	1,129,000
Total Project Cost	**$29,358,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$2,133,000
Operation and Maintenance:	
Pipelines and Pump Stations	297,000
Pumping Energy Costs	363,000
Total Annual Cost	**$2,793,000**
Available Project Yield (acft/yr)	**9,100 to 13,100**
Annual Cost of Water ($ per acft)	**$307 to $213 [3]**
Annual Cost of Water ($ per 1,000 gallons)	**$0.94 to $0.65 [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%.

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 WWTP's 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 TNRCC 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 TNRCC.
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.

5A.8.7 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 5A.8-8.

Table 5A.8-8.
Evaluation Summary of Modifications to Existing Reservoir Operating Policy

Impact Category	***Comment(s)***
a. Quantity, reliability, and cost of treated water	• Firm yield: 7,100 to 13,100 acft/yr (in 2010) • Generally low cost; between \$3 to \$307 per acft
b. Environmental factors	• Positive impacts to biological activity in the Nueces Estuary & Upper Nueces Delta • Cultural Resource Survey will be needed to avoid any significant sites
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. Comparison and consistency equities	• 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

5A.9 Pipeline between Choke Canyon Reservoir and Lake Corpus Christi

5A.9.1 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 as high as 29.7 percent and average about 14 percent.

Since the majority of the surface water supply for the City of Corpus Christi and its customers from the CCR/LCC System 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. Furthermore, if such a pipeline could be used to pump water from LCC when it is near full to CCR when it has available storage, the system could spill less water from LCC and potentially increase system yield.

Past studies[2] 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[3,4,5] 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 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. This alternative evaluates a pipeline project between CCR and LCC that could be implemented to reduce losses and increase yield of the CCR/LCC System. A two-way operation providing the ability to pump to and from each reservoir is compared against a one-way operation that only delivers water from CCR to LCC.

[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] Ibid.
[3] HDR, "Diversion from Nueces River to Choke Canyon Reservoir," Memo to James Dodson, September 8, 1997.
[4] HDR, Op. Cit., May 1991.
[5] Raushchuder, D.G., "Potential for Development of Additional Water Supply from the Nueces River between Simmons and Calallen Diversion Dam," 1985.

The pipeline route for implementing the pipeline between CCR and LCC is shown in Figure 5A.9-1. Going from CCR to LCC, the route follows a southeasterly direction from CCR, crosses the Nueces River, and terminates on the west side of LCC. In addition to the pipeline, the two-way operation will require an intake and outlet structure at each reservoir. The one-way operation will require an intake at CCR and an outlet structure at LCC.

5A.9.2 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 between the reservoirs that will provide the greatest yield increase at reasonable unit costs.

Simulations were made for the historical period from 1934 to 1997 using the City of Corpus Christi's Phase IV Operations Plan, the 1995 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 2050 reservoir sediment conditions. For modeling purposes, it was assumed that the same channel loss and reservoir seepage functions would apply to the water released into the stream system. The operating guidelines for both reservoirs and the pipeline are detailed below.

The reservoir and pipeline operations at CCR pertain to the delivery of water from CCR to LCC. CCR and the pipeline were operated in the following manner:

1) A minimum 2,000 acft/month was released from CCR to the Frio and Nueces Rivers, as specified in the existing permit;
2) When required, water supply releases at CCR larger than 2,000 acft in any month, are delivered through the pipeline between the two reservoirs up to the capacity of the pipeline; and
3) When monthly releases at CCR are larger than 2,000 acft per month plus 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 fully satisfy instream flow requirements in the reach between the two reservoirs. Additional water is also passed through CCR to satisfy senior water rights located on the reach between CCR and LCC.

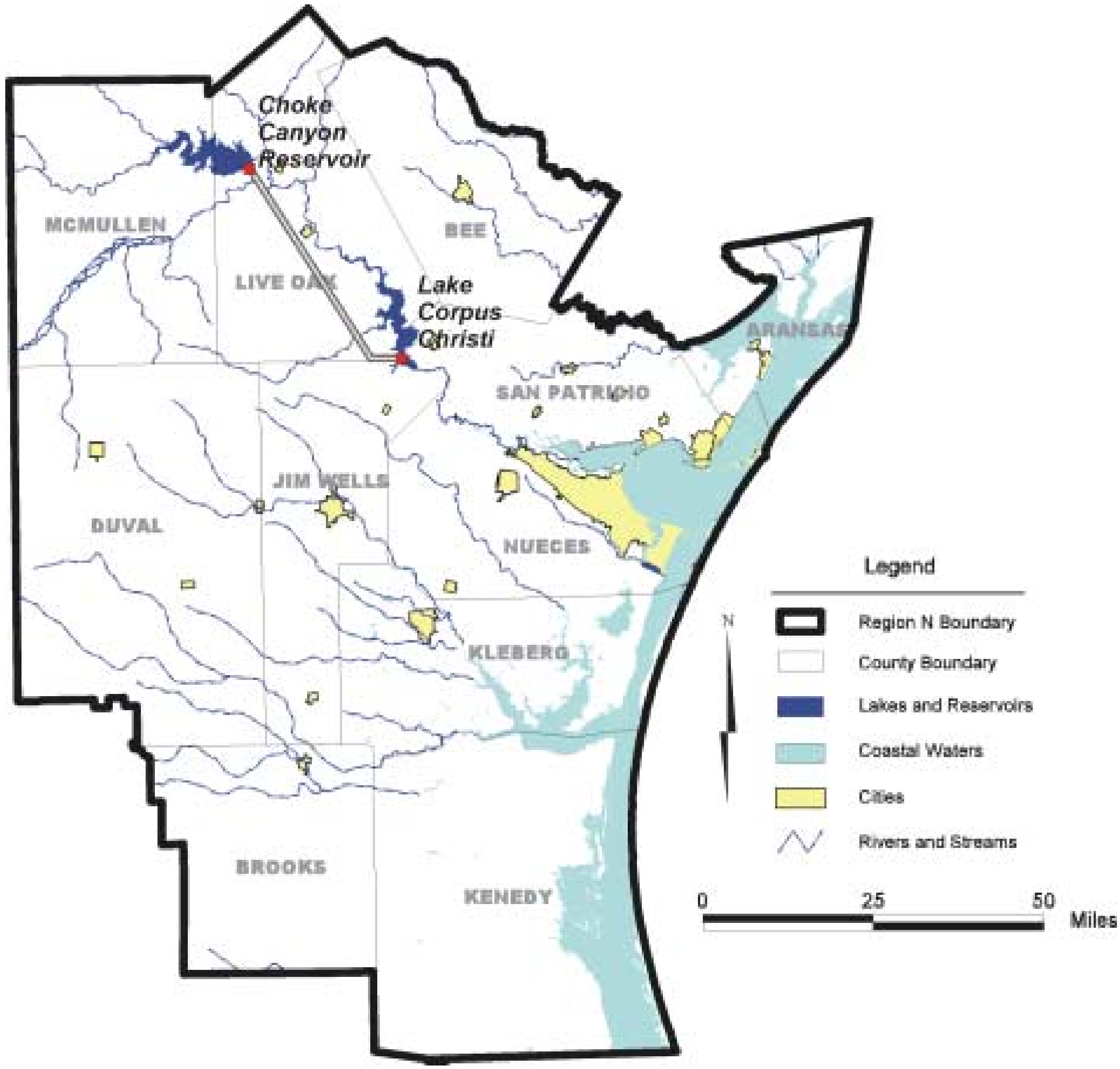


Figure 5A.9-1. Pipeline Between Choke Canyon Reservoir and Lake Corpus Christi

Pass-throughs needed to meet the full diversion rights of these senior rights in excess of the 2,000-acft/month minimum release are added to releases to the river.

For the two-way pipeline option, two reservoir level triggers control the pumpage of water from LCC. The first trigger elevation specifies the minimum water surface elevation in LCC at which pumpage from LCC can commence. If LCC is greater than or equal to the first trigger elevation, pumpage from LCC is possible. The second trigger level sets the maximum water surface elevation in CCR for pumpage to occur to insure storage space is available in CCR. If the water surface elevation in CCR is at or above the second trigger, no pumpage will occur. The second trigger helps to avoid unnecessary spills from CCR. As a further safeguard against spills at CCR resulting from pumpage from LCC, the amount of pumpage upstream to CCR is equal to the lesser of the maximum pipeline capacity or the available storage in CCR. One-way operations of the pipeline do not require the LCC operation triggers since the pipeline will only operate from CCR to LCC.

The resulting system operating with the CCR/LCC System and the two-way pipeline followed these three criteria:

1) If LCC is at or above the first trigger level and CCR is below the second trigger level, the two-way pipeline is operated in the upstream direction, pumping water stored in LCC back to CCR;
2) If LCC is below the first trigger level but above the system operations target elevation (i.e., 74 ft-msl for Phase IV policy operations), the two-way pipeline is not used; and
3) If LCC is below the systems operations target elevation and CCR is above the system operations target elevation (i.e., 155 ft-msl for Phase IV policy operations), water is released from CCR to maintain water surface elevations in LCC, with the two-way pipeline being used up to its maximum capacity for releases from CCR greater than 2,000 acft/month.

In order to find the optimum reservoir levels and delivery rates that provide the greatest yield at the lowest cost, a matrix of simulations were performed for the two-way operations. For six different pipeline delivery rates ranging from 150 to 400 cfs (300 to 800 acft/day), ten different trigger levels in LCC and three different trigger levels in CCR were evaluated. The trigger levels in LCC ranged from elevation 80.0 to elevation 93.0 and the three reservoir levels analyzed in CCR were elevations 220.4, 220.0, and 219.5. For each delivery rate, the optimum reservoir levels were found by determining which scenario produced the greatest yield at the lowest cost per acre-foot of increased yield. The optimum delivery rate was determined by comparing the optimum reservoir operation scenarios for each delivery rate. The costs used to evaluate each scenario considered both the debt service for capital costs necessary to build the pipeline facilities and the annual O&M and power cost for pumping the water. The transmission facilities and pipeline were sized for each delivery rate to keep the average velocity in the pipeline near 5 feet per second (fps). Table 5A.9-1 summarizes the results of the two-way pipeline yield analyses. As shown in the table, the 250-cfs delivery rate results in the lowest cost per acre-foot of yield. A detailed cost summary for the 250-cfs delivery rate project is given in Section 5A.9.4.

Table 5A.9-1.
Summary of Yield and Costs for
Two-way Pipeline Linking Choke Canyon Reservoir and
Lake Corpus Christi for 2010 Sediment Conditions

Delivery Rate (cfs)	*Pipe Diameter[1] (inches)*	*LCC Trigger Level (ft-msl)*	*CCR Trigger Level (ft-msl)*	*Firm Yield (acft/yr)*	*2010 Yield Increase[2] (acft/yr)*	*Annual Cost ($ Million)*	*Cost per Acre-Foot ($/acft/yr)*	*Incremental Cost per Acre-Foot ($/acft/yr)*
150	78	93.0	119.5	197,600	17,600	7.66	$435	—
200	90	93.0	119.5	205,400	25,400	9.14	$360	+190
250	90	93.0	119.5	209,100	29,100	9.88	$340	+200
300	96	90.0	120.0	211,200	31,200	12.06	$387	+1,038
350	102	93.0	119.5	213,400	33,400	12.96	$388	+409
400	108	90.0	120.0	213,700	33, 700	14.86	$441	+6,333

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 1995 Agreed Order equals 180,000 acft/yr.

Another point of interest in Table 5A.9-1 is the trigger level in LCC for pumping water back to CCR. The LCC trigger level is 93.0 ft-msl for a majority of the optimum scenarios. By plotting the cost per acre-foot versus LCC trigger level for both the 200-cfs and 250-cfs delivery rates as shown in Figure 5A.9-2, it is apparent that as the LCC trigger level approaches 94.0 ft-msl, the top of the conservation pool, the lower the cost per acre-foot of yield. In other words, the fewer times water is pumped from LCC to CCR, the lower the cost per acre-foot of yield. This suggests that a one-way pipeline operating from CCR to LCC may be more cost-effective than a two-way operation.

Past studies[6,7] indicated that a two-way operation would potentially be more cost effective than a one-way operation since there were times during the critical drought when spills

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

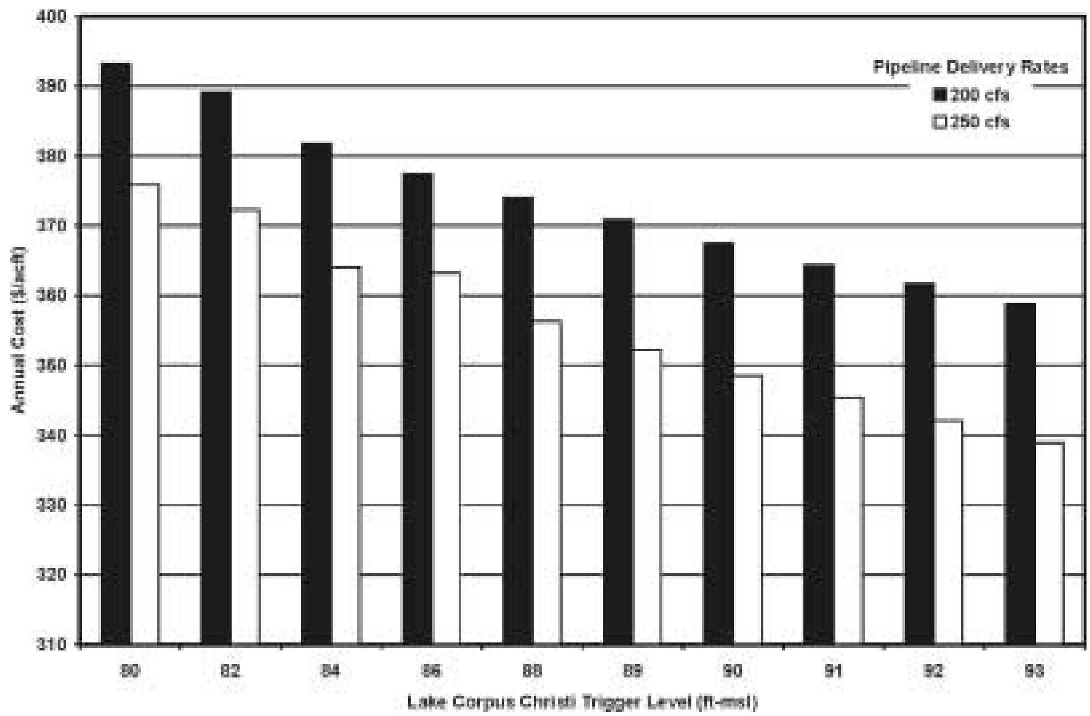


Figure 5A.9-2. Two-way Pipeline Annual Cost versus Lake Corpus Christi Trigger Level

from LCC could enhance system yield by being pumped back to CCR. In these previous studies the critical drought was during the 1960s. In the new critical drought of the 1990s, LCC never spills when there is available storage in the CCR. Therefore, the facilities to pump water from LCC to CCR provide no enhancement to the system yield. Table 5A.9-2 shows yields and costs for a one-way pipeline for the same delivery rates used in the two-way pipeline analysis.

The results of the one-way pipeline analysis show that the one-way operations result in the same increase in yield as the two-way pipeline but costs less per acre-foot of yield. As with the two-way operation, the 250-cfs delivery rate results in the least cost per acre-foot of yield. A detailed cost analyses for the one-way pipeline for the 250-cfs delivery rate is presented in Section 5A.9.4.

Table 5A.9-3 shows the yields for both 2010 and 2050 reservoir sediment conditions for each delivery rate, as well as the unit cost of water for 2050 conditions for the one-way pipeline. The increase in yield due to the pipeline in 2050 is greater than experienced in 2010. Therefore as the reservoirs fill with sediment, the benefit of the pipeline increases. Comparison of unit cost for 2050 sediment conditions shows that the delivery rate of 250 cfs produces the optimum unit cost of water for the one-way pipeline.

Table 5A.9-2.
Summary of Yield and Costs for
One-way Pipeline Linking Choke Canyon Reservoir and
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[3] ($ Million)	Cost per Acre-Foot ($/acft/yr)	Incremental Cost per Acre-Foot ($/acft/yr)
150	66	197,600	17,600	$6.75	$383	—
200	84	205,400	25,400	$7.37	$290	+79
250	90	209,100	29,100	$7.94	$273	+154
300	96	211,200	31,200	$9.24	$296	+619
350	108	213,400	33,400	$11.35	$339	+945
400	114	213,700	33,700	$11.63	$345	+1,033

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 1995 Agreed Order equals 180,000 acft/yr.

Table 5A.9-3.
Summary of Yield Increases for
both 2010 and 2050 Sediment Conditions and
2050 Unit Costs for One-way Pipeline

Delivery Rate (cfs)	2010		2050		Approximate 2050 One-way Pipeline Unit Cost ($ per acft/yr)	Incremental Unit Costs ($ 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	180,000	—	171,800	—	—	—
150	197,600	17,600	192,000	20,200	$334	—
200	205,400	25,400	199,500	27,700	$266	+82
250	209,100	29,100	202,500	30,700	$259	+190
300	211,200	31,200	205,200	33,400	$276	+481
350	213,400	33,400	206,900	35,100	$323	+1,223
400	213,700	33, 700	207,400	35,600	$326	+620

1 Yield calculated under phase IV operations policy and the 1995 Agreed Order.

5A.9.3 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;[8] 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 pipeline is intended to transfer water without using the bed and banks of the Nueces River. The construction of a pipeline from CCR to LCC would result in soil and vegetation disturbance within the approximately 630-acre pipeline construction corridor. Longer-term terrestrial impacts would be confined to the 210-acre maintained right-of-way. In Like Oak County, the Jaguarundi (*Felis yagouaroundi*), listed as endangered, has been reported to occur within the proposed pipeline corridor and habitat for several state-protected species may be present. Temporarily wet areas or drainages in uplands and in wetland portions of the pipeline corridor 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 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 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 50 percent as shown in the top plot of

[8] Ibid.

Figure 5A.9-3 for the 250-cfs delivery option. The bottom plot of Figure 5A.9-3 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 50 percent of the time without the project and 41 percent with the project. In contrast to the reduction in river flows at Three Rivers, river flows below LCC at Mathis and estuarine inflows would be increased. Both increases in flow result from the additional yield in the CCR/LCC System being delivered to Corpus Christi. Figures 5A.9-4 and 5A.9-5 display the monthly median streamflows and the 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 5A.9-6 displays plots of water surface elevation versus time for each reservoir and a system storage frequency comparison. Both plots indicate that reservoir levels increase with the one-way pipeline and are maximized with two-way operations.

5A.9.4 Engineering and Costing

Table 5A.9-4 provides detailed summaries of the estimated costs to implement either a two-way pipeline or a one-way pipeline between CCR and LCC. The major facilities necessary to implement the two-way project are intakes and outlet structures at both CCR and LCC and the transmission pipeline between the two reservoirs. For the 250-cfs delivery rate, the one-way pipeline operation is the most cost-effective, with annual costs equal to $259 per acft. The one-way project requires the same transmission pipeline but only needs an intake at CCR and an outfall in LCC. The removal of the intake at LCC and the outfall in CCR reduces the total project cost by almost $18 million after considering engineering, legal, environmental, land acquisition, and interest during construction costs. This results in a $1.9 million reduction in total annual cost. Therefore, the annual cost per acre-foot is reduced from $322 per acft with the two-way pipeline to $259 per acft with the one-way pipeline. Costs of the one-way pipeline could be further reduced if studies showed it feasible to shorten the pipeline length and discharge the water at a location further upstream in LCC.

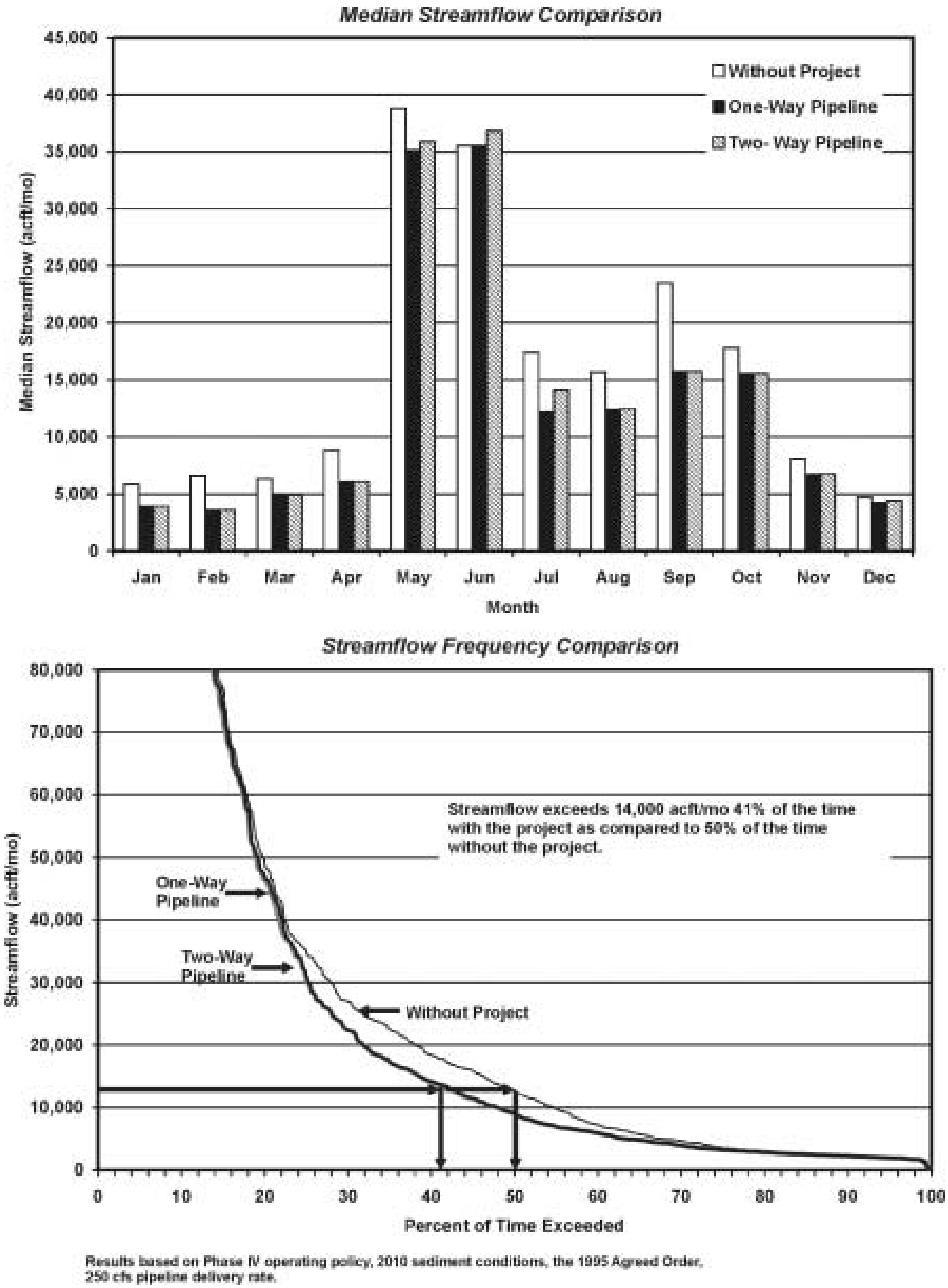
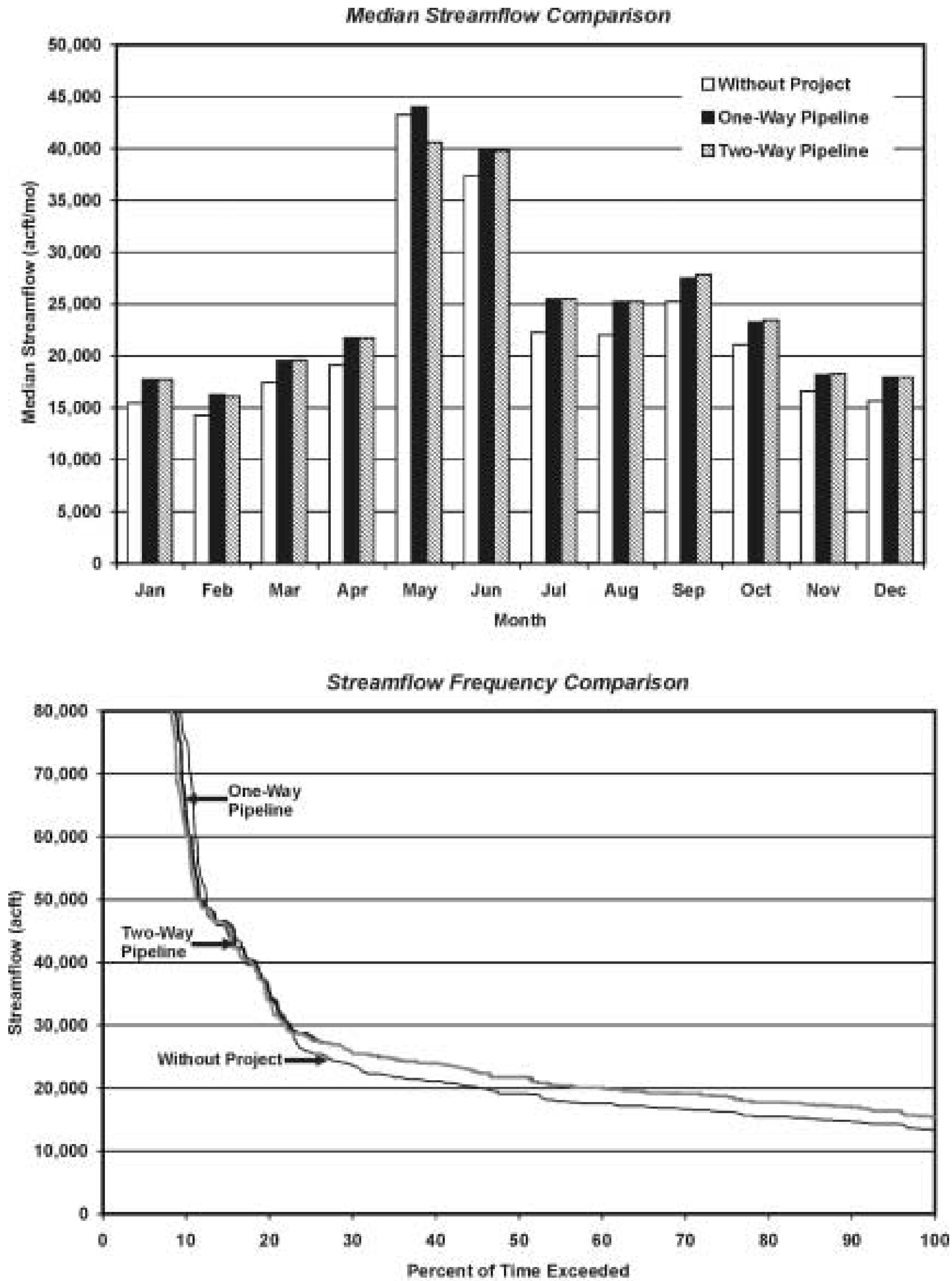


Figure 5A.9-3. Project Impacts on Streamflow, Nueces River at Three Rivers



Results based on Phase IV operating policy, 2010 sediment conditions, the 1995 Agreed Order, and 250 cfs pipeline delivery rate.

