11 Control of Naturally Occurring Salinity

11.1 Characterization of Salinity in the Brazos River

Natural salt pollution has been recognized as the most serious and widespread water quality problem in the Brazos River Basin. No other pollution source, man-made or natural, has had the impact of the natural salt sources located in the upper basin of the Brazos River. However, as the Brazos River flows to the Gulf of Mexico, inflows from tributaries decrease the concentration of dissolved minerals and salts, which in turn improves the quality of water.

11.1.1 Sources

The primary sources of natural salt concentrations in the Brazos River Basin are northwest of the City of Abilene, principally in the watersheds of the Salt and Double Mountain Forks of the Brazos River, which are within the Brazos G Area (Figure 11-1).

A substantial portion of the salt load in the Brazos River is contributed by Croton Creek and Salt Croton Creek, according to various reports.[1,2,3,4,5,6,7] The natural salt producing area is a semi-arid region, where sedimentary rocks containing gypsum and other salts outcrop in canyon-like stream valleys. The area is studded with salt springs and seeps. The highly erodible floodplain material in this region is continually washed away as the streams cut their way down to rock or other impervious basement material. This bedrock provides a cap over a brine aquifer that underlies this entire region of Texas and parts of Arkansas, Oklahoma, and Kansas. In areas where the erosion process has continued for centuries, the streambed has spread out to form large salt flats. Wherever there is a joint or fracture in the stream bedrock material, the highly mineralized water seeps to the surface under artesian pressure. Massive salt flats, often 400 to 500 acres in size, are formed by this process. Salt and other minerals are also leached out of the adjacent floodplain material that surround the salt flats and streams. The Brazos River receives a tremendous salt load when local rainfall is sufficient to dissolve the deposited salt.

[1] Blank, H.R, “Sources of Salt Water Entering the Upper Brazos River,” Report, Project 99, Texas A&M Research Foundation, 1955.

[2] Blank, H.R., “Supplementary Report on Sources of Salt Water entering the Upper Brazos Basin,” Project 99, Texas A&M University Research Foundation, 1956.

[3] Baker, R.C., Hughes, L.S., Yost, I.D., “Natural Sources of Salinity in the Brazos River, Texas, with Particular Reference to the Salt Croton and Croton Creek Basins, U.S,” 1962.

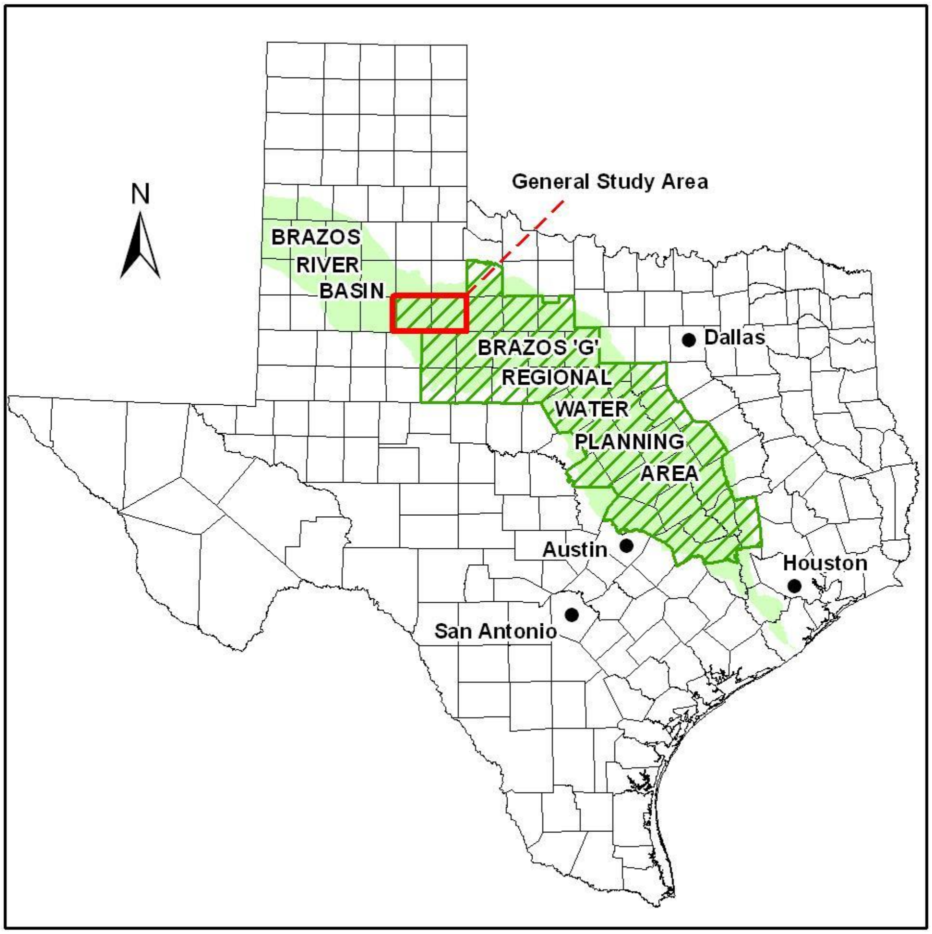
[4] Mason-Johnson & Associates, “Dove Creek Salt Study, Stonewall County, Texas,” 1955.

[5] U.S. Army Corps of Engineers Fort Worth District, “Natural Salt Pollution Control Study, Brazos River Basin, Texas,” Volumes 1-4, 1973.

[6] U.S. Army Corps of Engineers, Fort Worth District, “Brazos Natural Salt Pollution Control, Brazos River Basin, Texas, Design Memorandum No. 1, General Phase 1 – Plan Formulation,” 1983.

[7] Ganze, C.K., and Wurbs, R.A., “Compilation and Analysis of Monthly Salt Loads and Concentrations in the Brazos River Basin,” Civil Engineering Department, Texas A&M University, 1989.

Figure 11-1. Salinity Control Study Area



11.1.2 Quantification

Salinity in the Brazos River Basin is quantified in terms of concentrations or loads of total dissolved solids (TDS), chlorides (Cl), and sulfates (SO_4). Chlorides and sulfates are primary constituents of the TDS measured in the Basin. The US Geological Survey (USGS) conducted a water quality monitoring program in the Brazos River Basin during the 1964 through 1986 water years. Ganze and Wurbs (1989)[8] and Wurbs et. al. (1993)[9] prepared statistical summaries of the salinity data collected at 26 of the 39 USGS water quality monitoring stations having monthly data for at least 3 years during the monitoring period, excerpted from Wurbs et. al. (1993). The 26 gages were chosen based on their record durations and their locations, which are mapped in Figure 11-2. This section highlights data and findings from the Ganze and Wurbs (1989) and Wurbs et. al. (1993) studies.

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[8] Ganze, C.K. and , R.A. Wurbs, “Compilation and Analysis of Monthly Salt Loads and Concentrations in the Brazos River Basin,” Prepared for U.S. Army Corps of Engineers Forth Worth District under Contract DACW63-88-M-0793, January 1989.

[9] Wurbs, R.A., A.S. Karama, I. Saleh, and C.K. Ganze, “Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin,” Texas Water Resources Institute, 1993.

Table 11-2 is excerpted from Wurbs et. al. (1993) and provides the period-of-record mean discharges along with the TDS, Cl, and SO_4 loads and concentrations at the 26 gages. The Possum Kingdom and Whitney gages are located downstream of the respective reservoirs, and the salinity concentration data from these gages provide an indication of the quality of the water released from the reservoirs. Table 11-3, also excerpted from Wurbs et. al. (1993), lists the mean discharges and TDS, Cl, and SO_4 loads at 12 of the 26 gages based on available data from the 1964 through 1986 period. The table provides data from similar time periods to facilitate comparisons.

The majority of salinity in the watershed originates above the Seymour gage. A decrease in concentration with distance down the main stem of the Brazos River is evident, as tributaries having lower salinity concentrations join the main stem. Based on the data in Table 11-3, the mean TDS load in the main stem at Seymour for the 1964 through 1986 period was approximately 41% of the mean load at Richmond, while the mean discharge at Seymour was only approximately 3.9% of the mean discharge at Richmond.

Wurbs et. al. (1993) showed that salinity concentrations vary significantly over time. Table 11-4 lists concentration ranges at the Seymour and Richmond gages reported by Wurbs et. al. (1993). Wurbs et. al. (1993) found that, of the main stem gages at Seymour, Possum Kingdom, Whitney, College Station, and Richmond, the Seymour gage showed the greatest variability in monthly mean salinity concentrations over time and that streamflow regulation by Possum Kingdom Lake, Lake Granbury, and Lake Whitney dampen fluctuations in salinity concentrations at downstream gages.

Table 11-1. Selected USGS Streamflow Gaging and Water Quality Sampling Stations

USGS Station Number	Station Name	Drainage Area (sq mile)	Period Covered by Annual Data (water year)	Period Covered By Monthly Data (water year)
08080500	Double Mountain Fork Brazos River Near Aspermont	8,796	1949-51, 57-86	1964-86
08081000	Salt Fork Brazos River Near Peacock	4,619	1950-51, 65-86	1965-86
08081200	Croton Creek Near Jayton	290	1962-86	1966-86
08081500	Salt Croton Creek near Aspermont	64	1969-77	1969-77
08082000	Salt Fork Brazos River near Aspermont	5,130	1949-51, 57-82	1964-82
08082180	North Croton Creek near Knox City	251	1966-86	1966-86
08082500	Brazos River at Seymour	15,538	1960-86	1964-86
08083240	Clear Fork Brazos River at Hawley	1,416	1968-79, 82-84	1968-79, 82-84
08085500	Clear Fork River at Fort Griffin	3,988	1950-51, 68-76, 79, 82-84	1968-76, 79, 82-84
08086500	Hubbard Creek Near Breckenridge	1,089	1956-66, 68-75	1968-75

Table 11-1. Selected USGS Streamflow Gaging and Water Quality Sampling Stations

USGS Station Number	Station Name	Drainage Area (sq mile)	Period Covered by Annual Data (water year)	Period Covered By Monthly Data (water year)
08087300	Clear Fork Brazos River at Eliasville	5,697	1962-82	1964-82
08088000	Brazos River near South Bend	22,673	1942-48, 78-81	1978-81
08088600	Brazos River at Morris Sheppard Dam near Graford	27,190	1942-86	1964-86
08090800	Brazos River near Dennis	25,237	1971-86	1971-86
08092600	Brazos River at Whitney Dam near Whitney	27,189	1949-86	1964-86
08093360	Aquilla Creek above Aquilla	255	1980-82	1980-82
08093500	Aquilla Creek near Aquilla	308	1968-81	1968-81
08098290	Brazos River near Highbank	30,436	1968-79, 81-86	1968-79, 81-86
08104500	Littler River near Little River	5,228	1965-73, 80-86	1965-73, 80-86
08106500	Little River at Cameron	7,065	1960-86	1964-86
08109500	Brazos River near College Station	39,599	1962-83	1967-83
08110000	Yegua Creek near Somerville	1,009	1962-66	1964-66
08110325	Navasota River Above Groesbeck	239	1968-86	1968-86
08111000	Navasota River near Bryan	1,454	1959-81	1964-81
08114000	Brazos River at Richmond	45,007	1946-86	1964-86
08116650	Brazos River near Rosharon	45,339	1969-80	1969-80

Source: Wurbs, R.A., A.S. Karama, I. Saleh, and C.K. Ganze, “Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin,” Texas Water Resources Institute, 1993.