Figure 5A.9-4. Project Impacts on Streamflow, Nueces River at Mathis

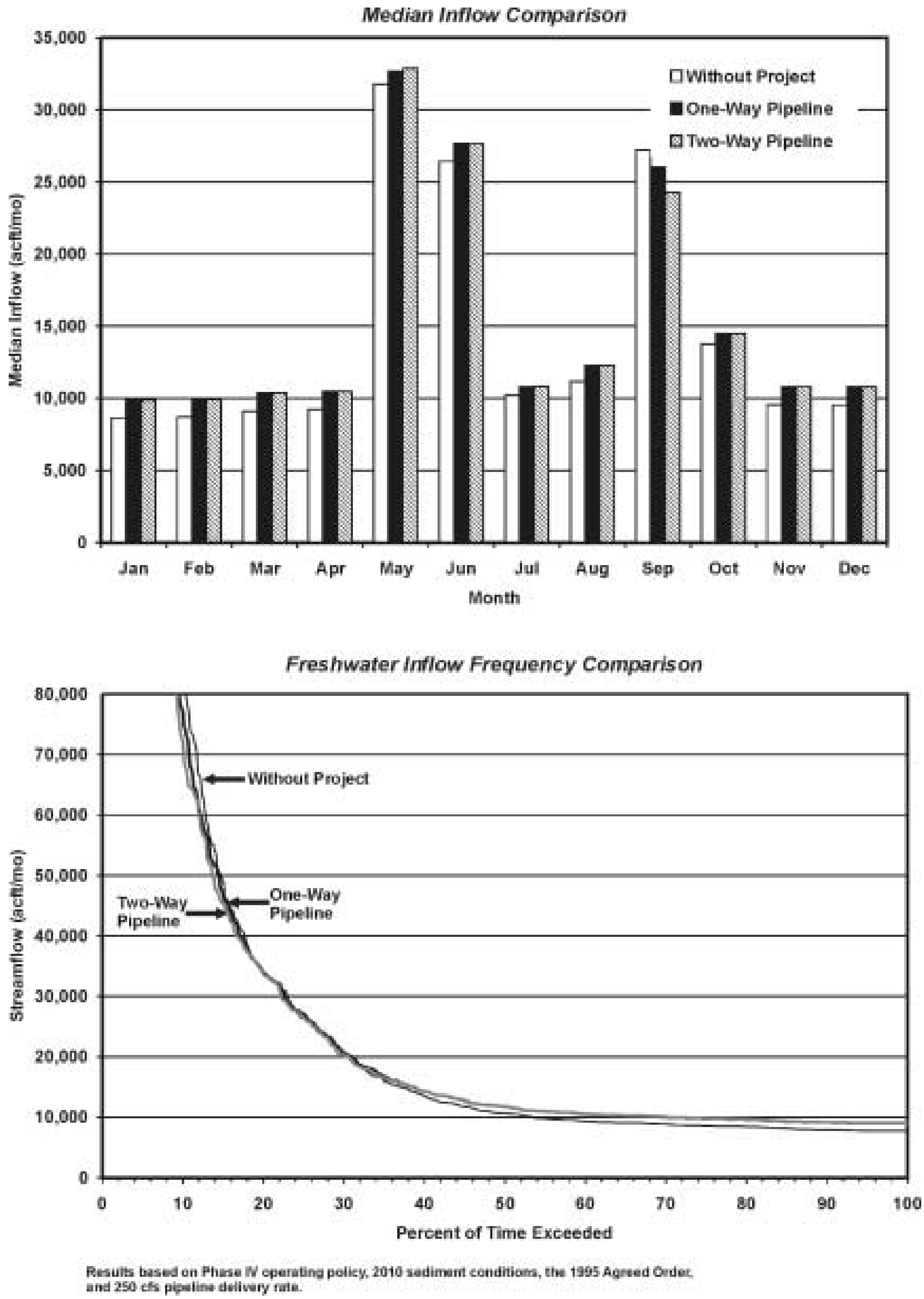


Figure 5A.9-5. Project Impacts on Freshwater Inflows into Nueces Estuary

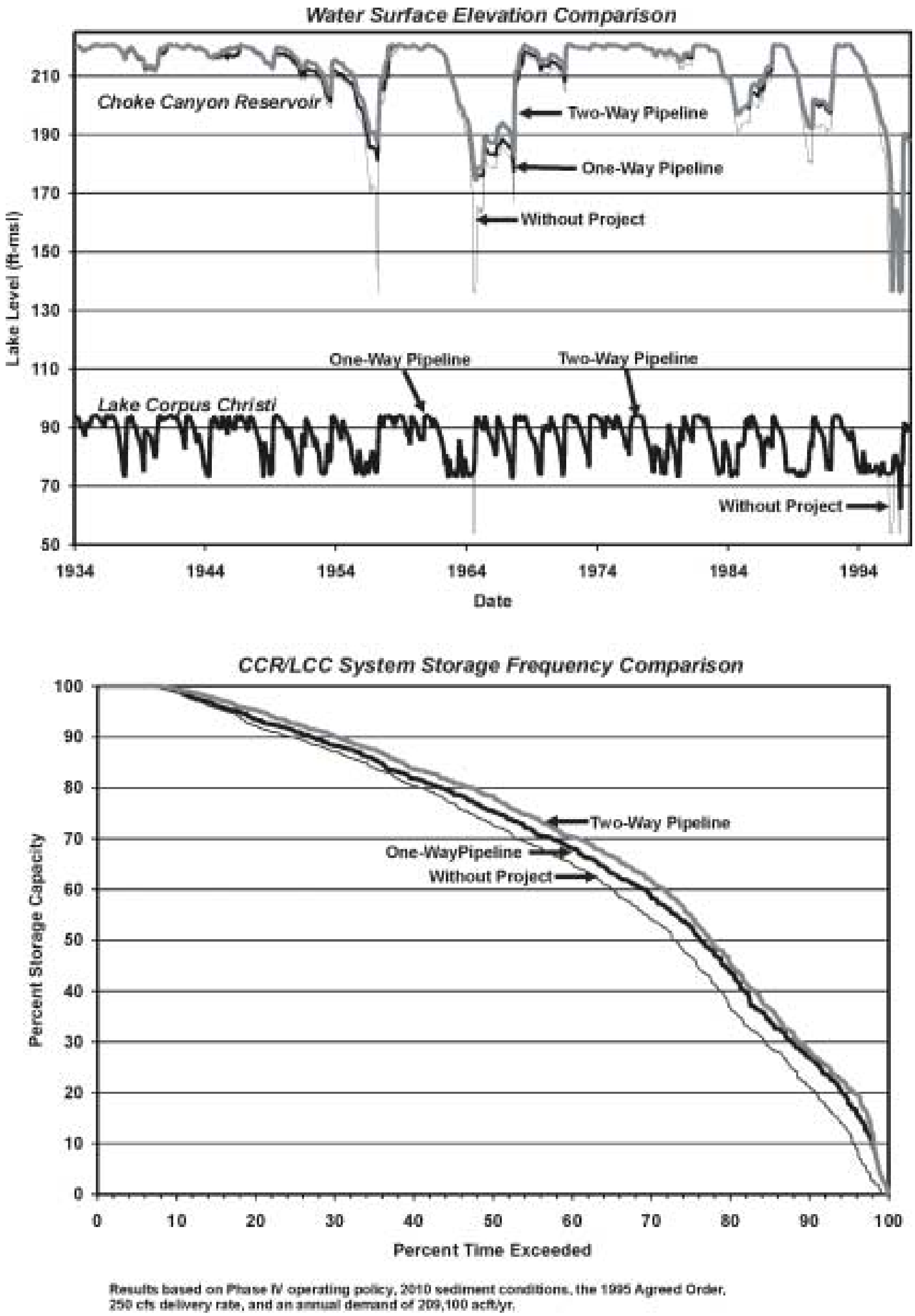


Figure 5A.9-6. Project Impacts on Choke Canyon Reservoir and Lake Corpus Christi

Table 5A.9-4.
Cost Estimate Summary
Pipeline Linking CCR and LCC
(Second Quarter 1999 Prices)

Item	Two-way Pipeline	One-way Pipeline
Capital Costs		
Intakes at Outlet Structures	$24,097,000	$11,169,000
Transmission Pipeline (34.8 miles; 90-inch dia.)	50,834,000	50,834,000
Access Roads	162,000	162,000
Total Capital Cost	**$75,093,000**	**$62,165,000**
Engineering, Legal Costs, and Contingencies	$22,528,000	$18,649,000
Environmental & Archaeological Studies and Mitigation	873,000	870,000
Land Acquisition and Surveying (204 acres)	2,021,000	2,018,000
Interest During Construction (1.5 years)	6,031,000	5,023,000
Total Project Cost	**$106,546,000**	**$88,725,000**
Annual Costs		
Debt Service (6 percent for 30 years)	$7,740,000	$6,446,000
Operation and Maintenance:		
Intake, Pipeline, Pump Station	1,111,000	788,000
Pumping Energy Costs ($0.06 per kWh)	1,028,000	710,000
Total Annual Cost	**$9,879,000**	**$7,944,000**
Available Year 2050 Project Yield (acft/yr)	**30,700**	**30,700**
Annual Cost of Water ($ per acft)	**$322**	**$259**
Annual Cost of Water ($ per 1,000 gallons)	**$0.99**	**$0.79**

5A.9.5 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. A detailed evaluation of the impacts of reduced flows on the river habitat would have to be undertaken to fully investigate the consequences of implementing this alternative. In addition, the

TNRCC permits may need to be amended depending on changes in locations of diversions. Additionally, before a 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 in this reach. In order to better quantify the channel losses in this reach, the City is currently working with the U.S. Geological Survey (USGS) and HDR on loss studies in order to begin long-term monitoring and documentation of losses between the two reservoirs immediately downstream of CCR. Additionally, the USGS is installing a new gage just upstream of LCC.

Requirements Specific to Pipelines:

1. Necessary Permits:
   - U.S. Army Corps of Engineers 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.

5A.9.6 Evaluation Summary

An evaluation summary of this regional water management option is provided Table 5A.9-5.

Table 5A.9-5.
Evaluation Summary for Pipeline between
Choke Canyon Reservoir and Lake Corpus Christi

Impact Category	*Comment(s)*
a. Quantity, reliability and cost of treated water	• Firm Yield: 27,700 to 33,400 acft/yr • Generally low cost; between $259 to $330 per acft
b. Environmental factors	• Reduction in streamflows between Choke Canyon Reservoir and Lake Corpus Christi • Increase in streamflows below Lake Corpus Christi and freshwater inflows to Nueces

	Estuary • Cultural Resource Survey needed to avoid impacts
c. State water resources	• No negative impacts on other water resources • Potential benefit to Nueces Estuary from increased freshwater return flows
d. Threats to agriculture and natural resources in region	• None
e. Recreational	• None
f. Comparison and consistency equities	• 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

5A.10 Voluntary Redistribution and Reallocation of Available Supplies

5A.10.1 Description of Strategy

The available supply in the Coastal Bend Region in 2050 consists of 72 percent surface water and 28 percent groundwater. The majority of the municipal and industrial surface water is supplied either directly or in-directly (via the San Patricio MWD or the STWA) by the City of Corpus Christi out of the CCR/LCC System / Mary Rhodes Pipeline (Texana Pipeline). Surface water for agricultural uses is from existing rights or local sources. There is an abundance of groundwater in the region, although it is not necessarily distributed where the needs are located, nor is it all of good quality.

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; reallocate groundwater surpluses to areas of need where possible; and the trading/transfer of surface water rights with the South Central Texas Regional Water Planning Area.

5A.10.2 Available Yield

5A.10.2.1 Utilization of Unused City of Three Rivers' Supply

Of the 223,418 acft of surface water in 2050 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 a year, without a renegotiation of the existing contract. The supply listed in Section 4 (Table 4-16) reflects the 3,363-acft contract amount. Three Rivers municipal demands range from 439 acft in 2000 to 448 acft in 2050. There is also a significant manufacturing demand in the City of Three Rivers. Based on current water demand projections for the City of Three Rivers, 2,924 acft of Three Rivers' contract could be made available to other entities, including local industries. In 2050, up to 2,915 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 5A.10-1.

Table 5A.10-1.
Evaluation Summary of the Utilization of Unused Surface Water

Impact Category	Comment(s)
a. Quantity, reliability, and cost of treated water	• Firm yield: Reallocation of CCR/LCC System firm yield • Quality: No change • Cost: Not applicable
b. Environmental factors	• No impacts
c. State water resources	• No impacts
d. Threats to agriculture and natural resources in region	• No impacts
e. Recreational	• No impacts
f. Comparison and consistency equities	• 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

5A.10.2.2 Purchase of Unutilized Irrigation Water Rights

A method to increase the yield of CCR/LCC System would be to purchase unutilized rights within the Nueces River Basin. Although there are a considerable number of water rights in adjacent coastal basins—the San Antonio-Nueces and the Nueces-Rio Grande—these rights were not considered as a viable means to economically increasing the firm yield of the CCR/LCC System for several reasons. First, freshwater availability to these rights is extremely limited during drought conditions due to the limited size of contributing watersheds and lack of storage reservoirs. Secondly, transfer of water on an intermittent basis would require large diversion rates and large capacity pump stations and pipelines.

There are 51 irrigation water rights in the Nueces Basin senior to Corpus Christi's right (January 15, 1925 priority).[1] The total permitted diversion of these rights is 9,737 acft/yr. During the most recent 10-year period of record available (1987 to 1997) these 51 rights reported zero use. Analysis of these rights was conducted using the recently completed TNRCC Water Rights Analysis Package (WRAP) model for the Nueces River Basin.[2] This model simulates the management and use of streamflow and reservoirs over a historical period of record, adhering to the water right priority system (see Section 3 for further details). The minimum annual diversion—availability during drought of record—of these unutilized irrigation rights is 3,880 acft.[3] It should be noted that these availabilities are at the diversion locations of each of the respective rights and actual increase in yield to CCR/LCC System would be significantly lower (due to channel losses).

At $450[4] per acft, plus legal and engineering fees, the one-time purchase price of 9,737 acft is $4.8 million. Annual cost for 30 years is $388,000. Assuming only one-third of the 3,880 acft (or 1,293 acft/yr) would be available due to channel losses within the watershed, cost per acft/yr is $300. These costs and other criteria are presented in Table 5A.10-2.

5A.10.2.3 Use or Purchase of Under-Utilized Nueces County WCID # 3 Water Right

The Nueces County WCID # 3 (the District) has two municipal 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 both 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 modeling (using the TNRCC's WRAP model), shows a minimum annual diversion of 7,104 acft/yr the for the District's right.

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[1] The City of Corpus Christi has five municipal water rights with a total diversion amount of 195,039 acft. Of these water rights, the largest is 150,000 acft, and has a priority date of January 15, 1925. Two of the rights, totaling 4,729 acft, have priority dates of December 26, 1913 and May 4, 1914, respectively. The other two rights, totaling 40,310 acft, have priority dates of May 21, 1931 and July 19, 1976. For this analysis the January 15, 1925 priority date was used.

[2] HDR Engineering, Inc. (HDR), "Water Availability in the Nueces River Basin," Texas Natural Resource Conservation Commission, October 1999.

[3] Ibid.

[4] $450 purchase price is based on purchase price of Garwood Water right by Corpus Christi in 1999. Legal and engineering fees are an additional 10 percent; annual costs are based on a 30-year debt at 7 percent interest.

Table 5A.10-2.
Evaluation Summary of the Purchase of Unutilized Irrigation Water Rights

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	• Firm yield: 1,293 acft (estimated at CCR/LCC System) • Quality: No change • Costs: $300/acft/year
b. Environmental factors	• Due to relatively low volume of water, no significant environmental impacts
c. State water resources	• No impacts
d. Threats to agriculture and natural resources in region	• Unutilized water rights; no impacts
e. Recreational	• No impacts
f. Comparison and consistency equities	• Standard analyses and methods used.
g. Interbasin transfers	• N/A
h. Third party social and economic impacts from voluntary redistribution of water	• Willingness of each water right owner to sell their rights
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None

The municipal demands placed on the District by their customers—City of North San Pedro, City of Robstown, and River Acres Water Supply Corporation— total 2,921 acft in 2050. The demands of the various irrigation customers are 713 acft in 2050. The 2050 surplus, total minimal annual diversion of the Districts' right less total municipal and irrigation demands, is 3,470 acft.

For this surplus to be fully utilized, two options are available. One is for the District to expand its existing distribution system to serve the County-Other population, if service County-Other users fall within service area boundaries of the District. This would provide an additional 3,470 acft/yr of firm supply to Nueces County-Other. The other option is for the City of Corpus Christi to purchase the unutilized 3,470 acft/yr of firm water and make it available to meet municipal need in Nueces County-Other. If it is assumed that the irrigation demands of 713 acft could be met with interruptible water, a total of 4,183 acft/yr of firm water could be made available for municipal supply to the region.

At $450 per acft, plus legal and engineering fees, the one-time purchase price of 4,183 acft is $2.1 million. Annual cost for 30 years is $167,000. With 4,183 acft in availability, cost per acft per year is $40.[5] These costs and other criteria are presented in Table 5A.10-3.

Table 5A.10-3.
Evaluation Summary of Use/Purchase of Nueces County WCID # 3 Water Right

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	• Firm yield: No change to CCR/LCC System • Quality: No change • Costs: - Nueces County WCID #3: costs of additional distribution system - Corpus Christi: $40/acft/yr for purchase of water right plus costs of distribution
b. Environmental factors	• No impacts
c. State water resources	• No impacts
d. Threats to agriculture and natural resources in region	• No impacts
e. Recreational	• No impacts
f. Comparison and consistency equities	• Standard analyses and methods used
g. Interbasin transfers	• Not applicable
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 to Corpus Christi
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• None

5A.10.2.4 Groundwater Re-Allocation

The groundwater allocation in Section 4 (Supply/Demand comparisons) was based on the groundwater supplies described in Section 3. Those supplies were determined based on safe-

[5] $450 purchase price is based on purchase price of Garwood Water right by Corpus Christi in 1999. Legal and engineering fees are an additional 10 percent; annual costs are based on a 30-year debt at 7 percent interest.

yield of the Carrizo-Wilcox, Gulf Coast, Queen City, and Sparta aquifers within each of the 11 counties of the region (see Appendix B and Section 3.4.1). The safe-yield analysis assumes that the current storage—the amount of groundwater supply above the safe yield—is not tapped. Once the supply was determined, the allocation was based on the most recent groundwater pumping information available (1997). It was meant to "assign" groundwater to a particular use, but does not necessarily reflect an exact supply.

Many of the groundwater shortages are not large, and in reality demands will be met by continuing current pumping or "overdrafting" of the aquifer. Overdrafting is defined as pumping more from the aquifer than annual recharges, thus removing groundwater from storage. It should be stated that this temporary overdrafting of the aquifers is minor in comparison to the total storage in the aquifers and is not expected to cause any measurable detrimental effects. Tables 5A.10-4 and 5A.10-5 show the cities/county-other and other non-municipal users that could meet their projected shortages with minor overdrafting strategies.

Table 5A.10-4.
Municipal Groundwater Shortages That Could Be Met With Additional Groundwater Pumping

County/City	Additional Pumping (acft)		
	2000	2030	2050
Brooks County			
Falfurrias	226	none	none
County-Other	567	363	267
Duval County			
County-Other	366	353	308
Jim Wells County			
Premont	none	202	327
County-Other	8	none	none
Kleberg County			
County-Other	44	none	none

Table 5A.10-5
Other Use Groundwater Shortages That Could Be Met with Additional Pumping

County/Use	Additional Pumping (acft)		
	2000	2030	2050
Aransas County			
Mining	46	none	none
Kleberg County			
Irrigation	106	none	none
Nueces County			
Mining	79	none	none

Additionally, throughout the region several counties have groundwater supplies in excess of their demands. These groundwater surpluses (Table 5A.10-6) could be used to meet needs in other counties in the region. An evaluation summary of additional groundwater pumping is presented in Table 5A.10-7.

Table 5A.10-6.
Groundwater Surpluses That Could be Used to Meet Needs in the Region

County/Use	Surpluses (acft)		
	2000	2030	2050
Bee County	9,762	10,715	11,072
Brooks County	136	423	822
Jim Wells County	578	1,169	1,595
Kenedy County	11,924	11,940	11,951
Kleberg County	1,572	2,030	2,729
Live Oak County	719	2,529	1,402
McMullen County	10,158	10,359	10,413

Table 5A.10-7.
Evaluation Summary of Additional Groundwater Pumping

Impact Category	Comment(s)
a. Quantity, reliability, and cost of treated water	• Quantity: varies (Tables 5A.10-4 & 5A.10-5) • Costs: additional pumping costs associated with operating existing wells
b. Environmental factors	• No impacts
c. State water resources	• No impacts
d. Threats to agriculture and natural resources in region	• No impacts
e. Recreational	• No impacts
f. Comparison and consistency equities	• 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	• Provides local opportunities
j. Effect on navigation	• Not applicable

5A.10.2.5 Trades/Transfers with South Central Texas Region

The Nueces River Basin covers three RWPA's: the Coastal Bend, the South Central Texas, and the Rio Grande. Options have been developed for the South Central Texas Region 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 seventeen options in Section 5).

5A.10.2.5.1 Recharge Enhancement in Exchange for Guadalupe River Water or Additional Lake Texana 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. Five separate enhancement project programs have been developed, one of which would be built if the option is determined to be a management supply solution. By capturing water before it arrives at the CCR/LCC System, the firm yield of the system is decreased from anywhere between 1,235 acft/yr to 4,700 acft/yr, depending on which program is built. Available yield to the South Central Texas Region would range from 1,958 acft/yr to 21,577 acft/yr.[6]

Two options exist to replace decrease in firm yield to the CCR/LCC System resulting from the recharge enhancement projects. The first option involves diversion and transmission of Guadalupe River water from the reservoir pool at the Saltwater Barrier via a new 7-mile pipeline connecting to the City of Corpus Christi's Mary Rhodes Memorial Pipeline (Texana Pipeline) for delivery to the City's O.N. Stevens Water Treatment Plant (Table 5A.10-8). Depending on which recharge enhancement projects are built, the amount of Guadalupe River Water diverted would need to be between 1,235 acft/yr and 4,700 acft/yr. The second option involves the diversion of 4,500 acft of interruptible water from Lake Texana and transmission to Corpus Christi via the Texana Pipeline. Interruptible water refers to that water which is available when Lake Texana's water level is higher than 1-foot below the spillway. The 4,500 acft of interruptible water from Lake Texana is the firm yield of Lake Texana (79,000 acft/yr) less the Lavaca-Navidad River Authority's (LNRA) contracts (74,500 acft/yr) to supply water from the reservoir.

Correspondence with LNRA staff indicate that this water is available about 80 percent of the time. As can be seen in Table 5A.10-10 at the end of this section, the mixing of either Guadalupe River water or Lake Texana with Nueces River Water at the O.N. Stevens Water Treatment Plant poses minimal water quality issues.

5A.10.2.5.2 Exchanging of Garwood Water for Guadalupe River Water

As detailed in Section 5A.13, the City of Corpus Christi entered into an agreement for the purchase of 35,000 acft/yr from the Garwood Irrigation Company. The amendment of the certificate of adjudication approved by the TNRCC on October 7, 1998 authorizes the City of Corpus Christi to divert 35,000 acft/yr from the Colorado River. For the City to receive this water, two options have been developed (See Section 5A.13 for complete analysis). One is for the water to be diverted near Bay City and pumped via a 41-mile pipeline to a terminal storage

[6] For further details please consult South Central Texas Initially Prepared Plan , August 2000.

Table 5A.10-8.
Evaluation Summary of Recharge Enhancement in Exchange for Guadalupe River Water or Additional Lake Texana Water

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	• Quantity: Net Gain of 0 acft to CCR/LCC System • Costs: to be covered by South Central Texas Regional Water Planning Area
b. Environmental factors	• Due to relatively small amounts of water, negligible impacts
c. State water resources	• Due to relatively small amounts of water, negligible impacts
d. Threats to agriculture and natural resources in region	• No impacts
e. Recreational	• No impacts
f. Comparison and consistency equities	• Standard analyses and methods used
g. Interbasin transfers	• Yes
h. Third party social and economic impacts from voluntary redistribution of water	• No impacts
i. Efficient use of existing water supplies and regional opportunities	• Provides regional opportunities
j. Effect on navigation	• No impacts

tank at the Texana Pipeline. The second option is for the water to be diverted from the Colorado River near Garwood and pumped via a 16-mile pipeline to Sandy Creek, which would convey the water to Lake Texana, and then through the Texana Pipeline for delivery to the City of Corpus Christi's O.N. Stevens Water Treatment Plant. This second option would require the TNRCC permit issued on October 7, 1998 to be amended to allow the water to be discharged to a natural stream.

The costs of these two options range from $145/acft/yr to $253/acft/yr. Additionally, there are significant implementation issues, namely permitting and water treatment operations, that would need to be considered (Table 5A.10-9).

Table 5A.10-9.
Evaluation Summary of Exchanging Garwood Water for Guadalupe River Water

Impact Category	***Comment(s)***
a. Quantity, reliability, and cost of treated water	• Quantity: Net Gain of 0 acft to CCR/LCC System • Water Quality: No significant change • Low cost: < $145/acft/yr
b. Environmental factors	• Diversion would occur under existing water rights and would not be significant
c. State water resources	• Optimizes use of State resources
d. Threats to agriculture and natural resources in region	• None
e. Recreational	• None
f. Comparison and consistency equities	• Standard analyses and methods used
g. Interbasin transfers	• Yes
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

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 from the reservoir pool at the Saltwater Barrier. As noted above Guadalupe River Water would be pumped via a pipeline approximately 7 miles in length to the Texana Pipeline. It can be safely assumed that the cost of the 7-mile pipeline would be less than either the 42-mile or 17-mile pipeline. The advantage for the South Central Texas Regional Water Planning Area is that if the trade occurred the major municipal demand center in the region would be able to divert the 35,000 acft/yr of Colorado River water upstream and potentially tie it to the development of other projects along the Colorado River it is currently analyzing.

As can be seen in Table 5A.10-10, the mixing of Guadalupe River water with Nueces River Water at the O.N. Stevens Water Treatment Plant poses minimal water quality issues.

Table 5A.10-10.
General Statistics on Water Quality at Potential Water Sources

Location		Chloride	Hardness	Sulfate
Nueces R. @ Stevens	Max	338	312	—
	Med	162	219	—
	Min	67	138	—
Guadalupe R. @ 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 R. @ Wharton	Max	140	280	110
	Med	48	210	38
	Min	11	75	12

5A.11 Sediment Removal in Lake Corpus Christi

5A.11.1 Description of Strategy

The Trans-Texas Water Program (Phase II Report) for the Corpus Christi Study Area initially studied a water supply option that involved dredging of Lake Corpus Christi. Past sedimentation surveys have documented the reduction in water storage capacity of Lake Corpus Christi as a result of sediment accumulation as indicated in Table 5A.11-1.

Table 5A.11-1.
Summary of Lake Corpus Christi Capacity Data

Year	Conservation Pool Capacity (acft)	Source of Capacity Data
1959	302,160	Initial Capacity of Enlarged Lake Corpus Christi, 1959
1972	272,352	1972 McCaughan & Etheridge Sediment Survey
1987	241,241	1987 USGS Sediment Survey Modified by HDR
1990	237,473	1987 USGS (Modified) Relationship Adjusted for 3 years of Sedimentation
2010	213,112	1987 USGS (Modified) Relationship Adjusted for 23 years of Sedimentation
2050	164,192	1987 USGS (Modified) Relationship Adjusted for 63 years of Sedimentation

Source: Trans-Texas Water Program Phase II Report.

The Phase II Report used a long-term sedimentation rate of 1,223 acft/yr, which was based on previous studies, to estimate the capacity of Lake Corpus Christi for 1990, 2010, and 2050 conditions. These estimates indicated that the conservation storage of the lake is projected to decrease by 73,000 acft (31 percent) between 1990 and 2050 as indicated in Table 5A.11-2. This is a high loss rate for a reservoir. As a comparison, the conservation storage of Choke Canyon Reservoir is projected to decrease by 13,620 acft (only 2 percent) during the same timeframe.

Reservoir operation studies of the Choke Canyon Reservoir/Lake Corpus Christi System were also conducted during preparation of the Phase II Report. The studies indicated that without a dredging program, the firm yield of the system is projected to decrease through 2050 at an average annual rate of 363 acft/year (for the period from 1959 to 2050), as indicated in Table 5A.11-2.

Table 5A.11-2.
Summary of Firm Yield Reductions in Lake Corpus Christi Due to Sedimentation

Lake Corpus Christi Capacity (acft)	Reduction in Lake Corpus Christi Capacity[1] (acft)	Reduction in System Yield[1] (acft/yr)	Average Annual Reduction in Yield (acft/yr)
302,160 (1959 conditions)	—	—	—
237,473 (1990 conditions)	64,687	14,700	475
213,112 (2010 conditions)	24,361	5,300	265
164,192 (2050 conditions)	48,920	13,000	325
Totals for 1959 to 2050 Conditions	137,968	33,000	363

[1] The reductions tabulated in columns 2 and 3 are reductions since the previous year tabulated. System firm yield was computed using the City's Phase 2 Operating Policy and the TNRCC Interim Release Order.

In order to offset the projected decrease in conservation storage and resulting decrease in firm yield, this section of the report discusses the possibility of removing some sediment in the reservoir by a dredging program.

5A.11.1.1 Scope of Dredging Program

The accumulation of sediment in Lake Corpus Christi is a serious long-term problem. A maintenance dredging program to offset the annual sedimentation rate of 1,223 acft will require that approximately 2 million cubic yards (CY) (in situ volume) of sediment be dredged each year. An accelerated dredging program to restore Lake Corpus Christi storage capacity to 1959 conditions (302,160 acft) will require that approximately 163 million CY (in situ volume) of sediment be dredged by the year 2020. The accelerated program would require the removal of about 6 million CY (in situ volume) of sediment each year.

5A.11.1.2 Sedimentation Survey Requirements

A new sedimentation survey will be required prior to dredging Lake Corpus Christi to determine existing depths within the project area. The City of Corpus Christi presently has a contract with TWDB to perform a new capacity survey of Lake Corpus Christi. However, the new survey cannot be performed until the water level of the reservoir returns to near full conditions (approximately elevation 94 feet).

Using the best available information, comparisons were made between the two most recent sedimentation surveys for Lake Corpus Christi. They are the 1972 McCaughan & Etheridge Sediment Survey and the 1987 USGS Sediment Survey, as modified by HDR. The differences between bottom elevations measured in 1972 and 1987 show widespread and significant sedimentation (depths in excess of 4 feet) in certain areas of the reservoir. Based on information from City Water Department reservoir operations staff, sedimentation has also occurred in many other areas. When the new capacity survey is completed, current sedimentation conditions will be verified. This report assumes that a dredging program would initially target the areas shown in Figure 5A.11-1.

5A.11.2 Dredging Methods

5A.11.2.1 General

The principal types of equipment used in dredging projects are:

- Hydraulic pipeline type dredges (cutterhead, dustpan, plain suction, and sidecaster).
- Hopper dredges.
- Clamshell dredges.

The three basic mechanisms by which dredging is accomplished are:

- Suction dredging, which removes loose materials using dustpan dredges, hopper dredges, hydraulic pipeline plain suction dredges and sidecaster dredges.
- Mechanical dredging, which removes loose or hard, compacted material using clamshell dredges.
- A combination of suction and mechanical dredging, which removes loose or hard, compacted materials using cutterhead dredges.

Based on discussions with dredging contractors and a review of similar past projects, the hydraulic pipeline cutterhead suction dredge is likely the most feasible equipment for a dredging project in Lake Corpus Christi.

5A.11.2.2 Cutterhead Suction Dredge

The hydraulic pipeline cutterhead suction dredge is the most commonly used type of dredging equipment and performs the major portion of the dredging workload in the United States. It is equipped with a rotating cutter apparatus that surrounds the intake end of the suction pipe. The cutterhead dredge can efficiently dig and pump all types of alluvial material and

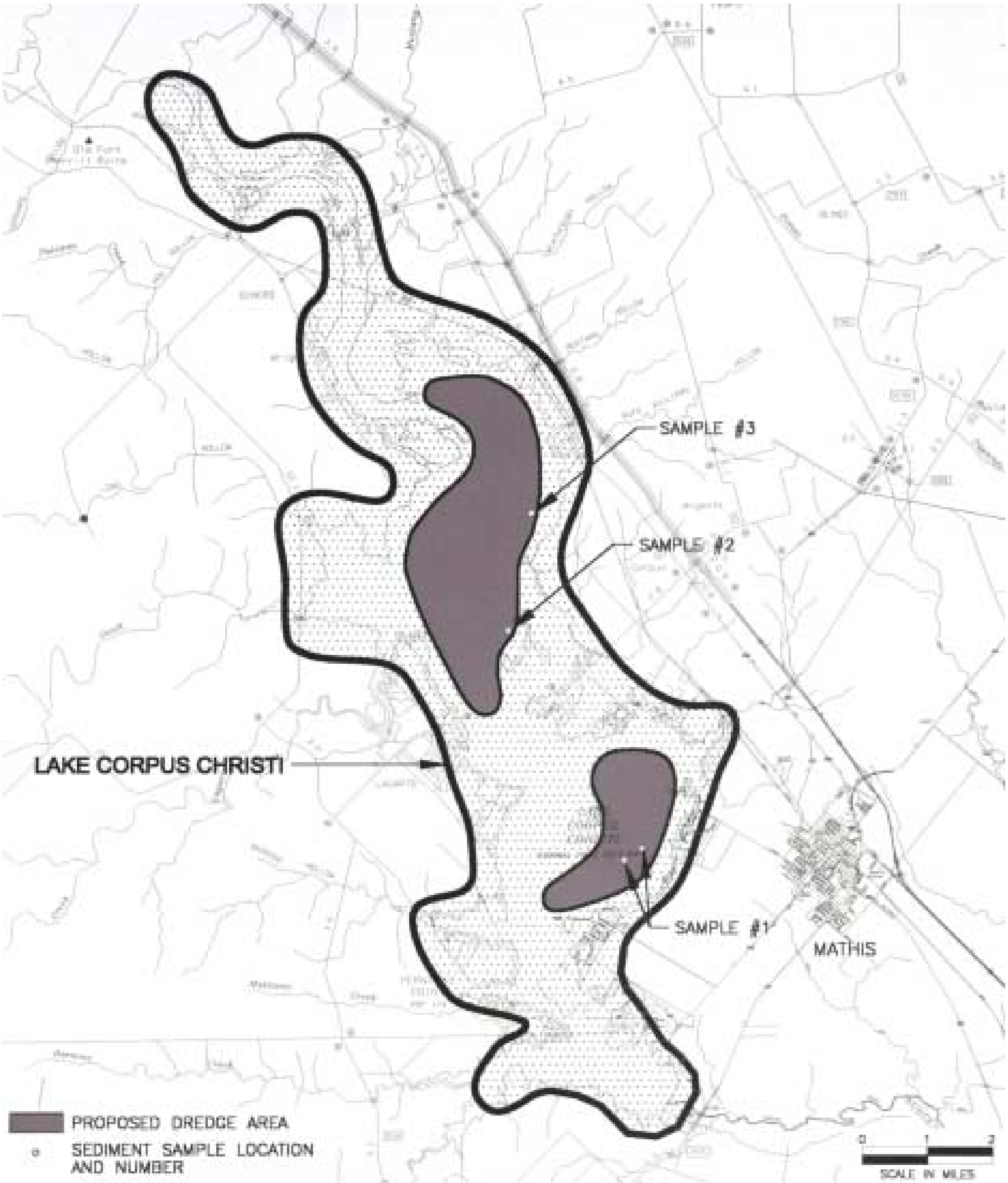


Figure 5A.11-1. Proposed Dredge Area in Lake Corpus Christi compacted deposits, including clay and hardpan. It usually has two stern spuds, which are extended into the bottom of the water body to hold the dredge in working position. During operation, the dredge swings from side to side alternately using the left and right spuds as a pivot, as shown in Figure 5A.11-2.

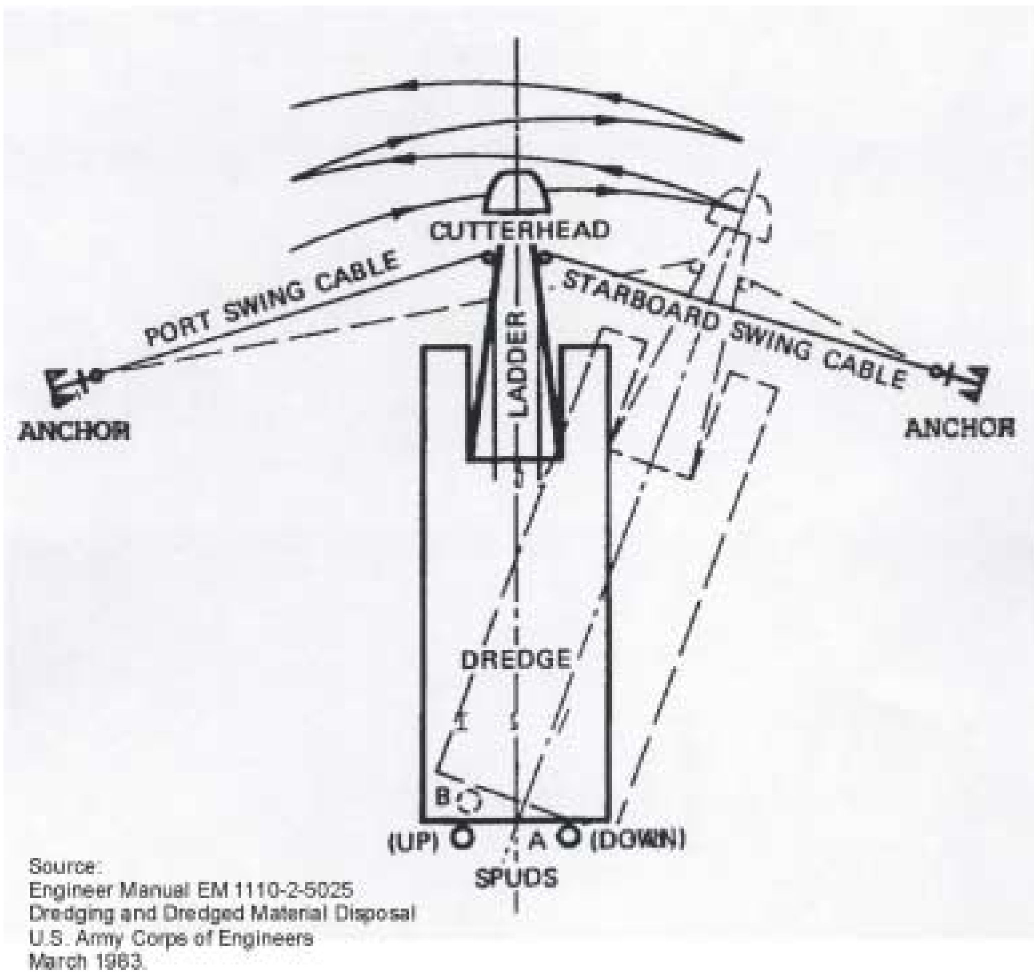


Figure 5A.11-2. Cutterhead Suction Dredge Operation

The dredged material is mixed with water and pumped hydraulically as a slurry. Solids concentrations of 10 to 20 percent are typical, depending upon the type of material being dredged, dredging depth and distance to disposal sites. Temporary discharge piping from the dredge is floated on the surface of the reservoir and is placed aboveground on land. In cutterhead dredging, the discharge pipeline can pump the slurry up to about 3 miles. Multiple booster pump stations along the discharge pipeline allow longer transport distances. It is feasible for a dredged material disposal site to be located 15 to 20 miles from the water body being dredged.

The production rate for a dredge is defined as the number of CY (in-situ volume) of sediment dredged during a given period and is usually expressed in CY per hour (CY/hr). Dredge size is given by the diameter of the discharge pipe (in inches). Due to factors affecting mobilization into an inland reservoir such as Lake Corpus Christi, an 18-inch dredge is about the largest dredge available for use on the lake. From a literature review and discussions with dredging contractors, the maximum production rate for an 18-inch dredge is estimated to range between 700 to 1,000 CY/hr. The production rate may be reduced substantially (to approximately 20 to 30 percent of the maximum rates), depending on the pumping distance. An 18-inch dredge would remove approximately 1.9 to 2.7 million CY/year, based on the following assumptions:

- Hourly production rate = 350 to 500 CY/hr
- Actual production time available during two 12-hour shifts = 18 hours
- Number of working days per year = 300 days

Based on the above rates, a project to dredge 2 million CY annually would require one 18-inch dredge. A 6 million CY/year project would require three 18-inch dredges.

5A.11.3 Dredged Material Disposal Alternatives

While selection of proper dredging equipment and techniques is essential for economic dredging, the selection of a disposal alternative is of equal or greater importance in determining the feasibility of a project, especially from an environmental standpoint. The major considerations in selecting disposal alternatives are the environmental impact and the economics of the disposal operation.

On a conceptual basis, the most feasible method of dredged material disposal for the Lake Corpus Christi area will likely consist of the construction of containment dikes in upland areas. The main advantages of this method include the following:

- Smaller land area is impacted.
- Damage to environmentally sensitive lowland areas is minimized.
- Quality and quantity of effluent discharged to receiving watercourses is controlled.

5A.11.4 Design and Construction of Diked Containment Areas

As mentioned, the operation of a cutterhead dredge produces a slurry mixture of sediment and water, which is discharged at the disposal site in a continuous stream. The two objectives in design and operation of a diked containment area are: (1) to provide adequate storage capacity to meet the dredging requirements, and (2) to meet applicable effluent standards by retaining suspended solids during filling operations. These considerations are interrelated and require effective design, operation, and management of the containment area.

Design of containment areas to meet effluent suspended solids limitations is based on determination of a surface area and detention time required to accommodate a continuous dredging operation. The design is based on removal of suspended solids by the process of gravity sedimentation and decanting of the clarified carrier water. The efficiency of suspended solids removal for freshwater sediments depends on the ponding depth and soil properties of the dredged material. When dredged material slurry is disposed in a well-designed, well-managed containment area, the vast majority of the solids will settle out of suspension and be retained within the settling basin. The major components of a dredged material containment area are shown schematically in Figure 5A.11-3.

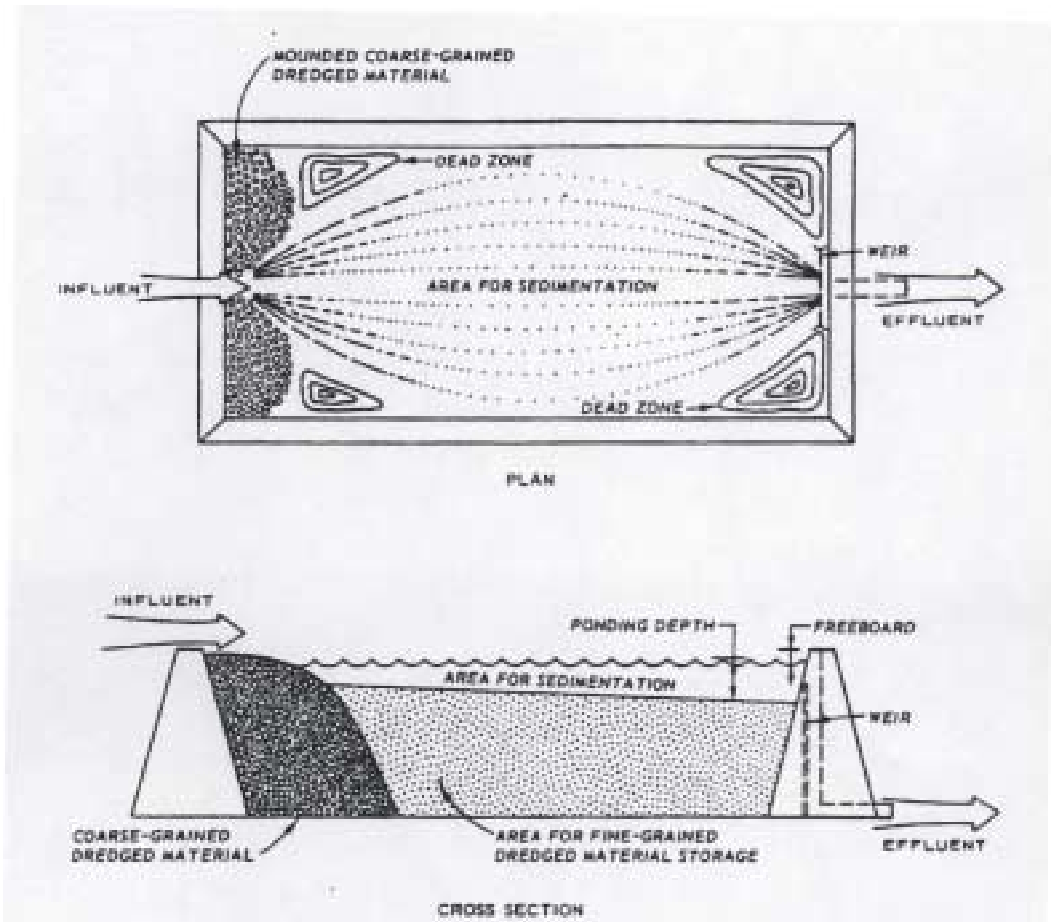
5A.11.4.1 Shape of Containment Area

The containment area can be any shape from square to oval to long and narrow, and is generally dictated by the available land. There are some advantages to long and narrow areas that tend to increase sedimentation rates and facilitate the use of draglines and/or clamshells for maintenance. The overall containment area should have a slight slope to provide natural gravity drainage of water.