Figure 11-2. Selected USGS Water Quality Monitoring Stations

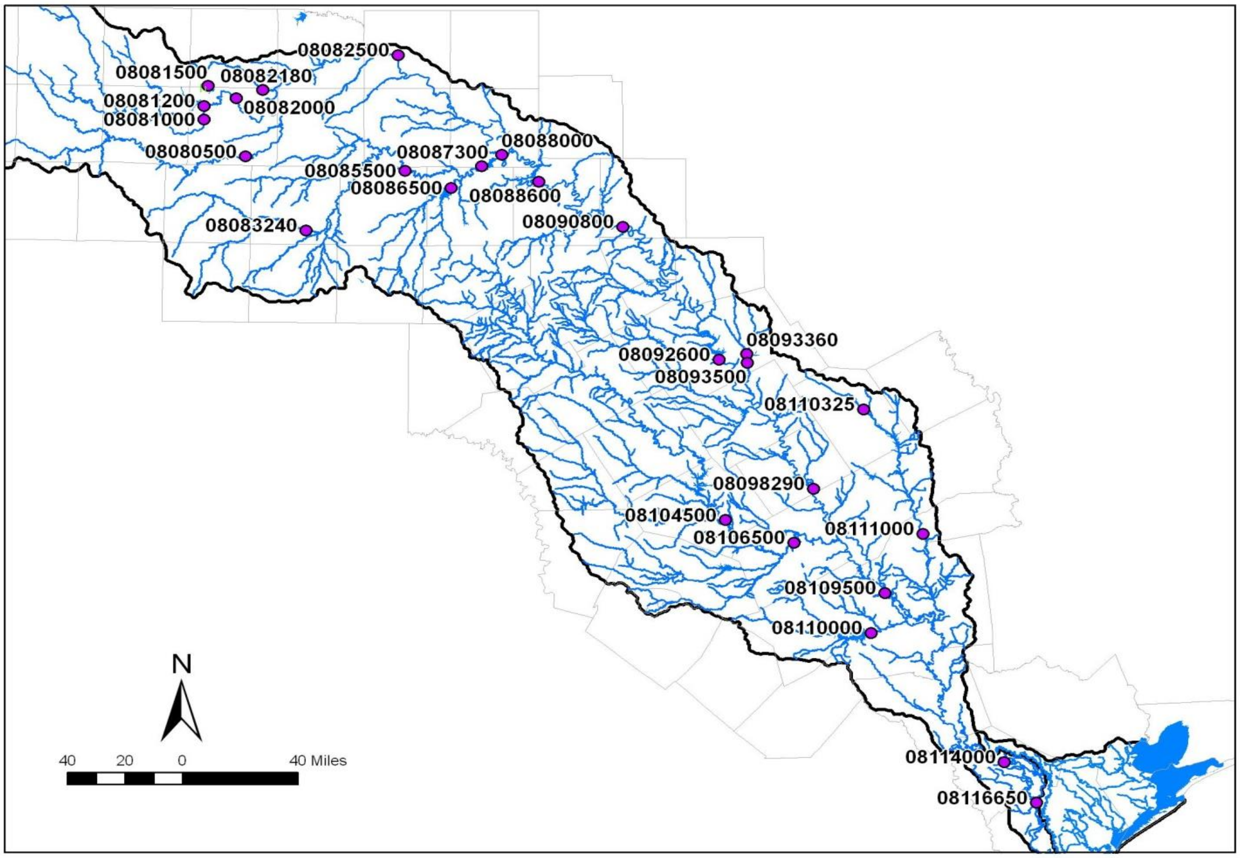


Table 11-2. Mean Discharges, Loads, and Concentrations for Period of Record

USGS Station Number	Abbreviated Station Name	Tributary	Years of Record	Mean Discharge (cfs)	Load (tons/day)			Concentration (mg/L)		
					TDS	Cl	SO_4	TDS	Cl	SO_4
08080500	Aspermont	Double Mountain Fork	33	147	562	136	218	1,353	324	510
08081000	Peacock	Salt Fork	24	43	680	334	83	5,317	2,585	657
08081200	Jayton	Croton Creek	24	13	237	96	58	6,321	2,487	1,617
08081500	Aspermont	Salt Croton Creek	9	4	673	388	27	56,923	32,856	2,273
08082000	Aspermont	Salt Fork	29	81	1,887	942	217	8,606	4,153	989
08082180	Knox City	North Croton Creek	21	17	216	82	60	4,723	1,786	1,323
08082500	Seymour	Main Stem	27	292	2,638	1,018	447	3,356	1,295	569