5A.11.4.2 Storage Capacity of Containment Area

The storage capacity of a containment area is generally designed on the basis of a bulking factor, which relates the volume of material in situ (to be dredged) to the volume it is expected to occupy after being pumped into the containment area. Sizing of the containment area is also a function of:

- Lift thickness of the placed dredged material.
- Flow rate of dredged material.
- Minimum effluent standards.



Source:
Engineer Manual EM 1110-2-5025
Dredging and Dredged Material Disposal
U.S. Army Corps of Engineers
March 1983.

Figure 5A.11-3. Schematic Diagram of Dredged Material Containment Area

Storage capacity is defined as the total volume available to hold dredged material and is equal to the total unoccupied volume minus the volume associated with ponding and freeboard requirements. Ponding depths should be as great as possible in order to provide adequate detention time and prevent short-circuiting. A minimum ponding depth of 2 feet is usually adequate for a continuous disposal operation. The total volume available depends on the surface area of the site and the ultimate height to which the dikes can be raised.

If the containment area is intended for one-time use, the initial storage capacity and retention of solids during filling are the only design considerations. However, if the containment area is intended for long-term use, the long-term storage capacity must also be considered. Assuming that a containment area occupies a given surface area, the storage capacity remaining at any time will be a function of the dredged material fill height.

5A.11.4.3 Containment Dikes

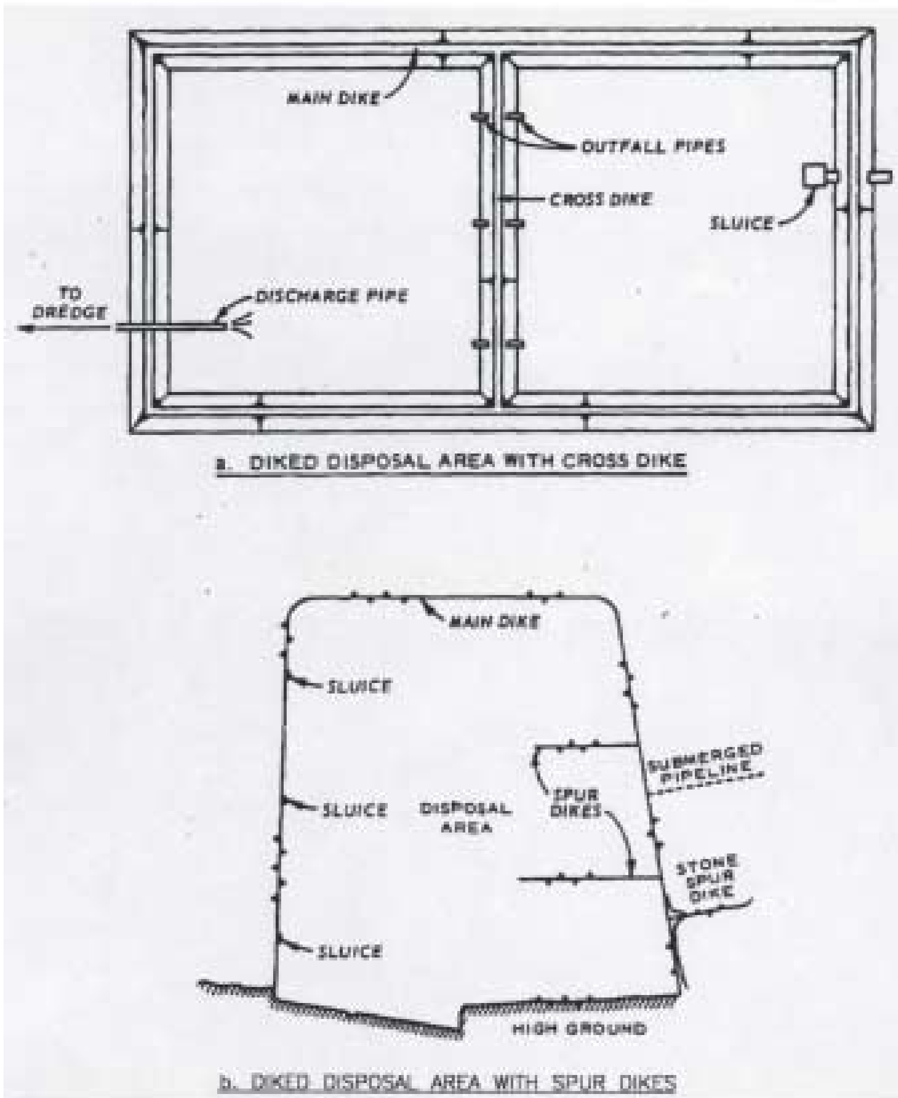
The primary objective of these earthen embankments is to retain solid particles from the dredged material and pond water within the containment area. The dikes form a confined surface area into which dredge sediments are pumped hydraulically.

Containment dikes must be designed properly to attain the highest possible efficiency in retaining solids during the dredging operation. They are usually constructed from the available soil at the site. The predominant retaining structure around the outer perimeter of the containment area is called the main dike. The main dike is divided into separate containment areas with cross dikes used to reduce the velocity of dredged material being discharged into a containment area, as shown in Figure 5A.11-4. Occasionally, spur dikes are installed within the main dike. Spur dikes protrude into, but not completely across, the disposal area. The main function of a spur dike is to prevent channelization by breaking up a preferred flow path and dispersing the slurry into the disposal area.

The containment area may be used in series or in parallel. In a series configuration, the first containment area acts as a primary sedimentation basin. The more containment areas available, the better the effluent quality will be. In a parallel configuration, dredged material is pumped into a containment area up to a desired elevation. The flow is then directed to a second containment area where uninterrupted settlement of particles can occur while the other area is being filled. After surface water is decanted from the first containment area, dredged material can again be pumped into that area. This method of disposal follows the sequence of filling, settling and surface drainage, dewatering, and dike raising by using dewatered dredge material (Figure 5A.11-5). A combined series of parallel containment areas provides maximum flexibility in dredged-material management.

5A.11.4.4 Discharge Facilities

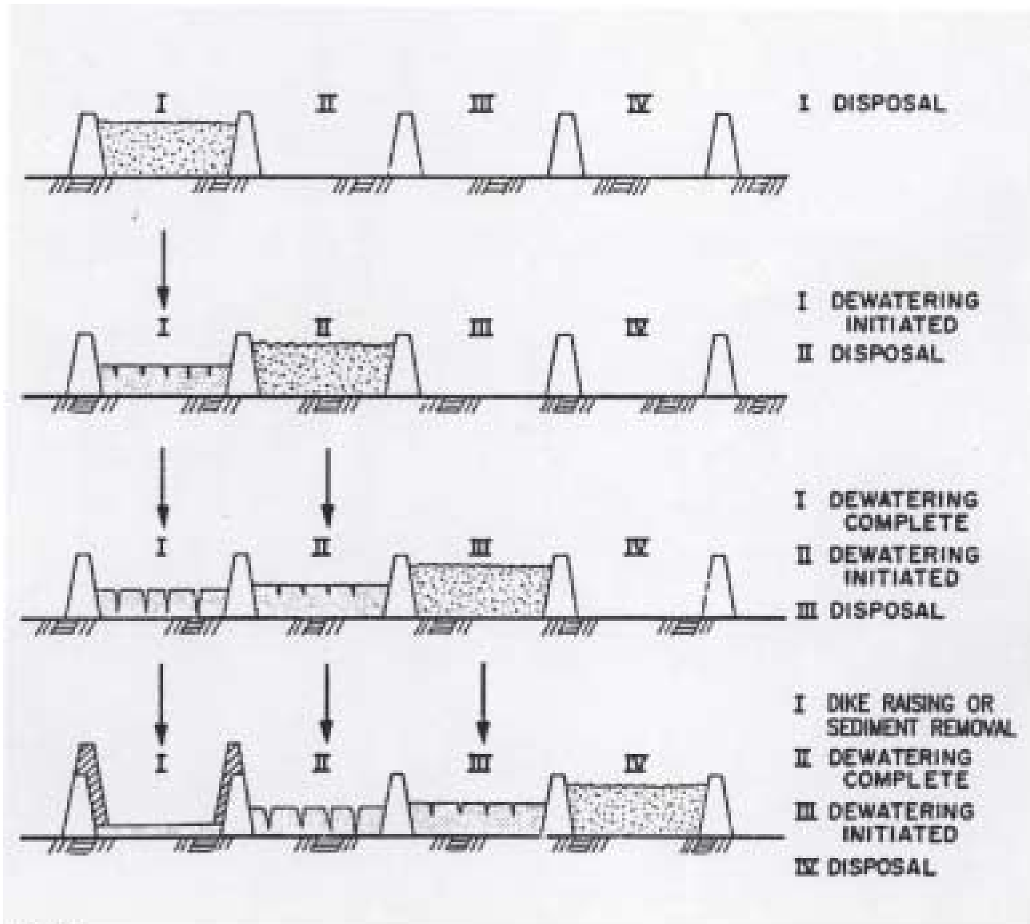
The purpose of the discharge facility is to regulate release of ponded water from the containment area. Types of discharge facilities include: simple outfall pipes, drop-inlet sluices, flumes and rectangular weirs. Discharge facilities must be designed and operated properly to



Source:
Technical Report D-77-9
Design and Construction of Retaining
Dikes for Containment of Dredged Material
U.S. Army Corps of Engineers
August 1977.

Figure 5A.11-4. Examples of Cross and Spur Dikes

control the possible resuspension and withdrawal of settled solids. They should also allow the clarified upper layer of ponded water to be selectively withdrawn. Adequate ponding depth during the dredging operation is maintained by controlling the overflow elevation. A simple operational method is to place boards within a weir structure to set the crest at the desired



Source:
Engineer Manual EM 1110-2-5025
Dredging and Dredged Material Disposal
U.S. Army Corps of Engineers
March 1983.

Figure 5A.11-5. Sequence of Containment Area Operation

elevation. Before the start of dredging, the weir boards are raised to the highest possible water surface elevation allowed by dike stability considerations. After the dredging operation is completed, boards are removed to lower the elevation of ponded water, thus promoting drying and consolidation of dredged material.

5A.11.4.5 Operation and Maintenance of Containment Areas

As the dredging operation begins, dredged material slurry is pumped into the containment area and no effluent is released until the water level reaches the preset level of the discharge facility. Since on the average, 80 percent of the dredged material slurry is water, a large volume of water will accumulate in the containment area. As the thickness of the dredged material deposit increases, the discharge facility outlet elevation must be raised to provide sufficient depth of water for settling of solids. As soon as the upper layers of water are sufficiently clear and meet the effluent water quality standards, the water should be discharged. The main objective is to drain the surface water to initiate evaporative drying of the sediments as soon as possible. No surface drying of material is possible as long as ponded water covers the containment area.

Once the dredged operation has been completed and the ponded water has been decanted, site management efforts should be concentrated on maximizing the containment storage capacity gained from continued drying and consolidation of dredged material. To ensure that rainfall does not affect pond water, the discharge facility outlet elevation must be kept at levels allowing efficient release of runoff water. This will require periodic lowering of the outlet elevation as the dredged material surface settles.

In summary, gains in long-term storage capacity of containment areas through natural drying processes can be increased by:

- Placing the dredged material in thin lifts,
- Dividing a large containment area into several compartments,
- Spreading and turning the sediment as it undergoes natural drying,
- Removal of coarse-grained material and dewatered fine-grained material from containment areas, in conjunction with dike maintenance or raising, and/or
- Beneficially reusing the sediment.

5A.11.5 Environmental Issues

Environmental issues related to the dredging of Lake Corpus Christi can be categorized as follows:

- Effects of the dredging operation on Lake Corpus Christi,
- Effects of carrier water return flows on Lake Corpus Christi or downstream,
- Effects related to the storage, processing and disposal of dredged sediment, and
- Issues associated with various dredge material beneficial reuse options.

5A.11.5.1 Dredging Activities

The potential sources of contaminants within the Lake Corpus Christi watershed are agricultural use of herbicides and pesticides, residuals from oil and gas production and transportation and some in-situ uranium mining. Existing contaminants may include metals such as arsenic (which is used to defoliate cotton), cadmium, chromium, copper, lead, mercury, zinc, pesticides, (i.e., chlordane, DDT) and other chemicals which can accumulate in bottom sediments. The presence of contaminants in the bottom sediments may indicate that additional studies would be necessary in order to determine whether contaminants could become resuspended in the lake or in the decant water.

5A.11.5.2 Water Quality/Land Use

Water quality issues may occur as a result of the dewatering process or sediment disposal, such as anoxic conditions common in sedimentation ponds. The presence of contaminants, nutrients, or total dissolved solids, for example, in excess of stream standards would require permits, possible treatment, and a monitoring program in order to discharge the carrier water and to dispose of the dewatered sediment. Depending on the possible beneficial reuse applications, such as agriculture, construction, land development, or habitat creation, various chemical and physical characteristics must also be evaluated. An initial series of chemical and physical tests to analyze carrier water and sediment for possible beneficial uses are provided in Table 5A.11-3. This initial list of parameters was developed based on U.S. Army Corps of Engineer and U.S. Department of Agriculture Information.[1,2] Additional analysis may be required in order to fully evaluate the discharge water and sediment during permitting and project implementation.

Various environmental and regulatory issues were identified for the proposed sites. Although considerable agricultural land is available, significant acreage will be required for dredge material placement. It is possible that some clearing of brush habitat may be necessary to provide all the necessary sediment containment capacity and dikes. Utilization of previously disturbed areas would reduce the impacts to undeveloped brush and woodland habitat. All sites have been tentatively screened with consideration given for minimizing impact to undeveloped

Table 5A.11-3
Chemical and Physical Parameters
Lake Corpus Christi Dredge Material

Parameter	*Sample Type*	*Purpose*[1]
Chemical		
USACE Basic Parameters[2]	elutriate	discharge

[1] U.S. Army Corps of Engineers, "Beneficial Uses of Dredged Material," June 1987.
[2] U.S. Department of Agriculture, "Soil Survey of Nueces County Soils Data," June 1992.

TPH - 1005	sediment	discharge / reuse / agriculture
Volatile Solids	sediment	agriculture
Ammonia Nitrogen	sediment / elutriate	agriculture / discharge
Total Phosphorus	sediment	agriculture
Radium 226[3]	sediment	discharge / reuse / agriculture
Natural Uranium[3]	sediment	discharge / reuse / agriculture
Reaction (pH)	sediment / elutriate	discharge / reuse / agriculture
Heavy Metals-Total Basis (As, Ba, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Zn)	sediment	agriculture / reuse
TDS	elutriate	discharge
TSS	elutriate	discharge
<u>Physical</u>		
Sieve Analysis	sediment	fills, foundation, liners
Atterberg Plasticity	sediment	fills, foundation, liners
Permeability	sediment	fills, foundation, liners
Moisture Content	sediment	fills, foundation, liners
Porosity	sediment	fills, foundation, liners
Soil Density	sediment	fills, foundation, liners

[1] Purpose refers to the principle dredge material disposal or reuse regulatory standards or criteria which influence the dredge material handling approach.
[2] Basic parameters include total metals including As, Ba, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Zn, Total PCB's, Chlordane and Derivatives, P,P[1] – DDT and derivatives, Total Organic Carbon, and Percent Solids
[3] Radiological parameters are included due to uranium mining practices in the watershed.

TPH = Total Petroleum Hydrocarbons; Ni = Nickel; Se = Selenium; TDS = Total Dissolved Solids
Zn = Zinc; Ba = Barium; Cd = Cadmium; As = Arsenic; TSS = Total Suspended Solids
Cr = Chromium; Pb = Lead; Cu = Copper; Hg = Mercury

or native brush habitat. Since potential habitat of the endangered ocelot and Jaguarundi could be an issue near undisturbed sites with dense brush habitat, coordination under the Endangered Species Act may be required for sites that involve such habitat. Additional potential environmental impacts including odors and/or surface/groundwater concerns will be minimized by reducing the amount of land required for dredge material placement and identifying previously impacted sites. In order to minimize potential environmental impacts, larger tracks of agricultural lands have been identified for dredge material placement.

5A.11.6 Permitting Requirements

Several permits and regulatory approval are involved with the project including U.S. Army Corps of Engineers Nationwide Permit No. 16 for "return water from upland contained disposal area" under Section 404 dredge and fill permit rules, a possible 401 "water quality certification" from the Texas Natural Resource Conservation Commission for discharge of decant water to a receiving stream or lake, and a National Pollutant Discharge Elimination System Permit (NPDES) Construction Site Stormwater Permit and Stormwater Pollution Prevention Plan for constructing pipelines and other construction sites greater than 5 acres. The NPDES Construction Site Permit would require submittal of a Notice of Intent from to the U.S. Environmental Protection Agency and certification that federally listed threatened and endangered species would not be adversely impacted. A possible Coastal Coordination Council consistency review under the Coastal Management Program may also be required. A TPWD Soil, Gravel, and Marl Permit is not expected since the dredging is not expected within the state-owned streambed (within Lake Corpus Christi). In addition, the TPWD provides an exemption for projects to restore or maintain the storage capacity of existing water supplies.

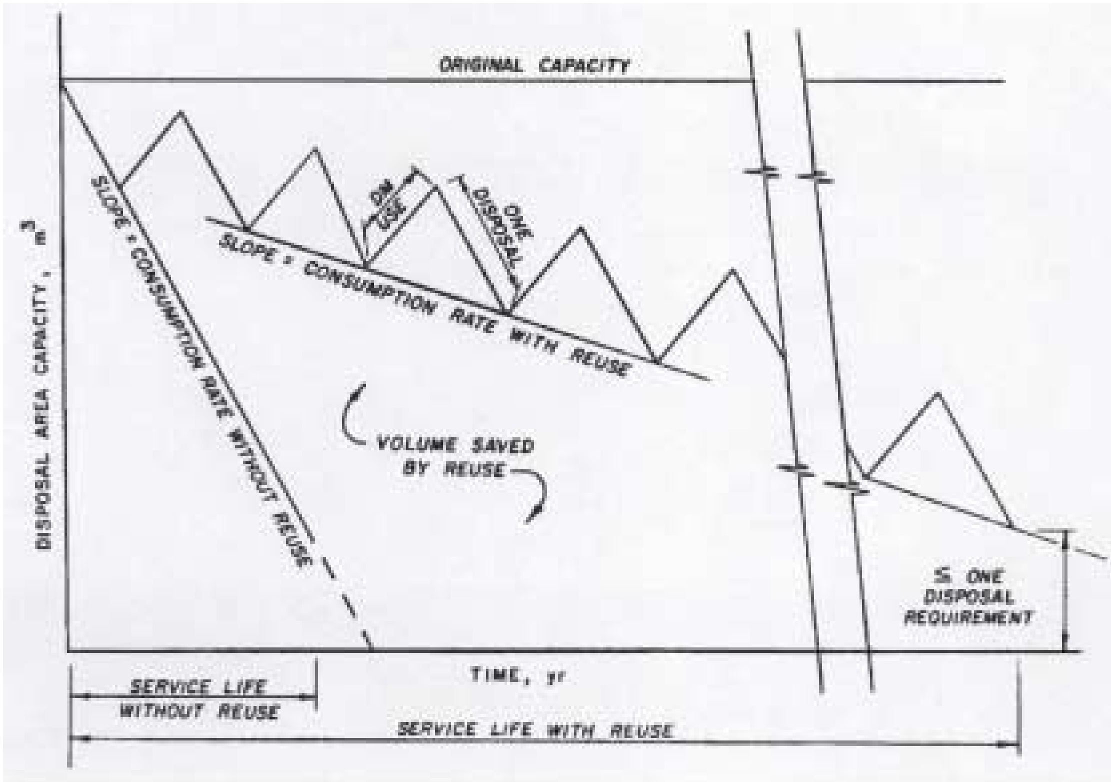
Various studies and agency coordination will be involved with these permitting actions. Table 5A.11-4 presents a summary of permits and additional studies that will be involved including the land rights issues and other regulatory approvals such as highway and railroad crossings.

Table 5A.11-4.
Summary of Permits and Additional Studies

1. A dredging program may make it necessary to obtain these permits:
    A. U.S. Army Corps of Engineers Nationwide Permit No.16
    B. Coastal Coordination Council review for Coastal Management Program consistency
    C. EPA Construction Site Stormwater NPDES permit and Stormwater Pollution Prevention Plan
    D. TNRCC water quality certification related to discharge decant water to a watercourse or lake.
    E. Cultural resource survey as required by Texas Antiquities Commission.
2. Permitting, at a minimum, will require these studies:
    A. Pipeline routing and sedimentation pond siting studies and environmental assessment
    B. Habitat mitigation plan
    C. Water quality and suspended sediment studies
    D. Characteristics of decant water at disposal sites
    E. Toxicity studies of accumulated sediment
    F. Sound impact studies and odor studies
    G. Characteristics of sediment at dredge material placement sites
    H. Decant wastewater treatment studies
    I. Groundwater impact studies at dredge material placement areas
3. Land rights for the disposal areas will need to be obtained including property site assessments for any land acquisitions
4. Disposal pipeline and return water pipelines will have to obtain permission for crossings at:
    A. Highways and railroads
    B. Creeks
    C. Other utilities and petrochemical pipelines

5A.11.7 Beneficial Use of Dredged Material

Beneficial reuse is the most effective solution to extending the service life of a disposal area (Figure 5A.11-6). A reusable disposal area can be regarded as a dredged material transfer station, where dredged material is collected, processed if necessary, and removed for productive use.



Source:
Technical Report DS-78-12
Guidelines for Dredged Material
Disposal Area Reuse Management
U.S. Army Corps of Engineers
January 1987

Figure 5A.11-6. Disposal Capacity versus Time with Reuse

When planning a reusable disposal area, major consideration should be given as to how the dredged material solids will be used. The fact that dewatered dredged material is a soil encourages the productive use of the material as a natural resource. The following should be evaluated as potential off-site productive uses for dredged material:

- Landfill and construction material,
- Surface mine reclamation,
- Sanitary landfill cover material, and/or
- Agricultural land enhancement.

Proven dredged material beneficial reuses include upland site development, shoreline stabilization, beach renourishment, agriculture uses, strip mine reclamation and landfill operations, construction and industrial use (dikes, levees, residential/commercial fills), and habitat and wetland development.[3] Various considerations must be evaluated in order to assess the viability of a particular beneficial use option. They include: logistics and cost for transport; handing and storage; sediment chemical and physical characteristics; evaluation of the dredged materials disposal site; and market availability and need for the sediment material. The acceptability of dredged sediment for agricultural use can be assessed using existing regulatory criteria. For example, the Texas Natural Resource Conservation Commission (TNRCC) has adopted the federal guidelines for the land application of sewage sludge. Part of the regulations govern acceptable levels of metals for the land application of the sewage sludge (including cropland and range land). These regulatory criteria can be used as a guide to evaluate the acceptability of the metals content in the dredged sediment for agricultural purposes. Other regulatory criteria are available to determine the suitability of various inorganic and organic constituents in the dredged sediment.