Table 11-2. Mean Discharges, Loads, and Concentrations for Period of Record

USGS Station Number	Abbreviated Station Name	Tributary	Years of Record	Mean Discharge (cfs)	Load (tons/day)			Concentration (mg/L)		
					TDS	Cl	SO_4	TDS	Cl	SO_4
08083240	Hawley	Clear Fork	15	46	235	51	94	1,893	411	759
08085500	Fort Griffin	Clear Fork	15	151	391	105	116	961	258	286
08086500	Breckenridge	Hubbard Creek	19	93	73	25	4	268	91	20
08087300	Eliasville	Clear Fork	21	319	614	201	148	715	234	172
08088000	South Bend	Main Stem	11	760	2,601	996	561	1,261	486	274
08088600	Possum Kingdom	Main Stem	45	836	2,959	1,127	636	1,299	493	279
08090800	Dennis	Main Stem	19	892	3,103	1,205	622	1,291	501	259
08092600	Whitney	Main Stem	38	1,376	3,174	1,120	633	856	302	171
08093360	Aquilla	Aquilla Creek	3	55	35	2	10	236	14	69
08093500	Aquilla	Aquilla Creek	14	147	102	6	29	257	14	73
08098290	Highbank	Main Stem	18	2,530	4,154	1,287	772	609	189	113
08104500	Little River	Little River	16	912	768	79	61	313	32	25
08106500	Cameron	Little River	26	1,544	1,094	129	126	263	31	30
08109500	College Station	Main Stem	22	4,364	5,315	1,379	944	452	117	80
08110000	Somerville	Yegua Creek	5	252	114	20	33	167	30	48
08110325	Groesbeck	Navasota River	19	161	56	9	6	131	22	13
08111000	Bryan	Navasota River	23	600	232	61	38	144	38	23
08114000	Richmond	Main Stem	41	6,545	6,140	1,431	1,020	351	81	58
08116650	Rosharon	Main Stem	12	7,305	6,462	1,491	1,004	328	76	51

Source: Wurbs, R.A., A.S. Karama, I. Saleh, and C.K. Ganze, “Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin,” Texas Water Resources Institute, 1993.

Table 11-3. Mean Discharges, Loads, and Concentrations for Comparable Time Periods

USGS Station Number	Abbreviated Station Name	Tributary	Years of Record	Mean Discharge (cfs)	Load (tons/day)			Concentration (mg/L)		
					TDS	Cl	SO_4	TDS	Cl	SO_4
08080500	Aspermont	Double Mountain Fork	1964-86	126	580	153	209	1,540	416	548
08081000	Peacock	Salt Fork	1965-86	40	684	339	81	5,782	2,830	698
08081200	Jayton	Croton Creek	1964-86	13	225	93	53	6,391	2,541	1,591
08081500	Aspermont	Salt Croton Creek	1969-77	4	676	425	33	56,923	32,856	2,273
08082000	Aspermont	Salt Fork	1964-82	60	1,660	1,094	219	12,407	6,066	1,235
08082180	Knox City	North Croton Creek	1966-86	17	211	80	58	4,723	1,786	1,323
08082500	Seymour	Main Stem	1964-86	269	2,601	1,074	504	3,591	1,482	696
08088600	Possum Kingdom	Main Stem	1964-86	686	2,795	111	571	1,512	601	309
08092600	Whitney	Main Stem	1964-86	1,230	3,075	1,134	591	928	342	178
08106500	Cameron	Little River	1964-86	1,481	1,024	123	119	256	31	30
08109500	College Station	Main Stem	1964-83	4,529	5,348	1,368	938	438	112	77
08114000	Richmond	Main Stem	1964-86	6,868	6,267	1,466	1,030	339	79	56

Source: Wurbs, R.A., A.S. Karama, I. Saleh, and C.K. Ganze, “Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin,” Texas Water Resources Institute, 1993.

Table 11-4. Ranges in Monthly Mean Salinity Concentration for Water Years 1964 through 1986

Abbreviated Station Name	Tributary	Con-stituent	Minimum Monthly Mean Concen-tration (mg/L)[1]	Date of Minimum Monthly Mean Concentration (mg/L)[1]	Maximum Monthly Mean Concen-tration (mg/L)[1]	Date of Maximum Monthly Mean Concentration (mg/L)[1]	Ratio of Maximum to Minimum
Seymour	Main Stem	TDS	618	Aug 1964	15,400	May 1984	24.92
Seymour	Main Stem	Cl	190	Jun 1975	7,740	May 1984	40.74
Seymour	Main Stem	SO_4	112	Nov 1963	2,225	Mar 1976	19.87
Richmond	Main Stem	TDS	153	Nov 1984	978	Oct 1978	6.39
Richmond	Main Stem	Cl	28	Nov 1984	355	Oct 1978	12.68
Richmond	Main Stem	SO_4	24	Dec 1965	185	Oct 1963	7.71

[1] Source: Wurbs, R.A., A.S. Karama, I. Saleh, and C.K. Ganze, "Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin," Texas Water Resources Institute, 1993.

Based on arithmetic averages of the monthly mean concentrations for each month of the year in the 1964 through 1986 analysis period, Wurbs et. al. (1993) also found that seasonal fluctuations in salinity concentrations were greater at the Seymour gage than at the gages located below the reservoirs. The month having the maximum average monthly mean concentrations of all three salinity parameters at Seymour is February.

Table 11-5 lists the range of the arithmetic averages of the monthly mean concentrations at the Seymour, Whitney, and Richmond gages. Of the three gages, the variation is least at the Whitney gage, which is likely due to the effects of the reservoir. With regard to trends over time, Wurbs et al. (1993) found that any trends or long-term changes in salinity concentrations are very small relative to the random variability in the data.

11.1.3 Effects of Salinity on Usability of Water

TDS concentration-duration curves at the Seymour, Possum Kingdom, Whitney, College Station, and Richmond gages based on the 1964 through 1986 water year (1964 through 1983 for the College Station gage) monthly mean data are plotted in Figure 11-3 through Figure 11-7.

Table 11-5. Range of Arithmetic Averages of Monthly Mean Salinity Concentrations for Each Month of the Year for Water Years 1964 through 1986

Abbreviated Station Name	Tributary	Con-stituent	Minimum Average Monthly Mean Concen-tration (mg/L)[1]	Month Having Minimum Average Monthly Mean Concen-tration (mg/L)[1]	Maximum Average Monthly Mean Concen-tration (mg/L)[1]	Month Having Maximum Average Monthly Mean Concen-tration (mg/L)[1]	Ratio of Maximum to Minimum
Seymour	Main Stem	TDS	3,240	Sep	10,600	Feb	3.27
Seymour	Main Stem	Cl	1,310	Sep	4,650	Feb	3.55
Seymour	Main Stem	SO_4	701	Sep	1,620	Feb	2.31
Whitney	Main Stem	TDS	880	Jul	996	Jan	1.13
Whitney	Main Stem	Cl	321	Jul	374	Jan	1.17
Whitney	Main Stem	SO_4	167	Jul	194	Dec	1.16
Richmond	Main Stem	TDS	335	May	546	Aug	1.63
Richmond	Main Stem	Cl	78	May	158	Aug	2.03
Richmond	Main Stem	SO_4	55	May	95	Aug	1.73

[1] Source: Wurbs, R.A., A.S. Karama, I. Saleh, and C.K. Ganze, "Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin," Texas Water Resources Institute, 1993.