5A.11.7.1 Results of Sampling and Testing of Lake Corpus Christi Sediments

In order to evaluate sediment and water quality from the dredging of Lake Corpus Christi, samples were collected and analyzed. The analytical results for the sediment sample and the elutriate samples were summarized and compared to appropriate regulatory criteria (Table 5A.11-5). Water quality analyses were conducted to evaluate the water quality of the sediment/water column interface during dredging and the water quality of the return flow water from the dredge spoil pond.

The evaluation of the water quality of the sediment/water column interface and the return flows from the dredge spoil pond consisted of the analysis of two elutriate (i.e., wash the sediment, settle, and decant) samples. Water quality at the water column/sediment interface is important to evaluate any potential toxicity issues created by the disturbance of the sediment during dredging. The return flow water quality is evaluated to identify any quality issues for the discharge of the return flows to the Nueces River basin. Elutriate samples were created by mixing Lake Corpus Christi water and sediment, at a method-specified ratio, allowing it to settle, and then analyzing the decanted water.

[3] U.S. Army Corps of Engineers, "Beneficial Uses of Dredged Material," June 1987.

The sediment sample was collected approximately mid-way along the length of Lake Corpus Christi, on the west side of the islands. Two water and sediment samples for the elutriate analysis were collected; a water and sediment sample (#1) was collected on the east side of the lake between the Lakeside and Lakeview subdivisions, and a second water and sediment sample (#2) was collected on the east side of the lake, south of Rufe Williams Hollow.

None of the data exceeded the standards or criteria evaluated. Based on the limited number of samples collected and analyzed, there are no apparent issues related to sediment and return flow quality.

Sample #2 was also analyzed for certain physical soil parameters. The results are shown in Table 5A.11-6. The results indicate that the sampled material is a fairly porous, non-plastic (Plasticity Index (PI) = 0), sandy soil.

5A.11.7.2 Potential for Viable Market for Use or Sale of Dredged Material

Results of analytical tests performed on the sediment samples do not rule out potential beneficial uses of the dredged material. The physical properties of the material (sandy soil with no plasticity) would also indicate that it may be suitable for certain uses in the construction industry. Material with a PI between 8 and 20 is generally considered to be a suitable select fill. Based on the limited number of samples collected and analyzed, it appears that the dredged material could be used as fill for certain construction purposes or surface mine reclamation. In the past, sand has been mined from designated local marine dredge disposal sites and used for concrete sand, asphalt binder sand, trench backfill and pipe bedding. The material had a value of approximately $1.00/CY.

Table 5A.11-6.
Physical Properties of Lake Corpus Christi Sediment

Parameter	Method	Results
Moisture Content	ASTM D2216	29.9%
(Gravimetric - % dry weight at 105^{o}C)		
Moisture Content	TNRCC RG-91, 2.2.2.1	0.44 cm^3/cm^3
(Volumetric)		
Porosity	ASTM D2166	0.44 cm^3/cm^3

Bulk Density	ASTM D2166	1.93 g/cm^3
Dry Density	ASTM D2166	1.49 gm/cm^3
Intrinsic Permeability	*	4.2x 10^{-9}cm^2
Atterberg Plasticity	ASTM D4318	No plasticity
*Falling Head Rigid Wall test EM-1110-2-1906, Corps of Engineers		
Sieve Analysis		
Sieve	Percent finer	
#4	100.0	
#10	99.8	
#20	99.4	
#40	96.5	
#60	83.2	
#70	73.5	
#100	72.8	
#140	35.5	
#200	26.8	

One primary factor that would impact the value of material dredged from Lake Corpus Christi is the relative locations of the disposal site and end use. Since the majority of new construction work is performed in the immediate Corpus Christi area, disposal areas located as far south of Lake Corpus Christi as possible would minimize the impact of transportation costs to haul the material.

The area of western San Patricio County bounded by IH-37 to the north, the Nueces River to the south, FM 666 to the west and Edroy to the east, may contain sites suitable for disposal of the dredged material. However, material is available from existing sand pits that are closer to the Corpus Christi metropolitan area. This fact would reduce the market value of the dredged material for construction use.

5A.11.7.3 Yield Restored through Dredging

Previous studies indicate that the removal of 60 million CY (37,200 acft) of sediment from Lake Corpus Christi has the potential to increase the firm yield of the reservoir system by about 9,000 acft/yr. This would be the approximate gain in yield after the 30 years of dredging. In the initial years of dredging, the yield increase would be much less and would increase, on the average, by about 300 acft/yr.

Two disposal scenarios are presented in the cost estimate summary (Table 5A.11-7). The best-case scenario assumes that the dredged material has a value of $0.50/CY. The annual cost for this scenario includes an annual income of $3,000,000 for the 6 million CY that are dredged. Disposal scenario 2 assumes that the dredged material has no value but is removed from the disposal site at no cost to the user.

5A.11.8 Description of Recent Similar Project in Texas

The U.S. Army Corps of Engineers (Fort Worth District Office) was contacted in order to identify similar dredging projects in Texas. The White Rock Lake dredging project in Dallas provides a recent case history that is relevant to a potential dredging project in Lake Corpus Christi.

Table 5A.11-7.
Project Cost Summary
Removal of Sediment from Lake Corpus Christi
(Second Quarter 1999 Prices)

Item	*Estimated Costs*	
Capital Costs		
Disposal Area Construction	$4,200,000	
Total Capital Costs	**$4,200,000**	
Engineering, Legal Costs and Contingencies	$7,155,000	
Environmental & Archaeological Studies and Mitigation	3,650,000	
Land Acquisition and Surveying	4,162,000	
Interest During Construction (1 year)	383,000	
Total Project Cost	**$19,550,000**	
	Disposal Scenario One [1]	Disposal Scenario Two [2]
Annual Costs		

Debt Service (6 percent for 30 years)	$ 1,420,000	$ 1,420,000
Dredging Costs	11,400,000	11,400,000
Booster Station Installation/Operation	6,300,000	6,300,000
Discharge Pipeline Installation/Operation	7,800,000	7,800,000
Operation and Maintenance	1,263,000	1,263,000
(disposal area)		
Sale of Dredged Material	(3,000,000)	0
Total Annual Cost	**$30,633,000**	**$33,633,000**
Available Project Yield (acft/yr)	9,000	9,000
Annual Cost of Water ($ per ac ft)	$3,404	$3,737

[1] Assumes dredged material is sold to others for unit price of $0.50/CY.
[2] Assumes dredged material is removed from disposal area by others at no cost.

5A.11.8.1 White Rock Lake – Dallas, Texas

In 1997, the City of Dallas completed the White Rock Lake restoration project, which included the dredging of approximately 3 million CY (in situ volume) of accumulated silt from a lake area of approximately 500 acres. The hydraulically dredged material was transported approximately 17.5 miles by means of temporary 24-inch diameter, above-ground pipeline to a designated upland dredged material disposal site.

The disposal site consisted of a large abandoned gravel mining area. Dredged sediments were placed in a manner that prevented runoff onto adjacent property. Valves were located on the discharge pipeline at the disposal site so flow could be diverted into several different abandoned gravel pits, which served as containment areas. Decanted water from the containment areas discharged over weirs into return ditches that flowed to adjacent natural watercourses.

5A.11.8.2 Estimated Construction Costs

Table 5A.11-8 shows actual construction costs for the White Rock Lake project described above, compared to the estimated costs presented in the Trans-Texas Water Program Phase II Report, dated September 1995.

Table 5A.11-8.
Project Cost Summary

White Rock Lake Restoration Dredging Project
Dallas, Texas

Item	*Description*	*Construction Cost (Note)*	*Unit Cost per CY Dredged*	*Estimated Dredging Costs (Trans-Texas Water Program Phase II Report, dated September 1995)*
1.	Mobilization/Demobilization	$200,000	$0.06/CY	$ 0.10/CY
2.	Dredging	$6,505,640	$2.00/CY	$1.40 to $2.85/CY
3.	Booster Stations	$3,500,000	$1.08/CY	$1.60 to $3.20/CY
4.	Discharge Piping	$4,399,000	$1.36/CY	
5.	Disposal Area	$2,300,000	$0.71/CY	$0.90 to $1.85/CY
Total		$16,904,640	$5.21/CY	$5.00 to $10.00/CY

Notes:
1. Project completed in late 1997.
2. Total volume dredged = 3,235,000 cubic yards.
3. Disposal area located approximately 17.5 miles from lake.

As shown, the total unit cost for construction of the White Rock Lake project ($5.21/CY) is approximately 4 percent higher than the lower range of costs estimated in the Trans-Texas Report ($5.00 to $10.00/CY). The White Rock Lake project is similar to the Lake Corpus Christi project in terms of volume of material dredged and distance from reservoir to disposal area.

Conclusions of this section of the report, related to project cost, are as follows:

- The minimum unit cost for a 2 million CY dredging project to remove sediment in Lake Corpus Christi is estimated to be approximately $5.20/CY.
- Economy of scale may lower the minimum cost for a larger dredging project (e.g., a 6 million CY project could potentially lower the unit cost by an estimated 8 to 10 percent).
- It is possible, however, for certain environmental and technical factors to result in unit costs for construction that are estimated to range up to $7.00 to $8.00/CY.
- The minimum unit cost for a project to dredge less than 2 million CY are estimated to be approximately $5.80/CY.

5A.11.9 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 5A.11-9.

Table 5A.11-9.
Evaluation Summary of Removal of Sediment from Lake Corpus Christi

Impact Category	***Comment(s)***
a. Quantity, reliability, and cost of treated water	• Long-term yield (30 yr) = 9000 acft/yr • High cost: $3,404 to $3,737/acft
b. Environmental factors	• Disturbance of sediments in LCC • Disposal of removed sediments • Cultural resources will need to be surveyed and avoided where possible
c. State water resources	• Potential negative impacts on water quality in LCC during dredging
d. Threats to agriculture and natural resources in region	• Potential threats to habitat due to disposal of dredge material
e. Recreational	• None
f. Comparison and consistency equities	• 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	• Provides for improved efficient use of LCC
j. Effect on navigation	• None

5A.12 Stage II of Lake Texana (Lavaca-Navidad River Basin)

5A.12.1 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 1 is operated by LNRA primarily for water supply purposes and has a firm yield of 79,000 acft/yr. In 1999, 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. Water supply from the development of Stage II is being evaluated as part of an inter-regional water supply by both the Coastal Bend Regional Water Planning Group (Region N) and the South Central Texas Regional Water Planning Group (Region L). 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.

The South Central Regional Water Planning Group is also considering Stage II as part of the following water supply options:

- Exchanging Stage II water for coastal area irrigation surface water rights now being met from streamflow and upstream storage in the Guadalupe River (delivery to the Saltwater Barrier for supplying the Calhoun Canal Division). The coastal area irrigation rights would be converted to municipal usage and diverted at a point to deliver water to the major demand center of the South Central Region; and
- Exchanging Stage II water for coastal area irrigation surface water rights now being met from streamflow and upstream storage in the Lower Colorado River (delivery to Bay City for local irrigators). The coastal area irrigation rights would be converted to municipal usage and diverted at a point to deliver water to the major demand center of the South Central Region

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, recent 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 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. Recent studies of the Matagorda Bay[3] indicate that releases made from Lake Texana exceed the mitigation requirements and in some cases 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.[4] 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.[5] Therefore, it is assumed that releases from Stage II will be in accordance with the Consensus Criteria for maintenance of the river reach just below the dam.

Figure 5A.12-1 shows the location of Stage II and route of the Mary Rhodes Memorial Pipeline. Also shown by dashed lines are the two other potential delivery points for Stage II

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[1] HDR Engineering, Inc. (HDR), "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.
[2] Texas Natural Resource Conservation Commission (TNRCC) Certificate of Adjudication No. 16-2096B, 1994.
[3] Lower Colorado River Authority, "Freshwater Inflow Needs of the Matagorda Bay System," December 1997.
[4] Texas Water Development Board (TWDB), "Environmental Water Needs Criteria of the Consensus Planning Process", January 1996.
[5] Personal communications with Gary Powell, TWDB, July 1999.

water being considered by the South Central Regional Planning Group. One of the potential projects delivers water from Stage II to coastal irrigation areas either near the Colorado River at Bay City and the other delivers Stage II water to the Guadalupe River near the Saltwater Barrier. Each option will require an intake station at the Stage II reservoir site, a transmission line, and an outlet structure. The Bay City and Saltwater Barrier options will require storage at the pipeline outfalls to accommodate seasonal diversion patterns associated with irrigation.

5A.12.2 Available Yield

At the alternative 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. After 50 years of sediment accumulation, the conservation storage capacity is reduced to 47,200 acft. Table 5A.12-1 shows the elevation, area, and capacity data for the site for initial conditions and after 50 years of accumulated sediment.

The firm yield of Stage II operated separately from Lake Texana was calculated for each of the three potential projects and for a seasonal demand pattern used by the TWDB in determining the yield at the original Stage II site for both the initial conditions and after 50 years of sediment accumulation. 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 the three delivery options, and simulation of the Stage II reservoir operations.

An 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 TNRCC 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

Table 5A.12-1.
Palmetto Bend Stage II
Elevation, Area and Capacity Table

Elevation (ft-msl)	*Initial Conditions*		*2050 Conditions*[1]	
	Area (acres)	*Capacity (acft)*	*Area (acres)*	*Capacity (acft)*
44.0 (Top of Pool)	4,697	57,676	4,697	47,592
40.0	3,888	40,543	3,371	31,148
35.0	2,940	23,475	2,418	16,675
30.0	1,774	11,695	1,336	7,291
25.0	914	4,980	589	2,478
20.0	352	1,819	142	644
15.0	138	596	30	201
10.0	40	152	7	93
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.

utilizing the average of published[6] 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 TNRCC's published water quality standards.[7] Table 5A.12-2 shows the daily release (inflow passage) requirements from Stage II.

Since each of the potential projects involve different types of usage in different geographic regions, different demand patterns were used for calculating the yield in each option. Table 5A.12-3 displays the monthly demand factors used for each delivery point. The first demand pattern in the table reflects the City of Corpus Christi's municipal demand pattern and the second two patterns represent the seasonal irrigation demands at the Guadalupe River

[6] TWDB, "Monthly Reservoir Evaporation Rates for Texas, 1940 through 1965," Report 64, October 1967.
[7] Texas Administrative Code, Chapter 307, Texas Surface Water Quality Standards.

Table 5A.12-2.
Consensus Criteria Release Requirements (cfs)
for Palmetto Bend Stage II

Month	Consensus Criteria Zone 1 >80% Capacity	Consensus Criteria Zone 2 <80% to >50% Capacity	Consensus Criteria Zone 3 <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	35.4	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

Saltwater Barrier and at Bay City, respectively. The fourth demand pattern is the generic seasonal pattern used by the TWDB in their determination of Stage II firm yield.

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 5A.12-3. Under initial conditions, the yields range from 27,900 acft/yr using the TWDB seasonal demand pattern to 30,200 acft/yr for the Bay City option. 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 50 years of sedimentation, the yields range from 22,800 acft/yr using the TWDB seasonal demand pattern to 25,000 acft/yr for the Bay City option. The delivery of Stage II water based on the City of Corpus Christi's demand pattern results in a yield of 23,000 acft/yr. Table 5A.12-4 compares initial condition yields to those calculated after 50 years of sedimentation.

Table 5A.12-4.
Palmetto Bend Stage II Firm Yields
Consensus Criteria vs. No Releases

Option	Firm Yield (acft/yr)			
	Initial Conditions		2050 Conditions	
	Consensus Criteria	No Releases	Consensus Criteria	No Release
Delivery to Lake Texana	28,200	32,300	23,000	27,000
Delivery to the Saltwater Barrier	28,100	32,000	23,300	26,900
Delivery to Bay City	30,200	34,700	25,000	29,200
TWDB Analysis	27,900	32,000	22,800	26,800

Table 5A.12-4 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 four cases analyzed. After 50 years of sedimentation, the releases reduce the yield by an average of 3,950 acft/yr.

Figure 5A.12-2 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 simulations are not plotted but exhibit similar behavior to that shown in Figure 5A.12-2. Storage frequency plots for the above two conditions are shown in Figure 5A.12-3. Each plot shows the storage frequency at the firm yield of Stage II 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.

5A.12.3 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 5A.12-5. 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" (LCRA, 1997). The changes in streamflow in the Lavaca River and the inflows into Lavaca Bay resulting from Stage II operation are shown in Figure 5A.12-4. 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 chart shows the monthly median flows in the Lavaca River 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.[8]

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

[8] 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.

Table 5A.12-5. 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 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

Table 5.12-5 (continued)

Common Name	Scientific Name	Summary of Habitat Preference	Listing Agency			Potential Occurrence in County
			USFWS[1]	TPWD[1]	TOES[2,3,4]	
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
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

range of salinity gradients that generally exhibit more or less predictable seasonal patterns. 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 extirpated by construction of Stage II.

The slight decrease in estuarine inflows associated with implementation of Stage II (Figure 5A.12-4) 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 (LCRA, 1997).

In addition to the Palmetto Bend Stage II Reservoir, this option includes three alternatives for the diversion of Stage II water. The alternative pipelines would divert water from Palmetto Bend to one of the three following areas: Lake Texana, the Guadalupe River near the Saltwater Barrier, or Bay City in Matagorda County. The reservoir and all three pipeline routes 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 three pipeline routes or the reservoir are listed in Table 5A.12-5. The Texas Natural Heritage Program (NHP) maps two plants, the Threeflower Broomweed (*Thurovia triflora*) and Welder Machaeranthera (*Psilactis heterocarpa*), on the pipeline route from Palmetto Bend to the Guadalupe River. 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 also passes through two rookeries, a wildlife management area, and ends near an area where endangered Attwater's Greater Prairie Chickens have been sighted.

All three pipeline routes pass through or in the vicinity of Bald Eagle (in 1999, downgraded from endangered to threatened status) habitat. The NHP has mapped Bald Eagle habitat on the Guadalupe River near the Saltwater Barrier, which the proposed pipeline to this area would border for approximately 10 miles. A second Bald Eagle habitat, which extends south from Lake Texana along the Lavaca and Navidad Rivers, could be affected by the construction of Palmetto Bend Stage II Reservoir or the proposed pipelines to Lake Texana or Bay City. 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 one of the three proposed pipelines, 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.

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.

5A.12.4 Engineering and Costing

The annual 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 5A.12-6. With a total project cost of $124,414,000 financed over 40 years at 6 percent, the annual debt service of constructing Stage II is $8,269,000. Annual operation and maintenance costs are estimated at $1,019,000, resulting in a total annual cost of $9,288,000 for constructing and maintaining Stage II. For an estimated firm yield of 23,000 acft/yr in year 2050, the annual cost of raw water at the reservoir would be $404 per acft. The facilities and costs involved with delivering Stage II raw water to the three potential usage locations are discussed below. Each option includes the total annual costs of constructing and maintaining Stage II.

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 capital costs associated with these facilities are shown in Table 5A.12-7. The total estimated capital cost of the new facilities is $7,097,000. An additional $1,639,000 of capital would be necessary to upgrade the existing pumping facilities to deliver the additional water. The total project cost with the reservoir is $138,056,000. 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 $9,260,000. The annual costs for operations and maintenance and power are estimated at $2,896,000, which includes $1,741,000 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 $12,133,000. Dividing annual cost by the year 2050 firm yield equates to an annual cost of $528 per acft (Table 5A.12-7).

If Stage II raw water is delivered to coastal irrigation areas in the lower Guadalupe River, an intake pump station, a 44-mile transmission line, and an outlet structure will be necessary. The total capital costs of the facilities is estimated at $55,265,000. The annual debt service of the new transmission facilities is $6,328,000. The total annual cost, including the reservoir, equals $16,427,000. Dividing the annual cost of the transmission facilities and the reservoir by the firm yield of 23,300 acft/yr results in an annual raw water cost of $705 per acft (Table 5A.12-7).

Table 5A.12-6.
Cost Estimate Summary
Palmetto Bend Stage II Dam and Reservoir
(Second Quarter 1999 Prices)

Item	Estimated Costs
Capital Costs	
Dam and Reservoir (Conservation Pool: 57,676 acft; 4,679 acres; 44 ft-msl)	$3,226,000
Mobilization	1,183,000
Care of Water	2,283,000
Spillway	32,428,000
Excess Excavation Disposal Berms & Drainage Channels	5,217,000
Upstream Slope Protection	1,135,000
Underdrain System	583,000
Channel Slope Protection	1,239,000
Revegetation	785,000
Clearing	1,312,000
Relocations	18,014,000
Total Capital Cost	**$67,967,000**
Engineering, Legal Costs, and Contingencies	$23,788,000
Environmental & Archaeological Studies and Mitigation	7,380,000
Land Acquisition and Surveying (8,200 acres)	8,118,000
Interest During Construction (4 years)	17,161,000
Total Project Cost	**$124,414,000**
Annual Costs	
Reservoir Debt Service (6 percent for 40 years)	$8,269,000
Operation and Maintenance	1,019,000
Total Annual Cost	**$9,288,000**
Available Project Yield – year 2050(acft/yr)	**23,000**
Annual Cost of Water ($ per acft) Raw Water at Reservoir	**$404**
Annual Cost of Water ($ per 1,000 gallons) Raw Water at Reservoir	**$1.23**

Table 5A.12-7.
Cost Estimate Summary
Palmetto Bend Stage II Dam and Reservoir
(Second Quarter 1999 Prices)

Item	*To Lake Texana*	*To Saltwater Barrier*	*To Bay City*
Capital Costs			
Dam and Reservoir (Conservation Pool: 57,676 acft; 4,679 acres; 44 ft-msl)	$67,966,000	$67,966,000	$67,966,000
Intake and Pump Station (33 MGD; 85 MGD; 76 MGD)	3,286,000	9,748,000	9,422,000
Outlet Structure	139,000	1,668,000	1,668,000
Transmission Pipeline (54-inch 4.5-mile; 64-inch 44-mile; 64-inch 46-mile)	3,672,000	43,849,000	46,314,000
Improvements to Lake Texana System	1,639,000	0	0
Total Capital Cost	**$76,702,000**	**$123,231,000**	**$125,370,000**
Engineering, Legal Costs, and Contingencies	$26,491,000	$40,368,000	$41,009,000
Environmental & Archaeological Studies and Mitigation	7,493,000	8,528,000	8,585,000
Land Acquisition and Surveying (8,222 acres; 8,412 acres; 8,423 acres)	8,327,000	10,209,000	10,315,000
Interest During Construction (4 years)	19,043,000	29,175,000	29,646,000
Total Project Cost	**$138,056,000**	**$211,511,000**	**$214,925,000**
Annual Costs			
Debt Service (6 percent for 30 years)	$991,000	$6,328,000	$6,576,000
Reservoir Debt Service (6 percent for 40 years)	8,269,000	8,269,000	$8,269,000
Operation and Maintenance			
Intake, Pipeline, Pump Station	113,000	632,000	643,000
Dam and Reservoir	1,019,000	1,019,000	1,019,000
Pumping Energy Costs (290,000 MWh; 2,983 MWh; 5,834 MWh @ $0.06 per kWh)	1,741,000	179,000	350,000
Total Annual Cost	**$12,133,000**	**$16,427,000**	**$16,857,000**
Available Project Yield (acft/yr)	**23,000**	**23,300**	**25,000**
Annual Cost of Water ($ per acft) Raw Water Delivered[1]	**$528**	**$705**	**$674**
Annual Cost of Water ($ per 1,000 gallons) Raw Water Delivered[1]	**$1.62**	**$2.16**	**$2.07**

[1] Reported Annual Cost of Water is for raw water delivered to specified location and does not include costs associated with treatment and distribution within municipal systems.
[2] Average annual power costs over 50 years.

Delivering Stage II raw water to coastal irrigation areas near Bay City will require an intake and pump station, a 46-mile transmission line, and an outlet structure. The total capital cost of the facilities is estimated at $57,404,000. The annual debt service of the transmission facilities is $6,576,000. The total annual cost, including the reservoir, equals $16,857,000. Dividing the annual cost of the transmission facilities and reservoir by the firm yield of 25,000 acft/yr results in an annual raw water cost of $674 per acft (Table 5A.12-7).