Figure 11-3. TDS Concentration-Duration Curve at Seymour

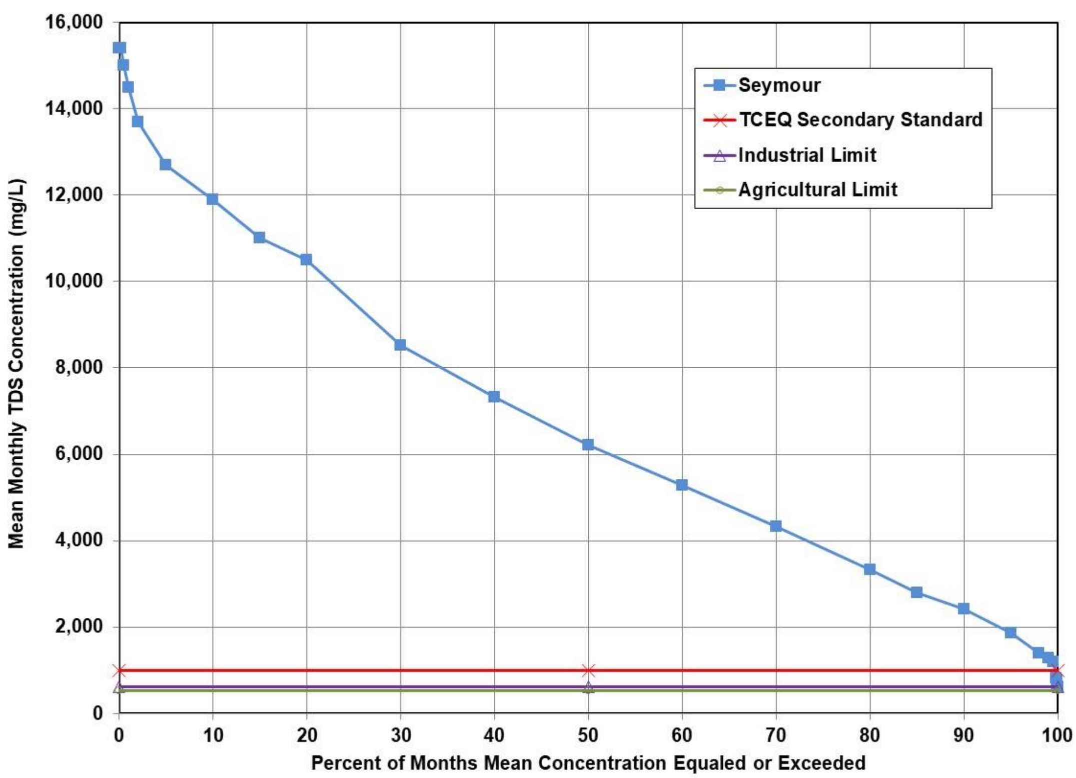


Figure 11-4. TDS Concentration-Duration Curve at Possum Kingdom

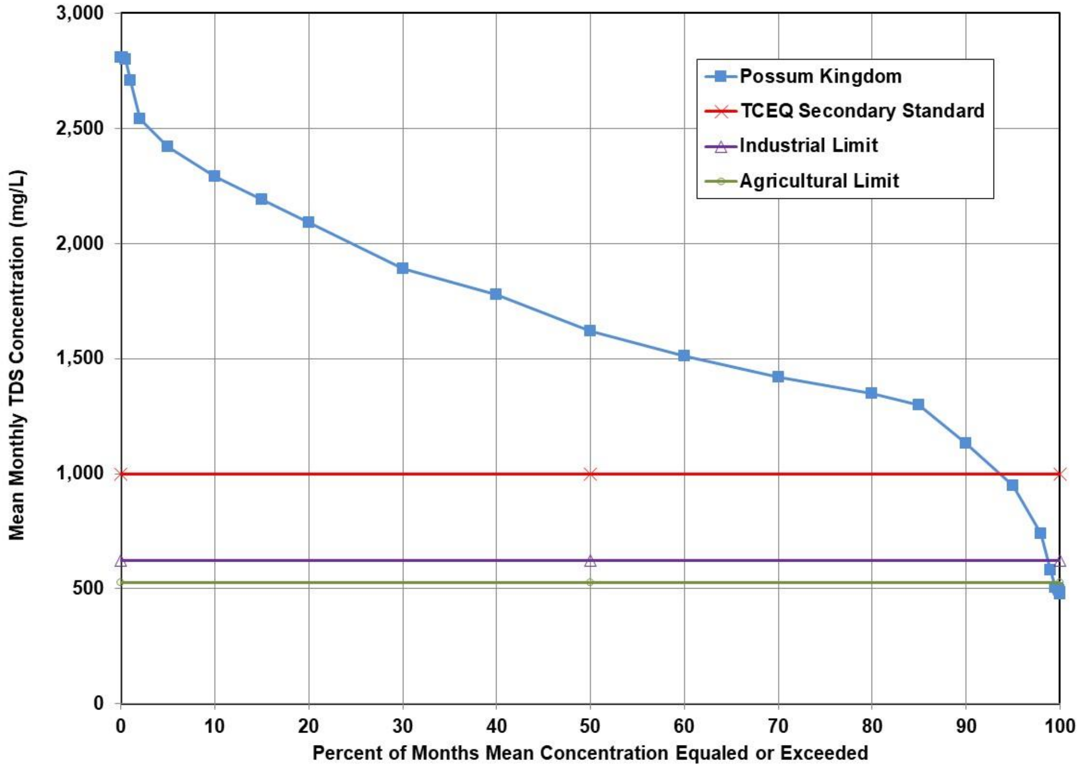


Figure 11-5. TDS Concentration-Duration Curve at Whitney

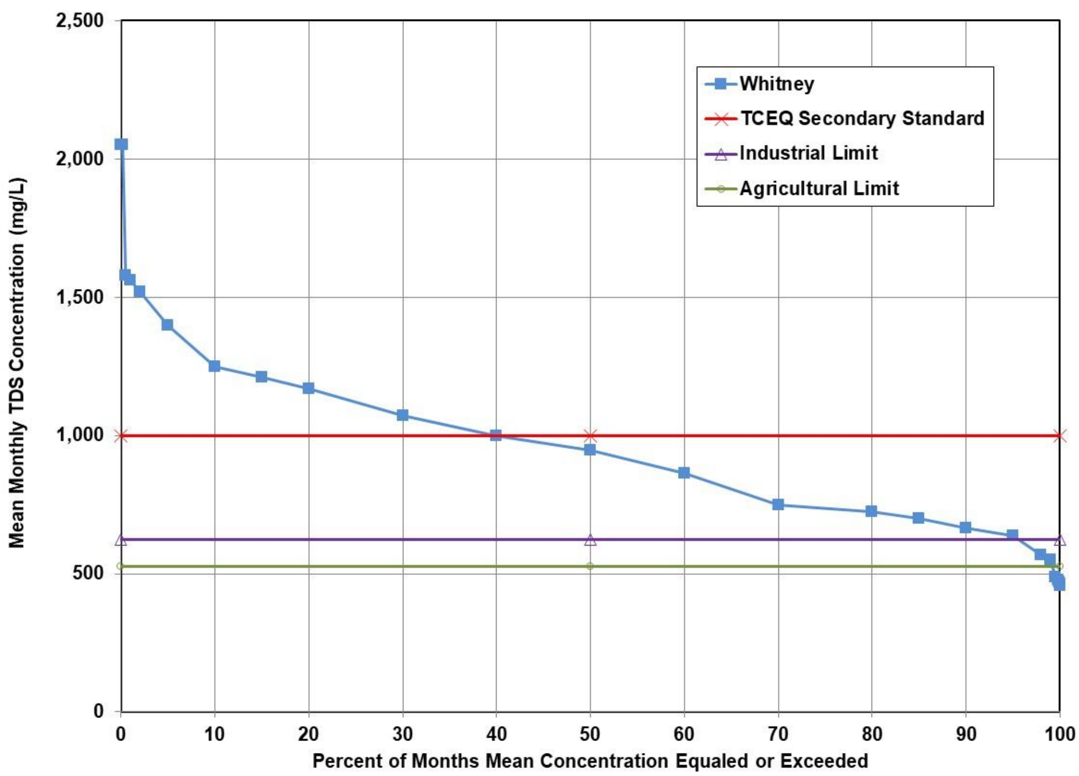


Figure 11-6. TDS Concentration-Duration Curve at College Station

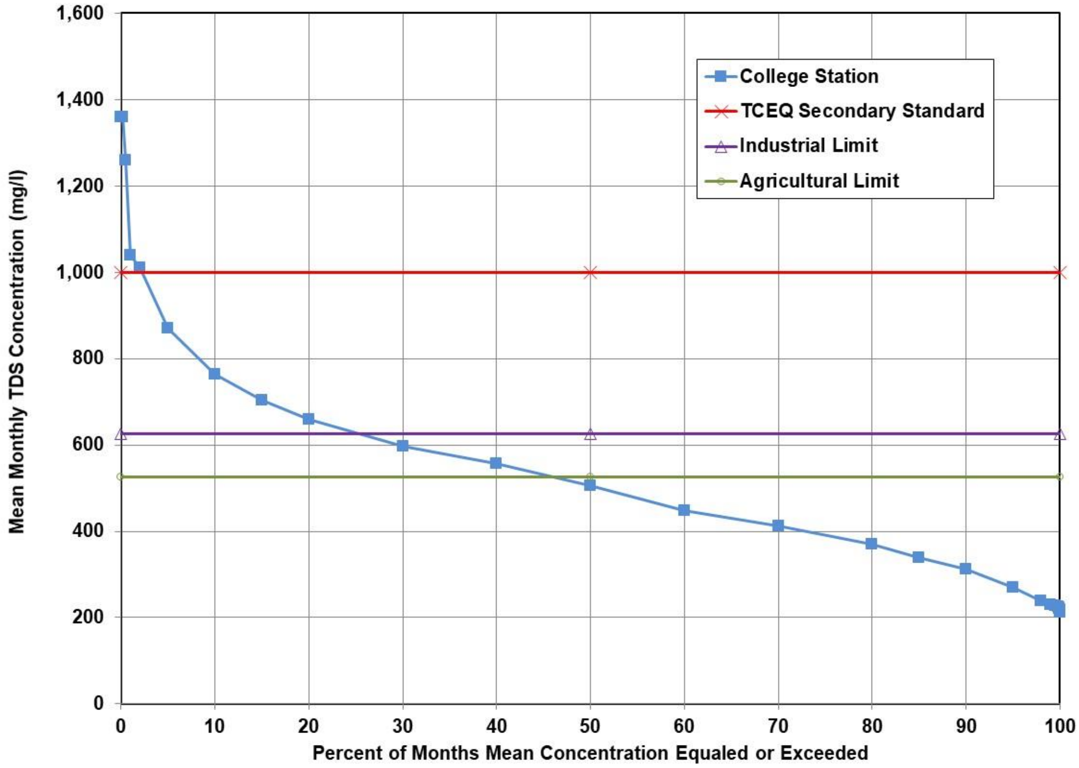
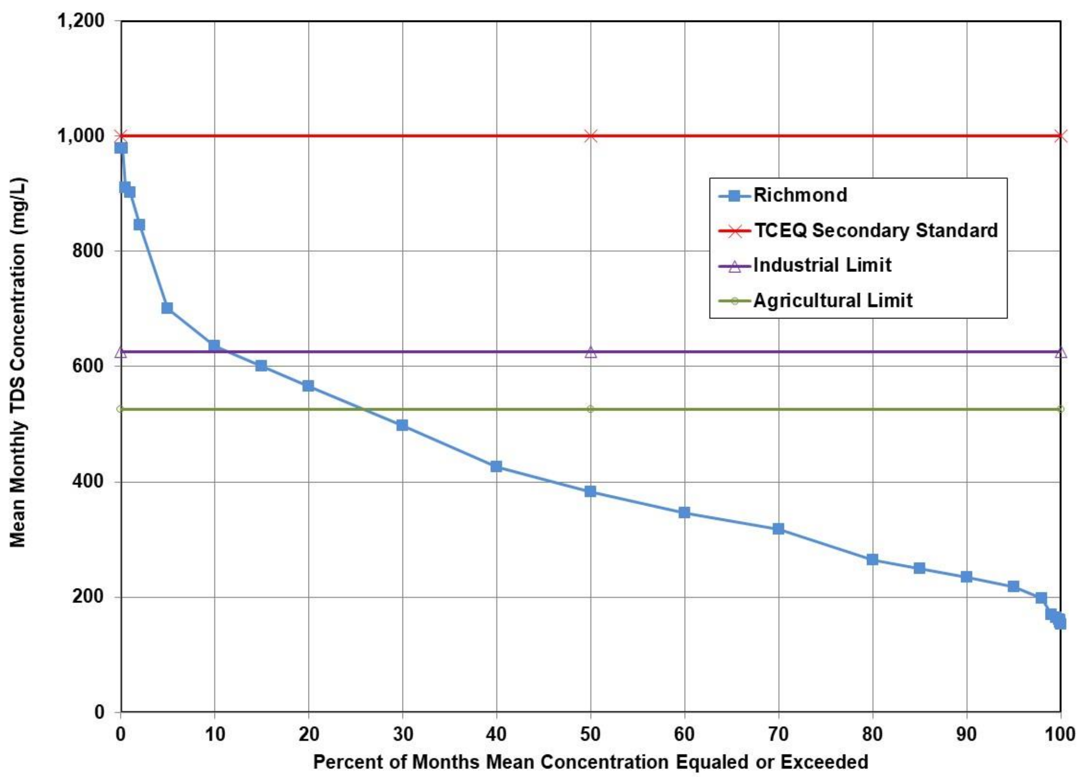


Figure 11-7. TDS Concentration-Duration Curve at Richmond



Comparison of the salinity concentration frequencies to requirements for municipal, agricultural, and industrial use provide insight into the usability of the water in the Brazos without desalination treatment.

The TCEQ secondary drinking water standard for TDS is 1,000 mg/L. Figure 11-2 indicates that concentrations at the Seymour gage equaled or exceeded the TDS limit in 99.7% of the study period months. Further downstream, below Possum Kingdom Lake and Lake Whitney, concentrations equaled or exceeded the TDS limit in 93.6% and 40.0% of the months, respectively. At College Station, concentrations equaled or exceeded the TDS limit in 2.2% of the months. Finally, at the Richmond gage, the downstream-most gage in the study (92 river miles above the Gulf of Mexico), concentrations remained less than the TDS limit.

Table 11-6 provides permissible TDS limits for classes of irrigation water, as presented by Fipps.[10] The table shows that at TDS concentrations above 525 mg/L, leaching is recommended to flush accumulated salts below the active root zone. Table 11-7 provides irrigation water quality guidelines published by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The NRCS guidelines indicate that irrigation water can be used without restriction, or without expectation of related problems, if TDS concentrations are below 450 mg/L and that with concentrations ranging from 450 mg/L to 2,000, use is slightly to moderately restricted. Additional information on the effects of salinity on the suitability of water for irrigation is provided by Hem.[11] Assuming a desirable TDS concentration of less than 525 mg/L for irrigation use, Figure 11-3 through Figure 11-7 indicate that TDS levels in the Brazos River at the Seymour, Possum Kingdom, Whitney, College Station, and Richmond gages equaled or exceeded the desirable level in 100%, 99.4%, 99.2%, 46.2%, and 26.0% of the months in the analysis period, respectively.