The option to deliver the water to Corpus Christi has a lower 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 specified locations. They do not include the additional costs necessary to deliver water to the South Central Texas Region in exchange for Stage II water.

5A.12.5 Implementation Issues

Implementation of Palmetto Bend Stage II Reservoir with potential delivery of raw water to Corpus Christi (via Lake Texana), to the Guadalupe River Saltwater Barrier, or to the Bay City area could directly affect the feasibility of other water supply options under consideration by the Coastal Bend Region and the South Central Texas 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 TNRCC will also be required to implement any of the option discussed above.

The projected 2050 water supplies of the Lavaca River Basin exceed projected 2050 water demands by 41,508 acft.[9] The transfers of 23,000 acft/yr to Corpus Christi from the development Stage II would decrease the surplus in 2050 to 18,508 acft.

Requirements Specific to Reservoirs

1. It will be necessary to obtain these permits:
   a. TNRCC 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.

[9] HDR and Paul Price Associates, Inc., "Engineering and Environmental Assessment Report on Application of the Lavaca-Navidad River Authority and the Texas Water Development Board to Amend Certificate of Adjudication No. 16-2095," September 1995.

   c. GLO Sand and Gravel Removal permits.
   d. GLO Easement for use of state-owned land.
   e. Coastal Coordination Council review.
   f. TPWD 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.

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. TPWD 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.

5A.12.6 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 5A.12-8.

Table 5A.12-8.
Evaluation Summary of Stage II of Lake Texana

Impact Category	***Comment(s)***
a. Quantity, reliability, and cost of treated water	• Firm yield: 23,000 to 25,000 acft/yr • Generally moderate cost; between $528 to $705 per acft
b. Environmental factors	• Direct impacts to 4,679 acres from reservoir impoundment • Cultural resources will need to be surveyed and mitigation for significant sites implemented • Negligible impact to Lavaca Bay
c. 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	• Increase in recreational use opportunities
f. Comparison and consistency equities	• 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

5A.13 Garwood Pipeline (Colorado River Basin) and Other Interbasin Transfers

5A.13.1 Description of Strategy

Interbasin transfer of water is already a part of the Coastal Bend Region's water supply. In 1999, the Mary Rhodes Memorial Pipeline was completed 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. 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 Lavaca-Navidad River Authority'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 currently uses a large part of its right for irrigation of land that is located in the Lavaca-Navidad River Basin. In 1993, TNRCC 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, TNRCC 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

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[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]

- Diversion of unappropriated streamflow and/or reclaimed water from the San Antonio River near Falls City and transferring it via pipeline to Choke Canyon Reservoir for water exchanged under a cooperative development of water supply with the City of Corpus Christi for the mitigation of effects of aquifer recharge enhancements on the yield of the CCR/LCC System.
- Diversion of enhanced supply in the CCR/LCC System from Choke Canyon Reservoir to the major demand center of the South Central Texas Region (in Bexar County). The CCR/LCC System yield would be enhanced by the delivery of water to the City of Corpus Christi from the Guadalupe River at the Saltwater Barrier under existing water rights purchased by the South Central Region.
- Diversion of enhanced supply in the CCR/LCC System from Choke Canyon Reservoir to the major demand center of the South Central Texas Region (in Bexar County). The enhanced supply in the CCR/LCC System would be created by the delivery of water to the City of Corpus Christi from the Guadalupe River at the Saltwater Barrier under existing water rights purchased by the South Central Region and by the delivery of unappropriated streamflow and treated effluent from the San Antonio River at Falls City.
- Exchanging available water after the construction of Palmetto Bend Stage II Dam (i.e., Stage II of Lake Texana) and Reservoir in the Lavaca-Navidad River Basin for coastal area surface water rights and/or options owned by Corpus Christi on the Colorado River. The Colorado River water would 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.

The first three options involve enhancing the CCR/LCC System yield through imports from the San Antonio River or Guadalupe River Basins. The forth option involves exchanging the water supply available after the construction of Palmetto Bend Stage II Dam and Reservoir in exchange for surface water rights purchased by the City of Corpus Christi from the Garwood Irrigation Company. The final water supply plan developed for the South Central Texas Region by the South Central Texas Regional Water Planning Group ended up not including these options. However, a detailed analysis of the development of Palmetto Bend Stage II is included

[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., August 2000.

in Section 5A.12 of this report. The remaining portion of this section focuses on the delivery of the Garwood Purchase to the City of Corpus Christi.

During the TNRCC permitting of the Texana Pipeline facilities on the U.S. Bureau of Reclamation (USBR) property at Lake Texana, the USBR indicated that it will exclude the Colorado River water purchased by the City of Corpus Christi from entering Lake Texana and this restriction was placed in the TNRCC permit authorizing Corpus Christi's use of the Garwood water. This requirement requires routing the pipeline and transmission facilities around Lake Texana, a diversion site near Bay City, and joining the pipeline from the Colorado River to the Texana Pipeline. The diversion site is located at an existing diversion dam near Bay City, and a pipeline to Lake Texana is needed to deliver the water to the Texana Pipeline at a point just downstream of Lake Texana for transmission to Corpus Christi (hereinafter referred to as the Garwood Pipeline).

Two options are available for delivering the Garwood Purchase to the Texana Pipeline, which are as follows:

1. Deliver the water at a peak diversion rate directly from the Colorado River to the Texana Pipeline.
2. Deliver the water at a uniform annual rate to the Texana Pipeline, utilizing an off channel storage site near the Colorado River diversion site.

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 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, which is evaluated in this section. The Colorado River water is diverted at a maximum rate during times of high flow, and is stored in the ring-dike reservoir. This provides a dependable water source during periods of drought for uniform delivery of the Garwood Purchase to the Texana Pipeline. Figure 5A.13-1 shows the location of the potential delivery route near Bay City to Corpus Christi.

5A.13.2 Available Yield

Previous studies[3,4] 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 Colorado River Daily Allocation Program (DAP). The DAP model was developed by LCRA and has been used extensively to evaluate the water availability in the Lower Colorado River Basin. A major assumption of the DAP model is in the daily simulation of water right diversions. Run-of-river water rights are issued subject to specified maximum annual and instantaneous diversion rates. For the significant water rights on the Lower Colorado River, there are no restrictions (other than the maximum pumping rate) as to when within the year that water may be diverted or how much of it may be used consumptively. This situation makes it difficult to model different conditions outlined in the water right permits.

While the DAP computer model is fairly comprehensive in addressing both the water rights and the hydrologic aspects of the Lower Colorado River System, it is still only an approximate representation of the real world system. One of the limitations is in the accuracy and the detail of the available records describing streamflows, return flows, and diversion which went into the derivation of the inflow data files. In addition to the data limitations are the computational limits and the simplifying assumptions of the DAP model. Several of the most important assumptions and limitations are as follows:

- All water rights attempt to divert at their fully authorized permit amount;
- The DAP model uses a fixed demand pattern with day-by-day values for each modeled water right. In the event of a shortage of water for a water right on any given day, DAP is not capable of carrying this over to the next day(s) to try and satisfy the remaining demand later. The net result of this limitation is that cumulative annual shortages for any given water right are somewhat over estimated;
- Demand patterns are the same from year to year which fails to reflect agricultural users reduction in demand in wet years;
- Return flows from the City of Austin's wastewater treatment plant are fixed, regardless of how much water the City diverts; and

[3] HDR, "Trans-Texas Water Program—Corpus Christi Study Area—Phase II Report," City of Corpus Christi, et al., September 1995.
[4] HDR, "Dependability and Impact Analyses of Corpus Christi's Purchase of the Garwood Irrigation Company Water Right," Draft Report, September 1998.

- The routing of streamflow downstream is calculated assuming constant travel and reach characteristics that in reality would vary with the magnitude of the streamflow.

The following conditions were applied to the DAP model, for modeling the availability of the Garwood Purchase:

- 35,000 acft/yr is diverted according to a uniform demand pattern with a maximum daily diversion rate of 150 cfs;
- 35,000 acft/yr is subordinate only to the remaining 133,000-acft/yr of the original Garwood Irrigation Company water right.
- Austin return flows are set to 75,000 acft/yr, which represents the City's current conditions. It is estimated that future return flows from Austin would be in excess of 75,000 acft/yr.

The DAP model predicts that the full 35,000 acft/yr of the Garwood Purchase can be diverted during the critical drought under the maximum diversion rate of 150 cfs. For evaluation of this option, DAP was operated with each right diverting at its maximum specified rate. Under this scenario, DAP allows the Garwood Purchase to divert up to 108,000 acft/yr (150 cfs for 365 days). (Note: In actual practice, diversions would be stopped when a total of 35,000 acft had been diverted.)

The off channel storage required for uniform delivery of the 35,000 acft/yr Garwood Purchase was also determined utilizing output from the DAP model. Various diversion rates and storage volumes were analyzed to determine the most dependable uniform water supply. 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. In addition, it was determined that the water should be pumped from the Colorado River at the maximum diversion rate, which is 150 cfs.

5A.13.3 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.

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 5A.13-1. 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.

Table 5A.13-1.
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

Table 5A.13-1 (continued)

Common Name	Scientific Name	Summary of Habitat Preference	Listing Agency			Potential Occurrence in County
			USFWS[1]	TPWD[1]	TOES[2,3,4]	
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
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 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 Colorado, Wharton, and Matagorda Counties, has substantially altered the annual hydrography of the lower river (below Austin) from its historical condition.[5]

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 Austin to Bay City).[6] 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

[5] Mosier, D.T. and R.T. Ray, "Instream flows for the Lower Colorado River," Lower Colorado River Authority (LCRA), Austin, Texas, 1992.
[6] Ibid.

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 U.S. Army Corps of Engineers 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), but hydrologic and modeling studies are still in progress.[7]

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 might be expected to benefit shrimp and some other aquatic species. However, in relation to natural variation in instream flows changes in freshwater inflows before and after the construction of Choke Canyon Reservoir and Lake Corpus Christi can be difficult to detect statistically.[8] The effect of additional freshwater contributed by this alternative alone would be negligible.

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.

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[7] Texas Water Development Board (TWDB), Unpublished data, "Bay and Estuaries Study Program," TWDB, Austin, Texas, 1990.
[8] Longley, W.L. ed., "Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs," TWDB and Texas Parks and Wildlife Department, Austin, TX, 386 pp., 1994.

Plant and animal species listed by TPWD, USFWS, and TOES that may be within the vicinity of the pipeline routes are listed in Table 5A.13-1.

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.

5A.13.4 Engineering and Costing

The major facilities required for pumping the Garwood Purchase from Bay City directly to the Texana Pipeline facilities and then to the City of Corpus Christi via the Texana Pipeline are:

- Surface water intake and pump station near Bay City;
- Transmission pipeline (41 miles) from Colorado River near Bay City 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.

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 are:

- Surface water intake and pump station near Bay City;
- Transmission pipeline from the Colorado River near Bay City to an 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.

Tables 5A.13-2 and 5A.13-3 provide a cost breakdown for each of the possible options of delivery the Garwood Purchase.

The total capital cost for building the transmission facilities to deliver water at a peak flow rate from Bay City to the Texana Pipeline is $56,648,00. This cost includes $1,640,000 of capital cost associated with upgrading the Texana Pipeline pumping facilities. After land acquisition costs and cost for engineering, legal, environmental mitigation, and interest during construction, the total project cost comes to $83,250,000. 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 $8,865,000. The energy costs include the additional power necessary to deliver the 35,000 acft/yr through the Texana Pipeline. Dividing by 35,000 acft/yr equates to an annual cost of $253 per acft.

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 $50,079,000. After land acquisition costs and cost for engineering, legal, environmental mitigation, and interest during construction, the total project cost comes to $75,010,000. 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 $9,064,000. As before, 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 $259 per acft.

Table 5A.13-2.
Cost Estimate Summary for
Garwood Pipeline Peak Delivery Rate Option
(Second Quarter 1999 Prices)

Item	Estimated Costs for 64-inch Pipeline"
Capital Costs	
Intake and Pump Station	$11,642,000
Transmission Pipeline (41 miles)	43,066,000
Texana Upgrade	1,640,000
Other (Access Road/Power Connection)	300,000
Total Capital Cost	**$56,648,000**
Engineering, Legal Costs and Contingencies	$16,995,000
Environmental & Archaeology Studies and Mitigation	1,027,000
Land Acquisition and Surveying (204 acres)	2,413,000
Interest During Construction (1.5 years)	6,167,000
Total Project Cost	**$83,250,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$6,048,000
Operation and Maintenance:	
Intake, Pipeline, Pump Station	697,000
Pumping Energy Costs[1]	2,120,000
Total Annual Cost[2]	**$8,865,000**
Available Project Yield (acft/yr)	**35,000**
Annual Cost of Water ($ per acft)	**$253**
Annual Cost of Water ($ per 1,000 gallons)	**$0.78**

[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 5A.13-3.
Cost Estimate Summary for
Garwood Pipeline Uniform Delivery Rate Option
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Off Channel Storage Reservoir (8,000 acft)	$9,344,000
Intake and Pump Station at Colorado River (150 cfs)	$6,342,000
Intake and Pump Station at Off Channel Storage (48 cfs)	$4,386,000
Transmission Pipeline (64-inch from Colorado River, 5.9 miles)	$5,170,000
Transmission Pipeline (48-inch from Off Channel Storage, 35.6 miles)	$22,938,000
Storage Tank	$1,129,000
Other (Access Roads/Stilling Basin)	$770,000
Total Capital Cost	**$50,079,000**
Engineering, Legal Costs and Contingencies	$15,260,000
Environmental & Archaeology Studies and Mitigation	$1,605,000
Land Acquisition and Surveying (781 acres)	$3,020,000
Interest During Construction (2 years)	$5,046,000
Total Project Cost	**$75,010,000**
Annual Costs	
Debt Service (6 percent, 30 years)	$4,088,000
Reservoir Debt Service (6 percent, 40 years)	$954,000
Operation and Maintenance:	
Intake, Pipeline, Pump Station	$568,000
Dam and Reservoir	$140,000
Pumping Energy Costs[1]	$3,314,000
Total Annual Cost[2]	**$9,064,000**
Available Project Yield (acft/yr)	**35,000**
Annual Cost of Water ($ per acft)	**$259**
Annual Cost of Water ($ per 1,000 gallons)	**$0.79**

[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.

Delivering the Garwood Purchase to the Texana Pipeline at a uniform rate results in a slightly higher annual cost than utilizing a peak delivery rate, despite the lower project cost associated with this option. This is due to the higher energy costs required to pump the water during the entire year through a smaller pipeline. As shown in the itemized cost tables, the peak delivery rate option requires upgrades to the Texana Pipeline, while the uniform delivery rate option does not exceed the current capacity of the Texana Pipeline.

5A.13.5 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 Lavaca-Navidad River Authority. Implementation of this option would require an agreement with the Lavaca-Navidad River Authority.

In addition to the differences in cost, the water treatment operations associated with each method of 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. Delivery of the Colorado River water directly to the Texana Pipeline at a peak flow rate would produce unpredictable surges in the volume of Colorado River water being delivered. As with both of the delivery options, 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.

A significant benefit is associated with the peak delivery rate option. The Garwood Pump Station and Pipeline would have the capacity to exceed its permitted annual diversion amount of 35,000 acft/yr by 73,000 acft/yr. Therefore, other surface water rights in the Colorado Basin could be purchased and transferred in the pipeline.

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. GLO Sand and Gravel Removal permits.
   c. Coastal Coordinating Council review.
   d. TPWD 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.

5A.13.6 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 5A.13-4.

Table 5A.13-4.
Evaluation Summary of the Garwood Pipeline

Impact Category	***Comment(s)***
a. Quantity, reliability, and cost of treated water	• Firm yield: 35,000 acft/yr • Generally low cost; between $253 to $259 per acft
b. Environmental factors	• Negligible impacts to Colorado River and Lavaca-Colorado Estuary • Cultural Resource Surveys will be required to avoid any significant sites
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. Comparison and consistency equities	• Standard analyses and methods used
g. Interbasin transfers	• Potentially could require the transfer of water from the Colorado River Basin to the Lavaca-Navidad River Basin to the 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

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5A.14 Brush Management

5A.14.1 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 control may result in increased water supplies for municipal, industrial, irrigation and other uses.

More problematic for brush control, 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 control. Some within this group of ranchers may practice brush control, but they do so for reasons other than agricultural economics.

5A.14.2 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 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,[7]

$$\text{Runoff} + \text{Deep Percolation} = \text{Precipitation} - \text{Evapotranspiration}$$

and its variables are defined as follows:

Runoff is water that leaves the watershed through surface flow;

[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] Thurow, T.L., Op. Cit., 1998.

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.[8] Thus, a 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 5A.14-1. 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 control) 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.[9] 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 acre-feet per acre and only 0.28 acre-feet per acre in the grazed tract for the growing season period, approximately April through September.[10]

5A.14.2.1 Areas in Coastal Bend Region Where Potential Yield Increase Exists

An increase in runoff resulting from brush control could result in two potential water supply benefits: increasing recharge of groundwater due to increased sheet and/or stream flow

[8] 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.
[9] Smiens, F., "Ashe Juniper: Consumer of Edwards Plateau Rangeland," Grazing Management Field Day, Sonora, Technical Report 90-1, Pages 17-21, 1990.
[10] 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.

Table 5A.14-1.
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)

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 control. In the Coastal Bend Region, Lake Alice was listed for enhancing the water supply of the City of Alice.

5A.14.2.2 Best Management Practices for Brush Control

In Texas, brush control 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 control. The counties in the area are those having 16 to 36 inches of precipitation per year. Cost of brush control 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 control that the TSSWCB can approve are those that:

1. Are proven effective and efficient for brush control,
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.[11]

Acceptable brush control 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.[12] The standard includes biological, chemical, mechanical and burning methods for brush control. 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 control. A review of Texas Agricultural Extension Service on-line Expert System for Brush and Weed Control Technology Selection, Version 1.09 (Excel)[13] for Jim Wells County provided information on chemical agents for control of brush (Table 5A.14-2).

The mechanical standard prescribes plowing, grubbing, chaining, and dozing as primary brush control methods. In most cases Natural Resources Conservation Service recommends burning to control sprouts. Prescribed burning is a very cost-effective method for controlling the sprouts. In addition, it is how nature controlled the brush before the grassland fires were suppressed. For control of mesquite, blackbrush, post oak, and shin oak the preferred mechanical method is root-plowing or grubbing. Control of these types of brush requires uprooting the plants.

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 control program is to equate rancher costs with rancher benefits. The benefit to ranchers would be the increases in

[11] Texas State Soil and Water Conservation Board, "Draft State Brush Control Plan," April 1, 1999
[12] Natural Resources Conservation Service, Conservation Practice Standard, Brush Management (Acre) Code 314.
[13] http://cnrit.tamu.edu/rsg/exsel/work/exsel.cgi

Table 5A.14-2.
Chemical Agents for Control of Brush

Brush	Chemical Agent	Control Level [1]
Blackbrush	Remedy (triclopyr)	Very high control level
	Spike 20P	Very high control level
Granjeno	Spike 20P	Very high control level
Live Oak	None recommended	
Mesquite	Remedy (triclopyr)	Very high control level
	Reclaim (clopyralid)	Very high control level
	Tordon 22K	Very high control level
	Velpar L	High control level
Post Oak	Velpar L	Very high control level
	Spike 20P	Very high control level
	Crossbow	High control level

[1] Very high means 76 to 100 percent of plants killed; High means 56 to 75 percent killed.

income from cattle, sheep, and wildlife businesses that result from brush control. 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 control 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 control 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 control. Presumably, if the rancher receives no benefits, then the rancher would not be interested in engaging in practices that increase costs. 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.

5A.14.2.3 Cost of Brush Management

Studies have been done to determine brush control costs for rangelands in Texas.[14,15] 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 one watershed within the Nueces River watershed (i.e., Seco Creek watershed in Medina County), 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. Table 5A.14-3 shows the present value in Second Quarter 1999 prices for controlling three different levels of mesquite of the North Concho Watershed near San Angelo, Texas. Costs are presented on a present worth basis because brush control requires an initial (year "0") investment plus a periodic future investment to maintain control.

Table 5A.14-3.
Initial and Interim Costs for Various Brush Control Methods

	One Time Costs		*Recurring Costs*	
Brush Condition (method)	*Year 0 ($/acre)*	*Year 1 or 2 ($/acre)*	*Periodic Cost[1] ($/acre)*	*Frequency of Control (years)*
Heavy mesquite (power grubber)	36.00	15.00	8.60	7
Moderate mesquite (chemical then prescribed burn)	15.00	0	8.60	6
Light mesquite (chemical then prescribed burn)	7.50	0	8.60	6

[1] Costs at intervals shown in column to the right (e.g.; heavy mesquite $8.60 per acre every 7 years.)

Source: Bach, Joel P. and J. Richard Connor, "Economic Analysis of Brush Control Practices for Increased Water Yield: The North Concho River Example," Proceedings, Water for Texas Conference, Austin, Texas, December 1998.

5A.14.2.4 Potential Increased Runoff and/or Deep Percolation Due to Brush Control

A computer simulation for estimating runoff and/or deep percolation was undertaken in the North Concho River Basin in the northern Edwards Plateau near San Angelo, Texas, and for Seco Creek watershed in Medina County.[16] The results of these simulations were then used in an

[14] 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.
[15] Bach, Joel P. and J. Richard Connor, "Economic Analysis of Brush Control Practices for Increased Water Yield: The North Concho River Example," Proceedings, Water for Texas Conference, Austin, Texas, December 1998.
[16] Walker, et al., Op. Cit., December 1998.

economic analysis of brush control undertaken to increase the quantity of runoff and/or deep percolation.[17]

The estimated runoff and/or deep percolation from these brush control simulations varied significantly between the two sites. The runoff and/or deep percolation per unit area of brush control was 30 to 70 times more in the Seco Creek simulation than in the North Concho River simulation (Table 5A.14-4). The values reported in Table 5A.14-4 represent an estimate of the enhanced runoff and/or deep percolation that could be expected from brush control (i.e., the difference between the current condition with brush and the condition without brush).

Table 5A.14-4.
Annual Runoff and/or Deep Percolation
for Brush Controlled Watersheds

Site	Brush Control Scenario	Annual Runoff and/or Deep Percolation	
		gallons per acre	acft per acre
North Concho*	Remove all brush	7,495	0.023
Seco Creek**	Remove all brush	35,192	0.108

Sources: * Bach and Connor, December 1998. ** Walker, et al., December 1998

Other studies in Texas have shown similar effects to those simulated for the Seco Creek 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.[18] However, improvements in deep percolation and runoff quantities would not necessarily result in an increase in aquifer or reservoir yields.

5A.14.2.5 Preliminary Evaluation of Areas within the Coastal Bend Region where Brush Control Can Potentially Increase Runoff and/or Deep Percolation

The Seco Creek simulation reported by Walker, et al., compared the runoff and/or deep percolation between "present" condition and removing all brush. The area of brush controlled at Seco Creek was 15 percent of the 51 square mile (32,750 acres) watershed, which represented removal of all brush on slopes less than 10 percent and replacing brush with grass. There are an

[17] Bach, Joel P. and J. Richard Connor, Op. Cit., December 1998.
[18] Thurow, T. L., Op. Cit., 1998

estimated 4.26 million acres of brush cover located on 10 percent slopes in the Coastal Bend Region (Table 5A.14-5).

Table 5A.14-5.
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	1
Bee	0	137,430	118,344	0	0	255,774	6
Brooks	121,823	2,331	0	434,802	0	558,956	13
Duval	0	667,796	0	84,884	22,201	774,881	19
Jim Wells	0	64,153	0	36,472	173,228	273,853	7
Kenedy	217,111	0	0	662,644	4,512	884,267	21
Kleberg	2,021	0	0	362,302	97,794	462,117	11
Live Oak	0	262,232	0	0	0	262,232	6
McMullen	0	510,629	0	0	7,539	518,168	12
Nueces	2,689	36,807	0	29,567	0	69,063	2
San Patricio	17,738	34,212	40,970	0	0	92,920	2
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).

5A.14.3 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.[19] 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.

5A.14.4 Engineering and Costing

The cost of enhanced water yield from brush control cannot be estimated because associated hydrologic data are not adequate. However, the costs of brush control can be reasonably estimated because of the history of brush control practices in Texas (Table 5A.14-6). The costs in Table 5A.14-6 were computed using 30 years as the project horizon, 6 percent interest, and the initial and periodic costs in Table 5A.14-3 for brush control. Cost for each condition is the uniform annual cost of the present worth of the initial costs and the periodic control costs.

[19] Hart, Charles and Allan McGinty, "Treatment Life Following Control of Mixed Brush in the Davis Mountain Area," 1998.

Table 5A.14-6.
Present Worth and Uniform Annual Costs for
30-Year Brush Control Projects under Varying Brush Conditions

Brush Condition	Present Worth Per Acre (2nd Quarter 1999 Costs)	Uniform Annual Cost (per acre) [1]
Heavy mesquite	$72.79	$4.88
Moderate mesquite	$23.60	$1.58
Light mesquite	$16.10	$1.08

[1] Amortized over 30 years at 6 percent interest.

Three assumptions have been made to simplify the estimation of brush control 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 ($4.88/acre/year, Second Quarter 1999 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 5A.14-7 and are estimated to cost $1.58 per year per acre.

The average annual cost per acre for each county (Table 5A.14-8) is determined by dividing the total annual costs in Table 5A.14-7 by the estimated acreages in Table 5A.14-5, which are the estimated areas that might increase runoff and/or deep percolation as a result of brush control. Estimated annual cost of brush control in counties in the Coastal Bend Region range from $118,000 in Nueces County to $2.13 million in Kenedy County (Table 5A.14-7).

5A.14.5 Implementation Issues

Several implementation issues pertain to this potential water supply option. *In situ* brush control 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 control 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 control 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 control. To ensure cooperation of these ranch owners, additional subsidies or other consideration may be required which could alter the cost profiles for brush control.

Table 5A.14-7.
Annual Cost of Brush Control 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	$183,939	$0	$0	$15,879	$0	$199,817
Bee	$0	$217,140	$577,520	$0	$0	$794,660
Brooks	$594,497	$3,683	$0	$686,987	$0	$1,285,167
Duval	$0	$1,055,118	$0	$134,117	$108,343	$1,297,577
Jim Wells	$0	$101,362	$0	$57,625	$845,351	$1,004,338
Kenedy	$1,059,503	$0	$0	$1,046,977	$22,016	$2,128,496
Kleberg	$9,865	$0	$0	$572,437	$477,233	$1,059,535
Live Oak	$0	$414,327	$0	$0	$0	$414,327
McMullen	$0	$806,794	$0	$0	$36,790	$843,584
Nueces	$13,122	$58,155	$0	$46,716	$0	$117,993
San Patricio	$86,564	$54,056	$199,934	$0	$0	$340,553
Totals	**$1,947,488**	**$2,710,634**	**$777,454**	**$2,560,737**	**$1,489,734**	**$9,486,047**

Table 5A.14-8.
Average Annual Cost of Brush Control for
Counties in the Coastal Bend Region

County	***Annual Average Cost per Acre***	***County***	***Annual Average Cost per Acre***
Aransas	$4.19	Kleberg	$2.29
Bee	$2.48	Live Oak	$1.58
Brooks	$2.30	McMullen	$1.63
Duval	$1.67	Nueces	$1.71
Jim Wells	$3.67	San Patricio	$3.66
Kenedy	$2.41		

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 control 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?

5A.14.6 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 5A.14-9.

Table 5A.14-9.
Evaluation Summary of Brush Management to Enhance Water Supply Yield

Impact Category	*Comment(s)*
a. Quantity, reliability, and cost of treated water	• Indeterminate low reliable quantity • Low cost
b. Environmental factors	• Brush control techniques may adversely affect existing wildlife populations • Chemical brush control methods may result in residual chemicals in aquifers and streams
c. 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	• None
f. Comparison and consistency equities	• Cost model for brush control 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

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5A.15 Weather Modification

5A.15.1 Description of Strategy

Weather modification as it has been applied in Texas over the past 25 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 (Jensen, 1994). 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.

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).[1] The criteria used in Texas to find promising clouds, is to locate "feeder" cells near developing cloud formations which 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 AgI 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 TNRCC in a public information document entitled, "Some Facts about Cloud Seeding from Recent Research on Rain Enhancement in Texas" (Bomar, 1999). The TNRCC concludes the following:

[1] Clouds may also be seeded using ground-based silver iodide dispensers. However, in this discussion, only the aircraft method is considered.

- Cloud seeding with AgI 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.
- 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." (Bomar, 1999)

5A.15.2 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 Southwest Texas Rain-Enhancement Association (SWTREA) Program, and the South Texas Weather Modification Association (STWMA) Program**.** Each of these programs is described below.

<u>Southwest Cooperative Program (SWCP)</u>. 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" (Bomar, et. al., 1999). 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 event of 43 percent, an increase in the storm duration of 36 percent, and an increase in rain volumes of 130 percent (Rosenfeld and Woodley, 1993).

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 (Jones, 1988, 1997).

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 (TNRCC). The Authority contracted with Weather Modification, Inc., to complete and submit the permit application on the Authority's behalf, and work with the TNRCC. The permit was granted by TNRCC in October 1998 and is valid for four years from January 1999 through December 2002. The permit allows the Authority to conduct precipitation enhancement anytime during the year, including the traditional period of April through September. The Authority has committed $500,000 for the 1999 program with half the expenses reimbursed by the TNRCC."

"The target area of the program covers over 6 million acres at a cost of about 4 cents an acre." (Table 5A.15-1.)

Table 5A.15-1.
Edwards Aquifer Authority Weather Modification Program Counties

Target Counties	*Operational Counties*	*SCTWAC Counties**
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

* Coastal Bend Water Advisory Committee (SCTWAC), as created by SB 1477.

"Each county in the target and Coastal Bend 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 first year of this program operated from April 15 to September 15, 1999. Consequently, no definitive results regarding estimated rainfall enhancement will be available for several months. The assumption for enhanced aquifer recharge was 10 percent above the recharge quantity, which would occur without enhancement."

<u>South Texas Weather Modification Association (STWMA) Program.</u> 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. To date, there have not been any published results of the cloud seeding efforts; however, the STWMA has observed an increase in rainfall from seeded storms of up to 20 percent.

<u>Rainfall Enhancement Programs Underway in Summer 1999</u>. Several active cloud seeding programs were performed during the summer of 1999 including some as part of the programs described above. The programs, the counties they cover and the approximate areas of coverage are presented in the Table 5A.15-2.

Table 5A.15-2.
Cloud Seeding Programs Underway in Texas during Summer 1999

Cloud Seeding Program	Counties Involved	Area (sq. miles)
Colorado River MWD	Bordon, 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	6,891
High Plains Underground Water Conservation District	Yoakum, Terry, Lynn, Cochran, Hockley, Lubbock, Bailey, Lamb, Hale, Parmer, Castro, Floyd, and part of Deaf Smith, Potter, Randall, and Crosby	12,438
Texas Border Weather Modification Association	Val Verde, Kinney, and Maverick	5,922
Edwards Aquifer Authority Program	Medina, Bandera, Kerr, Kendall, Blanco, Hays, Caldwell, Comal, Guadalupe, Bexar, and part of Real	8,500
Southwest Rain Enhancement Association	Uvalde, Zavala, Dimmit, La Salle, 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.

5A.15.3 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, Colorado River Municipal Water District (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 (Jensen, 1999). 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 (Jensen, 1999).

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 transported to a reservoir or was recharged to an aquifer. 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 man-made 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 5A.15-3). 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 5A.15-3.
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.

5A.15.4 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 TNRCC, 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. Weather modification is now considered a long-term water augmentation strategy for freshwater supplies.[2]

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 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.

5A.15.5 Engineering and Costing

The EAA program is in its first year of operation and has not reported official results for 1999. The cost is $500,000 per year. Using the EAA program coverage area (8,500 square miles), the resulting unit cost of this program is about 8.3 cents per acre.

5A.15.6 Implementation Issues

In terms of a measurable and dependable regional water supply option, weather modification in the form of cloud seeding appears to be a beneficial, but uncertain, source of usable water. However, data are not adequate to specify firm yield.

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 perhaps meet some of the agricultural needs, as well as making contributions to aquifer recharge and streamflows of the region that could be developed to meet municipal and industrial needs

5A.15.7 Evaluation Summary

An evaluation summary of this strategy is included in Table 5A.15-4.

[2] Bomar, George, TNRCC Senior Meteorologist, Austin, Texas.

Table 5A.15-4.
Evaluation Summary of Weather Modification to Enhance Water Supplies

Impact Category	***Comment(s)***
a. Quantity reliability and cost of treated water	• Low, uncertain quantity and timing • Low cost
b. Environmental factors	• None
c. 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 flooding
e. Recreational	• None
f. Comparison and consistency equities	• 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

5A.16 Seawater Desalination

5A.16.1 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. 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.

5A.16.1.1 General Desalination Background

The commercially available processes that are currently 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.

5A.16.1.1.1 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° F.

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 (SDWA) 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.

5A.16.1.1.2 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 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 31 percent of the world's desalting capacity, range from a few gallons per day to 15 MGD. The largest RO seawater plant in the United States is the 6.7 MGD plant in Santa Barbara, California. 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).

Table 5A.16-1.
Municipal Use Desalt Plants in Texas
(>25,000 gpd and as of December 1998)

Location	Source	Total Capacity (MGD)	Desalt Capacity (MGD)	Membrane Type[1]
Bayside, City of	Groundwater	0.15	0.15	RO
Dell City, City of	Groundwater	0.11	0.11	EDR
Ft. Stockton, City of	Groundwater	6.5	3	RO
Granbury, City of	Lake Water	0.35	0.35	EDR
Haciendas del Norte (El Paso)	Groundwater	0.133	0.133	RO
Homestead MUD (El Paso)	Groundwater	0.1	0.1	RO
Kenedy, City of	Groundwater	2.86	0.72	RO
Lake Granbury	Lake Water	3.5	3.5	EDR
Robinson, City of	River	2	2	RO
Seadrift, City of	Groundwater	0.24	0.17	RO
Sherman, City of	Lake Water	6.0	6.0	EDR
Sportsman's World	Lake Water	0.1	0.1	RO
Texas Resort Co.	Lake Water	0.144	0.144	EDR

[1] RO = Reverse Osmosis EDR = Electrodialysis Reversal

5A.16.1.1.3 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, has 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 is to be $2.08 per 1,000 gallons on a 30-year average, with first year cost being $1.71 per 1,000 gallons. 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.
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.[1]

[1] Desalination & Water Reuse Quarterly, vol. 7/4, Feb/Mar 1998.

5A.16.2 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 water is the limiting factor.

The target area for well field development 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-ft per mile. In the western part of the county, a high capacity well is about 700 ft deep and yields up to 750 gallons per minute (gpm). Near the coast, a high capacity well would be about 1,500 ft deep and yield about 500 gpm.

For purposes of this evaluation, three potential well fields were considered. As shown in Figure 5A.16-1, 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 Coastal Bend Regional Water Planning Group, water level declines from well fields were allowed to decline up to 250 ft in the confined zone of the Goliad Sand. Considering this criteria and in consideration of other well fields in the area, allowable drawdown of 200-250 feet was used to establish the availability of groundwater from these well fields.

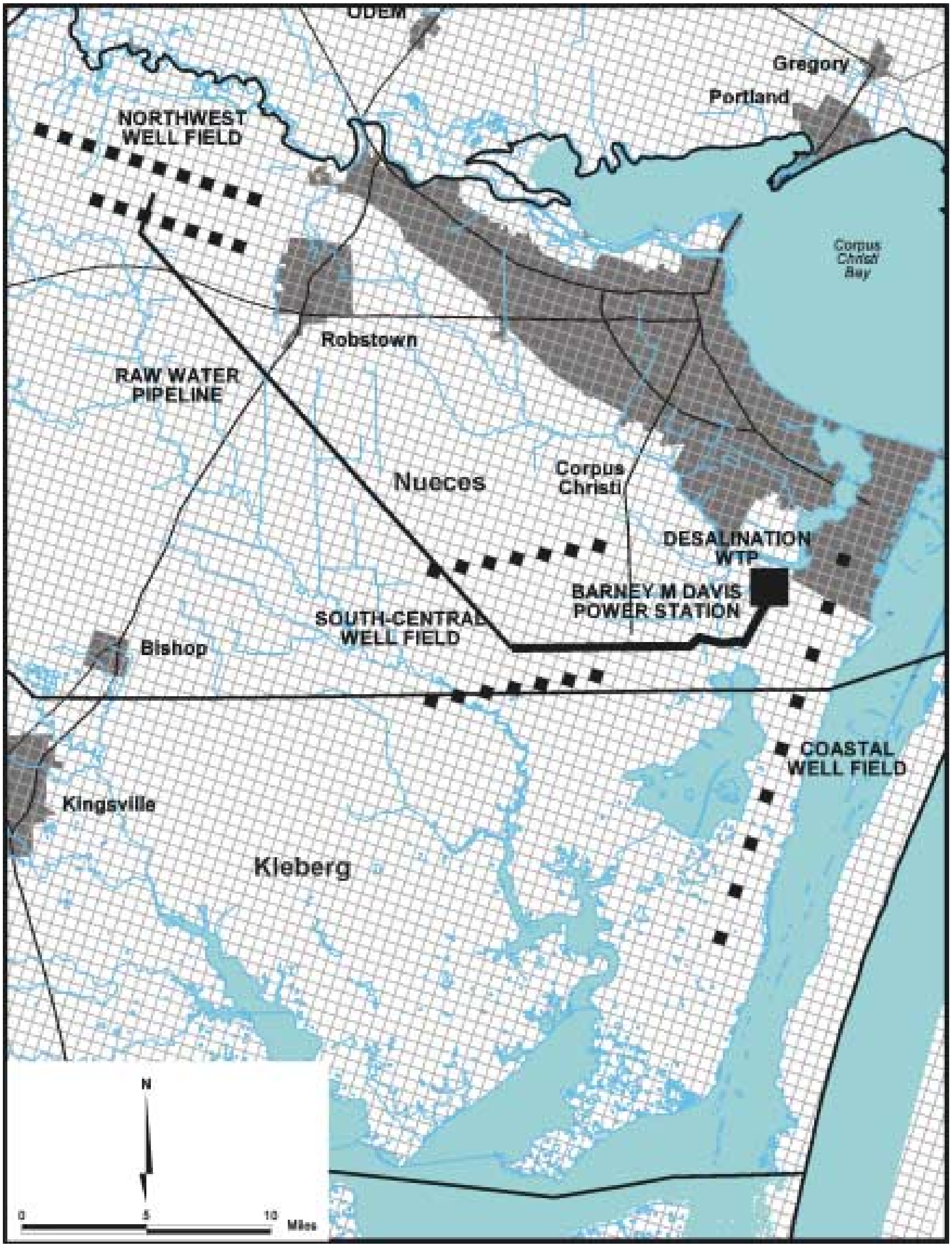

Figure 5A.16-1. Combined Seawater and Brackish Groundwater Desalination at Barney M. Davis Power Plant

In the coastal well field, the analysis suggests that a 4 million gallon per day (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.

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 field 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 5A.16-2.

Table 5A.16-2.
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

5A.16.3 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 plant cooling water. Since the brine concentrate for the seawater only option is planned to be located offshore 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 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 all 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.

5A.16.4 Engineering and Costing

5A.16.4.1 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 5A.16-2 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 5A.16-3.

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 5A.16.1.1.3) and from information and estimating models developed in a previous desalination study).[2]

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.

[2] HDR Engineering, Inc (HDR), "Desalination for Texas Water Supply," Texas Water Development Board, Nueces River Authority, August 2000.

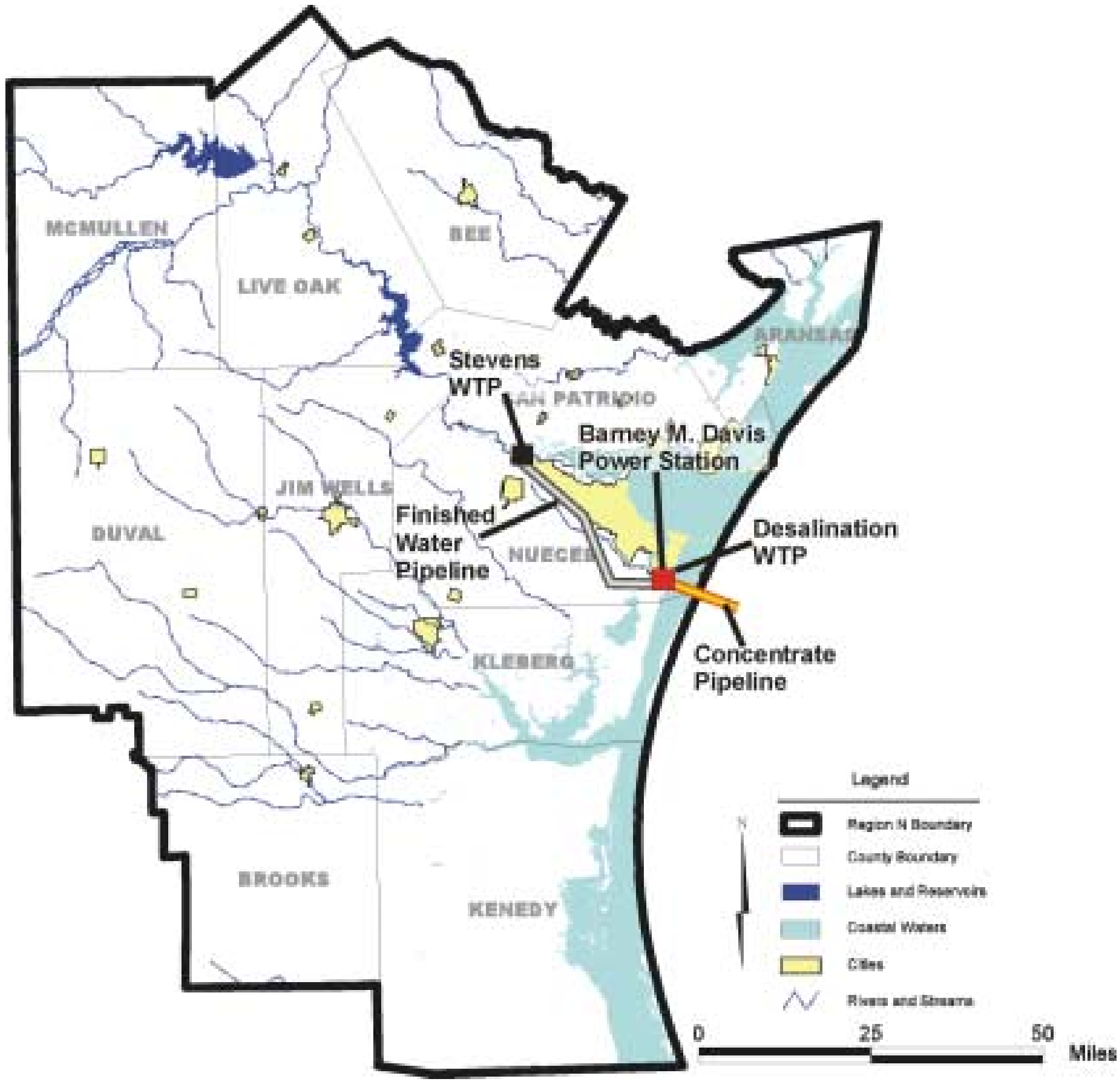

Figure 5A.16-2. Desalination Plant Location and Pipeline Route

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.

Table 5A.16-3.
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	½ day's capacity	
Concentrate Pipeline Length	10 miles	Diffused in open gulf in over 30 feet 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
Land for WTP Plant	20 acres	Add 10 acres for each 25 MGD capacity increase
Land for Easements	141 acres	Pipeline right-of-way
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	

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 5A.16-4.

Table 5A.16-4. 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)	161	171	181	191

Land acquisition for the base option includes 20 acres for the 25 MGD desalination plant and 141 acres for the desalted water storage tank and transmission pipeline. No land acquisition is included for the concentrate disposal pipeline but surveying costs are included.

Tables 5A.16-5 and 5A.16-6 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 5A.16-5.
Cost Estimate Summary
Seawater Desalination at Barney M. Davis Power Station
for Base Option (29-mile pipeline)
(Second Quarter 1999 Prices)

Item	Estimated Costs 25 MGD	Estimated Costs 50 MGD	Estimated Costs 75 MGD	Estimated Costs 100 MGD
Capital Costs				
Source Water Supply	$800,000	$1,300,000	$1,700,000	$2,000,000
Water Treatment Plant	72,000,000	126,600,000	175,700,000	224,000,000
Concentrate Disposal	32,000,000	49,500,000	67,000,000	86,000,000
Finished Water Transmission	36,000,000	51,000,000	70,000,000	89,000,000
Total Capital Cost	**$140,800,000**	**$228,400,000**	**$314,400,000**	**$401,000,000**
Engineering, Legal Costs and Contingencies (35 percent)	$49,280,000	$79,940,000	$110,040,000	$140,350,000
Land Acquisition and Surveying	2,410,000	2,880,000	3,380,000	3,930,000
Environmental & Archaeology Studies and Mitigation	7,360,000	9,260,000	11,250,000	13,475,000
Interest During Construction (6 percent for 2.5 years)	19,985,000	32,048,000	43,907,000	55,875,500
Total Project Cost	**$219,835,000**	**$352,528,000**	**$482,977,000**	**$614,630,500**
Annual Costs				
Debt Service (6 percent for 30 years)	$15,971,000	$25,611,000	$35,088,000	$44,652,000
Operation and Maintenance:				
Source Water Supply	200,000	300,000	350,000	400,000
Water Treatment Plant (Except Energy)	8,000,000	15,900,000	23,400,000	31,000,000
WTP Energy Cost (108,216,324,425 x 10^6 kWh @ $0.06 per kWh)	6,480,000	12,960,000	19,440,000	25,500,000
Concentrate Disposal	1,155,000	2,100,000	3,000,000	3,900,000
Finished Water Transmission	913,000	1,650,000	2,150,000	2,460,000
Total Annual Cost	**$32,719,000**	**$58,521,000**	**$83,428,000**	**$107,912,000**
Available Project Yield (acft/yr)	**28,004**	**56,008**	**84,012**	**112,016**
Annual Cost of Water ($ per acft)	**$1,168**	**$1,045**	**$993**	**$963**
Annual Cost of Water ($ per 1,000 gallons)	**$3.59**	**$3.21**	**$3.05**	**$2.96**

Table 5A.16-6.
Cost Estimate Summary
Seawater Desalination at Barney M. Davis Power Station
for Alternate Option (5-mile pipeline)
(Second Quarter 1999 Prices)

Item	Estimated Costs 25 MGD	Estimated Costs 50 MGD	Estimated Costs 75 MGD	Estimated Costs 100 MGD
Capital Costs				
Source Water Supply	$800,000	$1,300,000	$1,700,000	$2,000,000
Water Treatment Plant	72,000,000	126,600,000	175,700,000	224,000,000
Concentrate Disposal	32,000,000	49,500,000	67,000,000	86,000,000
Finished Water Transmission	10,300,000	16,700,000	24,100,000	31,000,000
Total Capital Cost	**$115,100,000**	**$194,100,000**	**$268,500,000**	**$343,000,000**
Engineering, Legal Costs and Contingencies (35 percent)	$40,285,000	$67,935,000	$93,975,000	$120,050,000
Land Acquisition and Surveying	1,230,000	1,724,000	2,250,000	2,810,000
Environmental & Archaeology Studies and Mitigation	6,100,000	8,000,000	10,000,000	12,200,000
Interest During Construction (6 percent for 2.5 years)	16,271,500	27,175,900	37,472,500	47,806,000
Total Project Cost	**$178,986,500**	**$298,934,900**	**$412,197,500**	**$525,866,000**
Annual Costs				
Debt Service (6 percent for 30 years)	$13,003,000	$21,717,000	$29,946,000	$38,204,000
Operation and Maintenance:				
Source Water Supply	200,000	300,000	350,000	400,000
Water Treatment Plant (Except Energy)	8,000,000	15,900,000	23,400,000	31,000,000
WTP Energy Cost (108,216,324,425 x 10^6 kWh @ $0.06 per kWh)	6,480,000	12,960,000	19,440,000	25,500,000
Concentrate Disposal	1,155,000	2,100,000	3,000,000	3,900,000
Finished Water Transmission	304,000	575,000	805,000	1,000,000
Total Annual Cost	**$29,142,000**	**$53,552,000**	**$76,941,000**	**$100,004,000**
Available Project Yield (acft/yr)	**28,004**	**56,008**	**84,012**	**112,016**
Annual Cost of Water ($ per acft)	**$1,041**	**$956**	**$916**	**$893**
Annual Cost of Water ($ per 1,000 gallons)	**$3.19**	**$2.93**	**$2.81**	**$2.74**

5A.16.4.2 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 5A.16.4.1 next to the Barney M. Davis Power Station. The location of the two well fields, pipelines, and desalination plant are shown in Figure 5A.16-1. 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 flow of 14 MGD. Engineering assumptions utilized for all three options are shown in Table 5A.16-7. Parameters that vary for the three options are shown separately in Table 5A.16-8.

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. 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 5A.16-7.
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	1/2 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
Land for water treatment plant	20 acres	
Flux	8 gfd	Rate product water passes through membrane
Membrane cleaning frequency	6 months	Membranes cleaned once every 6 months
Membrane life	5 yr	Membrane elements replaced every 5 years

Table 5A.16-8.
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 5A.16-9 and 5A.16-10 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.

The costs in Tables 5A.16-9 and 5A.16-10 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 5A.16-11 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 5A.16-11 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 5A.16-11 to determine the cost of a $0.02 per kWh increase in power .

Table 5A.16-9.
Cost Estimate Summary
Combined Seawater and Brackish Groundwater Desalination
for Base Option (29-mile pipeline)
(Second Quarter 1999 Prices)

Item	*Estimated Costs (25 MGD)*	*Estimated Costs (19 MGD)*	*Estimated Costs (14 MGD)*
Capital Costs			
Seawater Supply	$500,000	$300,000	$0
Brackish Groundwater Wells, Pump Stations, and Pipelines	$27,500,000	$27,500,000	$27,500,000
Water Treatment Plant	$41,000,000	$26,600,000	$13,600,000
Concentrate Disposal	$300,000	$200,000	$150,000
Finished Water Transmission	$36,000,000	$30,000,000	$25,500,000
Total Capital Cost	**$105,300,000**	**$84,600,000**	**$66,750,000**
Engineering, Legal Costs and Contingencies (35%)	$36,855,000	$29,610,000	$23,362,500
Land Acquisition and Surveying	$3,190,000	$3,190,000	$3,190,000
Environmental & Archaeology Studies and Mitigation	$2,860,000	$2,860,000	$1,474,000
Interest During Construction (6% for 2.5 years)	$15,795,000	$12,690,000	$10,012,500
Total Project Cost	**$164,000,000**	**$132,950,000**	**$104,789,000**
Annual Costs			
Debt Service (6 percent, 30 years)	$11,914,000	$9,659,000	$7,613,000
Operation and Maintenance:			
Seawater Supply	$100,000	$40,000	$0
Brackish Groundwater Wells, Pump Stations, and Pipelines	$1,410,000	$1,410,000	$1,410,000
Water Treatment Plant (Except Energy)	$4,380,000	$2,660,000	$1,180,000
Water Treatment Plant Energy Cost	$3,840,000	$2,180,000	$1,060,000
Concentrate Disposal	$50,000	$30,000	$10,000
Finished Water Transmission	$913,000	$809,000	$590,000
Total Annual Cost	**$22,607,000**	**$16,788,000**	**$11,863,000**
Available Project Yield (acft/yr)	**28,004**	**21,280**	**15,680**
Annual Cost of Water ($ per acft)	**$807**	**$789**	**$756**
Annual Cost of Water ($ per 1,000 gallons)	**$2.48**	**$2.42**	**$2.32**

Table 5A.16-10.
Cost Estimate Summary
Combined Seawater and Brackish Groundwater Desalination
for Alternate Option (5-mile pipeline)
(Second Quarter 1999 Prices)

Item	***Estimated Costs (25 MGD)***	***Estimated Costs (19 MGD)***	***Estimated Costs (14 MGD)***
Capital Costs			
Seawater Supply	$500,000	$300,000	$0
Brackish Groundwater Wells, Pump Stations, and Pipelines	$27,500,000	$27,500,000	$27,500,000
Water Treatment Plant	$41,000,000	$26,600,000	$13,600,000
Concentrate Disposal	$300,000	$200,000	$150,000
Finished Water Transmission	$10,300,000	$8,350,000	$6,640,000
Total Capital Cost	**$79,600,000**	**$62,950,000**	**$47,890,000**
Engineering, Legal Costs and Contingencies (35%)	$27,860,000	$22,032,500	$16,761,500
Land Acquisition and Surveying	$2,340,000	$2,340,000	$2,340,000
Environmental & Archaeology Studies and Mitigation	$2,252,000	$2,252,000	$692,000
Interest During Construction (6% for 2.5 years)	$11,940,000	$9,442,500	$7,183,500
Total Project Cost	**$123,992,000**	**$99,017,000**	**$74,867,000**
Annual Costs			
Debt Service (6 percent, 30 years)	$9,008,000	$7,193,000	$5,439,000
Operation and Maintenance:			
Seawater Supply	$100,000	$40,000	$0
Brackish Groundwater Wells, Pump Stations, and Pipelines	$1,410,000	$1,410,000	$1,410,000
Water Treatment Plant (Except Energy)	$4,380,000	$2,660,000	$1,180,000
Water Treatment Plant Energy Cost	$3,840,000	$2,180,000	$1,060,000
Concentrate Disposal	$50,000	$30,000	$10,000
Finished Water Transmission	$304,000	$250,000	$185,000
Total Annual Cost	**$19,092,000**	**$13,763,000**	**$9,284,000**
Available Project Yield (acft/yr)	**28,004**	**21,280**	**15,680**
Annual Cost of Water ($ per acft)	**$682**	**$647**	**$592**
Annual Cost of Water ($ per 1,000 gallons)	**$2.09**	**$1.99**	**$1.82**

Table 5A.16-11.
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

5A.16.5 Implementation Issues

5A.16.5.1 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.

5A.16.5.2 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;
- U.S. Army Corps of Engineers Section 10 and 404 dredge and fill permits for pipelines;
- GLO Sand and Gravel Removal permit for pipeline and crossings of streams and roads;
- GLO Easement for use of State-owned lands, if any;
- TPWD 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.

5A.16.6 Evaluation Summary

Evaluation summaries of this regional water management strategy are provided in Tables 5A.16-12 and 5A.16-13.

Table 5A.16-12.
Evaluation Summary of the Seawater Desalination Option

Impact Category	***Comment(s)***
a. Quantity, reliability, and cost of treated water	• Firm yield: Virtually unlimited highly reliable quantity • Generally high cost; between $1,168 to $893 per acft
b. Environmental factors	• Environmental impact to estuary • Disposal of concentrated brine created from process • Construction and maintenance of transmission pipeline corridor • Cultural resource survey will be needed to identify any significant sites
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
e. Recreational	• None
f. Comparison and consistency equities	• 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

Table 5A.16-13.
Summary Evaluation of the Combined Seawater and Brackish Groundwater Desalination Option

Impact Category	Comment(s)
a. Quantity, reliability, and cost of treated water	• Firm yield: Virtually unlimited highly reliable quantity of seawater • Brackish groundwater yield is limiting factor with maximum product water yield of 25 MGD • Generally high cost; between $807 to $592 per acft
b. Environmental factors	• Environmental impact to estuary • Disposal of concentrated brine created from process • Construction and maintenance of transmission pipeline corridor • Negligible impacts from use of groundwater • Cultural resource survey will be needed to identify any significant sites
c. 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	• None
f. Comparison and consistency equities	• 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

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5A.17 Potential Water System Interconnections

5A.17.1 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 5A.17-1. 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 Texas Water Authority's (STWA) surface water system.

5A.17.2 Available Yield

5A.17.2.1 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 5A.17-1.
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 Pat/Corpus
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	Emergency Backup Wells
Driscoll	1985	South Texas Water Authority
Nueces Co. WCID #4-Port Aransas	1958	Corpus & 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 Choke Canyon/Lake Corpus Christi 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 5A.17-1)
Alternative 2 - Alice to San Diego, Benavides and Freer (Figure 5A.17-2)
Alternative 3 - Alice to San Diego and Benavides (Figure 5A.17-3)
Alternative 4 - Alice to San Diego and Freer (Figure 5A.17-4)
Alternative 5 - Alice to San Diego (Figure 5A.17-5)

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 (2050) 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 5A.17-2 through 5A.17-6.

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 5A.17-1. Duval County Interconnection Alternative 1

Figure 5A.17-2. Duval County Interconnection Alternative 2

Figure 5A.17-3. Duval County Interconnection Alternative 3

Figure 5A.17-4. Duval County Interconnection Alternative 4

Figure 5A.17-5. Duval County Interconnection Alternative 5

Table 5A.17-2.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 1[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (85.4 miles)	$8,851,000
Storage and Pump Stations	2,625,000
Total Capital Costs	**$11,476,00**
Engineering, Legal Costs and Contingencies	$3,443,000
Environmental & Archaeology Studies and Mitigation	2,135,000
Land Acquisition and Surveying	2,705,000
Interest During Construction (2 years)	790,000
Total Project Cost	**$20,549,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$1,493,000
Operation and Maintenance:	
Pipelines and Pump Stations	154,000
Pumping Energy Costs	221,000
Treated Water Cost	1,150,000
Total Annual Cost	**$3,018,000**
Available Project Yield[2] (acft/yr)	**2,520**
Annual Cost of Water ($ per ac ft)	**$1,198**
Annual Cost of Water ($ per 1,000 gallons)	**$3.68**

1 Interconnection between Alice Water Authority Water Treatment Plant, and San Diego, Freer, Benavides, Realitos and Concepcion.
2 Average Day Demand in 2030.

Table 5A.17-3.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 2[1]
(Second Quarter 1999 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (54.6 miles)	$6,230,000
Storage and Pump Stations	2,551,000
Total Capital Costs	**$8,781,000**
Engineering, Legal Costs and Contingencies	$2,634,000
Environmental & Archaeology Studies and Mitigation	1,365,000
Land Acquisition and Surveying	1,730,000
Interest During Construction (2 years)	580,000
Total Project Cost	**$15,090,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$1,096,000
Operation and Maintenance:	
Pipelines and Pump Stations	126,000
Pumping Energy Costs	190,000
Treated Water Cost	1,109,000
Total Annual Cost	**$2,521,00**
Available Project Yield[2] (acft/yr)	**2,430**
Annual Cost of Water ($ per ac ft)	**$1,037**
Annual Cost of water ($ per 1,000 gallons)	**$3.18**

1 Interconnection between Alice Water Authority Water Treatment Plant and San Diego, Freer, and Benavides.
2 Average Day Demand in 2030.

Table 5A.17-4.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 3[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (28 miles)	$2,951,000
Storage and Pump Stations	1,321,000
Total Capital Costs	**$4,272,000**
Engineering, Legal Costs and Contingencies	1,282,000
Environmental & Archaeology Studies and Mitigation	700,000
Land Acquisition and Surveying	887,000
Interest During Construction (2 years)	286,000
Total Project Cost	$7,427,000
Annual Costs	
Debt Service (6 percent for 30 years)	540,000
Operation and Maintenance:	
Pipelines and Pump Stations	63,000
Pumping Energy Costs	67,000
Treated Water Cost	700,000
Total Annual Cost	**$1,370,000**
Available Project Yield[2] (acft/yr)	**1,534**
Annual Cost of Water ($ per ac ft)	**$893**
Annual Cost of Water ($ per 1,000 gallons)	**$2.74**

1 Interconnection between Alice Water Authority Water Treatment Plant and San Diego and Benavides.
2 Average Day Demand in 2030.

Table 5A.17-5.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 4[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (38.8 miles)	$4,809,000
Storage and Pump Stations	1,822,000
Total Capital Costs	**$6,631,000**
Engineering, Legal Costs and Contingencies	1,989,000
Environmental & Archaeology Studies and Mitigation	970,000
Land Acquisition and Surveying	1,229,000
Interest During Construction (2 years)	433,000
Total Project Cost	$10,819,000
Annual Costs	
Debt Service (6 percent for 30 years)	$817,000
Operation and Maintenance:	
Pipelines and Pump Stations	94,000
Pumping Energy Costs	123,000
Treated Water Cost	853,000
Total Annual Cost	**$1,187,000**
Available Project Yield[2] (acft/yr)	**1,870**
Annual Cost of Water ($ per ac ft)	**$1,009**
Annual Cost of Water ($ per 1,000 gallons)	**$3.10**

[1] Interconnection between Alice Water Authority Water Treatment Plant, San Diego and Freer.
[2] Average Day Demand in 2030.

Table 5A.17-6.
Cost Estimate Summary
Regional Surface Water Supply
Duval County Interconnection Alternative 5[1]
(Second Quarter 1999 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (12.2 miles)	$1,413,000
Storage and Pump Stations	592,000
Total Capital Costs	**$2,005,000**
Engineering, Legal Costs and Contingencies	$602,000
Environmental & Archaeology Studies and Mitigation	305,000
Land Acquisition and Surveying	386,000
Interest During Construction (1 year)	66,000
Total Project Cost	$3,364,000
Annual Costs	
Debt Service (6 percent for 30 years)	$244,000
Operation and Maintenance:	
Pipelines and Pump Stations	29,000
Pumping Energy Costs	24,000
Treated Water Cost	445,000
Total Annual Cost	**$742,000**
Available Project Yield[2] (acft/yr)	**974**
Annual Cost of Water ($ per ac ft)	**$762**
Annual Cost of Water ($ per 1,000 gallons)	**$2.34**

1 Interconnection between Alice Water Authority Water Treatment Plant and San Diego.
2 Average Day Demand in 2030.

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5A.17.2.2 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 5A.17-6) and Premont (Figure 5A.17-7) 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 5A.17-7 through 5A.17-8.

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 5A.17-6. Jim Wells County Interconnection Alternative 1

Figure 5A.17-7. Jim Wells County Interconnection Alternative 2

Table 5A.17-7.
Cost Estimate Summary
Regional Surface Water Supply
Jim Wells County Interconnection Alternative 1[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (19.1 miles)	$1,442,000
Total Capital Costs	**$1,442,000**
Engineering, Legal Costs and Contingencies	$433,000
Environmental & Archaeology Studies and Mitigation	478,000
Land Acquisition and Surveying	605,000
Interest During Construction (1 year)	59,000
Total Project Cost	**$3,017,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$219,000
Operation and Maintenance:	
Pipelines and Pump Stations	14,000
Treated Water Cost	112,000
Total Annual Cost	**$345,000**
Available Project Yield[2] (acft/yr)	**246**
Annual Cost of Water ($ per ac ft)	**$1,402**
Annual Cost of Water ($ per 1,000 gallons)	**$4.31**

[1] Interconnection between Alice Water Authority Water Treatment Plant and Orange Grove.
[2] Average Day Demand in 2030.

Table 5-17-8.
Cost Estimate Summary
Regional Surface Water Supply
***Jim Wells County Interconnection Alternative 2*[1]**
(Second Quarter 1999 Prices)

Item	*Estimated Costs*
Capital Costs	
Transmission Pipelines (26.9 miles)	$4,322,000
Total Capital Costs	**$4,322,000**
Engineering, Legal Costs and Contingencies	$1,297,000
Environmental & Archaeology Studies and Mitigation	673,000
Land Acquisition and Surveying	852,000
Interest During Construction (2 years)	286,000
Total Project Cost	**$7,430,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$540,000
Operation and Maintenance**:**	
Pipelines	43,000
Treated Water Cost	654,000
Total Annual Cost	**$1,237,000**
Available Project Yield[2] (acft/yr)	**1,434**
Annual Cost of Water ($ per ac ft)	**$863**
Annual Cost of Water ($ per 1,000 gallons)	**$2.65**

1 Interconnection between Alice Water Authority Water Treatment Plant and Premont.
2 Average Day Demand in 2030.

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5A.17.2.3 Brooks County

The allocation of groundwater from the county supply and the current well capacity for the community of Falfurrias are estimated to be sufficient to meet the projected demands through 2050. However, if future regional surface water supply facilities are constructed from Alice to Premont (Figure 5A.17-7), it may be feasible to extend the system an additional 10.5 miles to Falfurrias (Figure 5A.17-8). Total capital costs and annual costs for regional surface water supply facilities to serve Premont and Falfurrias are shown in Table 5A.17-9.

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 5A.17-8. Brooks County Interconnection Alternative 1

Table 5A.17-9.
Cost Estimate Summary
Regional Surface Water Supply
Jim Wells and Brooks County Interconnection Alternative 1[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (37.4 miles)	$6,015,000
Storage and Pump Station	550,000
Total Capital Costs	**$6,565,000**
Engineering, Legal Costs and Contingencies	$1,970,000
Environmental & Archaeology Studies and Mitigation	935,000
Land Acquisition and Surveying	1,185,000
Interest During Construction (2 years)	476,200
Total Project Cost	**$11,081,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$805,000
Operation and Maintenance:	
Pipelines and Pump Stations	74,000
Pumping Energy Costs	72,000
Treated Water Cost	1,339,000
Total Annual Cost	**$2,290,000**
Available Project Yield[2] (acft/yr)	**2,554**
Annual Cost of Water ($ per ac ft)	**$897**
Annual Cost of Water ($ per 1,000 gallons)	**$2.75**

[1] Interconnection between Alice Water Authority Water Treatment Plant and Premont and Falfurrias.
[2] Average Day Demand in 2030.

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5A.17.2.4 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 5A.17-1 shows that the Ricardo Water Supply Corporation, located south of Kingsville, converted to surface water from SWTA in 1985.

The community of Riviera is another potential candidate for interconnection to the STWA System. Riviera is located approximately 5 miles south of Ricardo on US Highway 77. It is currently served by a privately owned water system that includes one well, two ground storage tanks and distribution lines. The water system serves approximately 200 connections, with a total population of approximately 1,000 persons.

Similar to Kleberg County, local groundwater in Kenedy County can be slightly saline. The Sarita Sewer Service and Water Supply Corporation serves less than 100 connections (population of approximately 300 persons) in the community of Sarita, the county seat of Kenedy County.

Due to the rural nature of the county, municipal water demand is not likely to increase in the future, unless the proposed Spaceport Project becomes a reality in the area. The proposed Spaceport site is located approximately 9 miles south of Sarita and 6 miles east of US 77, on property owned by the Kenedy Memorial Foundation.

If the project is constructed, it is estimated that the facility will have a water demand of approximately 500,000 gpd. Water service would be through a connection to the STWA system in Kingsville. It is estimated that a 16-inch diameter transmission line would be required from the STWA's 42-inch transmission main in Kingsville to the Spaceport site. An intermediate storage and booster station would also be required. If the Spaceport site becomes a reality, the 16-inch transmission line that would be extended to the site could also provide interconnection to the Riviera and Sarita water supply systems. (Figure 5A.17-9)

The required regional facilities would include intermediate storage and booster pump stations as well as new transmission pipelines. Total capital costs and annual costs (debt service, power cost, O&M cost, and treated water cost) were estimated for this alternative and presented in Table 5A.17-10.

Figure 5A.17-9. Kleberg and Kenedy Counties Interconnection Alternative 1

Table 5A.17-10.
Cost Estimate Summary
Regional Surface Water Supply
Kleberg and Kennedy County Interconnection Alternative 1[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (27miles)	$3,564,000
Storage and Pump Station	550,000
Total Capital Costs	**$4,114,000**
Engineering, Legal Costs and Contingencies	$1,234,000
Environmental & Archaeology Studies and Mitigation	675,000
Land Acquisition and Surveying	855,000
Interest During Construction (2 years)	275,000
Total Project Cost	**$7,153,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$520,000
Operation and Maintenance:	
Pipelines and Pump Stations	49,000
Pumping Energy Costs	18,000
Treated Water Cost	332,000
Total Annual Cost	**$919,000**
Available Project Yield[2] (acft/yr)	**728**
Annual Cost of Water ($ per ac ft)	**$1,262**
Annual Cost of Water ($ per 1,000 gallons)	**$3.88**

[1] Interconnection between South Texas Water Authority transmission main and Riviera and Sarita.
[2] Average Day Demand in 2030.

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5A.17.2.5 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 Natural Resource Conservation Commission (TNRCC) 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 TNRCC 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 2050. 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 5A.17-10). 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 5A.17-11.

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 5A.17-11 outlines the recommended EDAP plan. The cost of construction for these facilities is shown in Table 5A.17-12.

Figure 5A.17-10. San Patricio County Interconnection Alternative 1

Table 5A.17-11.
Cost Estimate Summary
Regional Surface Water Supply
San Patricio County Interconnection Alternative 1[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (8.1miles)	$770,000
Storage and Pump Station Modifications	200,000
Total Capital Costs	**$970,000**
Engineering, Legal Costs and Contingencies	
Environmental & Archaeology Studies and Mitigation	
Land Acquisition and Surveying	222,000
Interest During Construction (1.5 years)	46,000
Total Project Cost	**$1,704,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$124,000
Operation and Maintenance:	
Pipelines and Pump Stations	12,000
Pumping Energy Costs	36,000
Treated Water Cost	511,000
Total Annual Cost	**$683,000**
Available Project Yield[2] (acft/yr)	**1,120**
Annual Cost of Water ($ per ac ft)	**$610**
Annual Cost of Water ($ per 1,000 gallons)	**$1.87**

[1] Interconnection between San Patricio Municipal Water District transmission main and Sinton.
[2] Average Day Demand in 2030.

Figure 5A.17-11. San Patricio County Interconnection Alternative 2

Table 5A.17-12.
Cost Estimate Summary
Regional Surface Water Supply
San Patricio County Interconnection Alternative 2[1]
(Second Quarter 1999 Prices)

Item	***Estimated Costs***
Capital Costs	
Transmission Pipelines (8.5 miles)	$665,000
Storage and Pump Station	636,000
Total Capital Costs	**$1,301,000**
Engineering, Legal Costs and Contingencies	$390,000
Environmental & Archaeology Studies and Mitigation	213,000
Land Acquisition and Surveying	135,000
Interest During Construction (2 years)	82,000
Total Project Cost	**$2,121,000**
Annual Costs	
Debt Service (6 percent for 30 years)	$154,000
Operation and Maintenance:	
Pipelines and Pump Stations	23,000
Pumping Energy Costs	10,000
Treated Water Cost	57,000
Total Annual Cost	**$244,000**
Available Project Yield[2] (acft/yr)	**125**
Annual Cost of Water ($ per ac ft)	**$1,952**
Annual Cost of Water ($ per 1,000 gallons)	**$5.99**

[1] Interconnection between San Patricio Municipal Water District transmission main and Edroy.
[2] Average Day Demand in 2030.

5A.17.3 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, Kleberg, Kennedy, 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.

5A.17.4 Evaluation Summary

An evaluation summary of this regional water management strategy is provided in Table 5A.17-13.

Table 5A.17-13.
Evaluation Summary of the Potential Water System Interconnections

Impact Category	***Comment(s)***
a. Quantity, reliability, and cost of treated water	• Firm yield: Range from 2,554 acft/yr to 246 acft/yr depending on interconnection project • Generally interconnect project high cost; between $1,952 to $610 per acft
b. Environmental factors	• Cultural resource survey will be needed to avoid significant sites • Construction and maintenance of transmission pipeline corridor(s)
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	• 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