Water quality requirements for industrial usage vary widely depending upon the industrial process.[12] A 625 mg/L TDS limit is assumed here. The limit is derived from a desirable chloride concentration for water used in cooling towers of less than 200 mg/L. Based on the USGS water quality data, mean chloride concentration as a percentage of mean TDS concentration in the Brazos River ranges from 23% at Richmond to 41% at Seymour. Using the midpoint of this range, 32%, as a representative percentage of TDS that is chloride, a 200 mg/L chloride limit equates to a 625 mg/L TDS limit (200/.32 = 625). Figure 11-3 through Figure 11-7 indicate that TDS levels in Brazos at Seymour, Possum Kingdom, Whitney, College Station, and Richmond gages equaled or exceeded this concentration in 100%, 98.7%, 95.6%, 25.4%, and 11.5% of the months in the analysis period, respectively.

[10] Fipps, G. "Irrigation Water Quality Standards and Salinity Management Strategies," Texas A&M Agricultural Research and Extension Center, April 2003.

[11] Hem, J.D., "Study and Interpretation of the Chemical Characteristics of Natural Water," United States Geological Survey Water Supply Paper 2254, Third Edition, 1989.

[12] Ibid.

Table 11-6. Permissible TDS Limits for Classes of Irrigation Water

Classes of Water	TDS Concentration (mg/L)	Comment
Class 1, Excellent	175	
Class 2, Good	175-525	
Glass 3, Permissible	525-1,400	Leaching needed if used.
Class 4, Doubtful	1,400-2,100	Good drainage needed and sensitive plants will have difficulty obtaining stands.
Class 5, Unsuitable	2,100	Good drainage needed and sensitive plants will have difficulty obtaining stands.

Source: Fipps, G., "Irrigation Water Quality Standards and Salinity Management Strategies," Texas A&M Agricultural Research and Extension Center, April 2003.

Table 11-7. Irrigation Water Quality Guidelines

Degree of Restriction on Use	TDS Concentration (mg/L)
None	< 450
Slight to Moderate	450 – 2,000
Severe	> 2,000

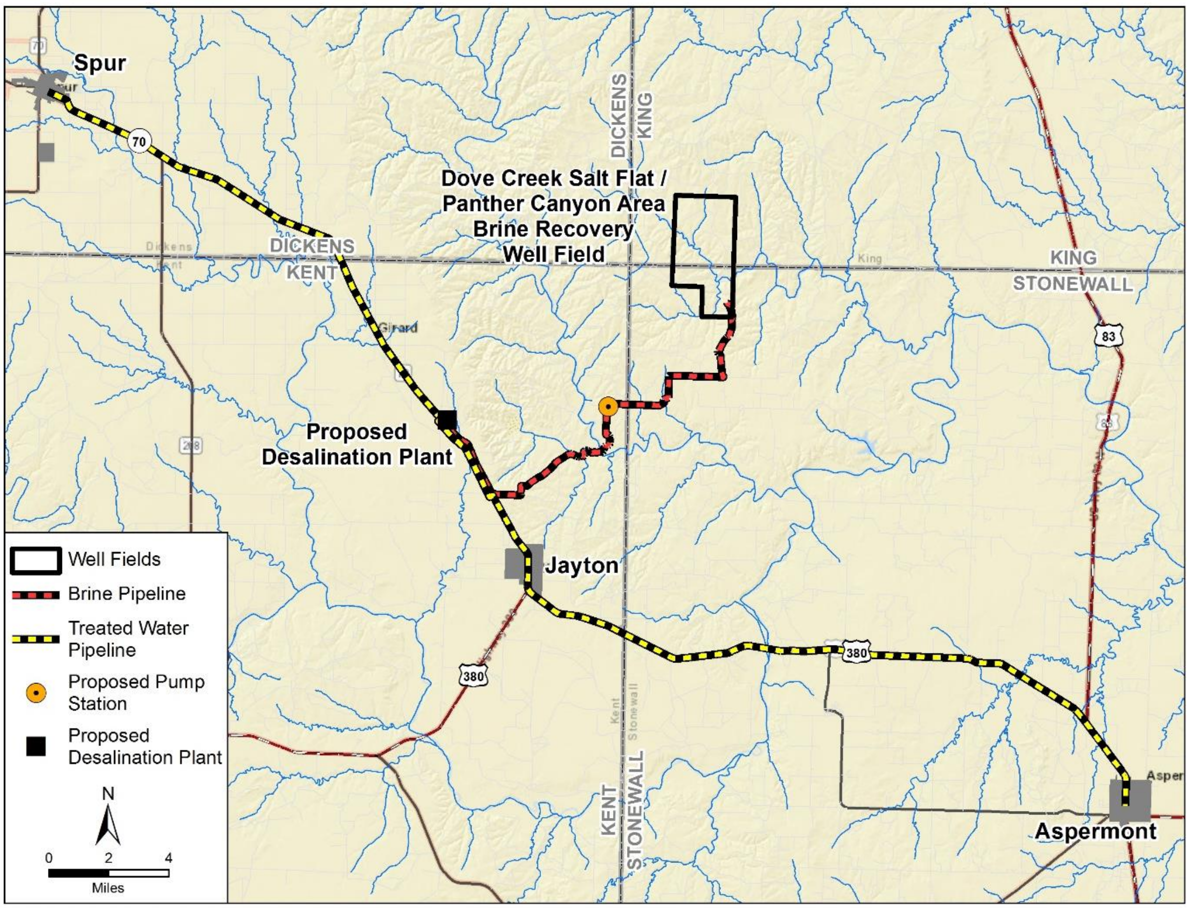
Source: Ayers, R.S., and D.W. Westcot, "Water Quality for Agriculture," Food and Agricultural Organization of the United Nations, Irrigation and Drainage Paper No. 29, rev. 1, 1985, as cited in U.S. Department of Agriculture Natural Resources Conservation Service. Part 623 National Engineering Handbook, Chapter 2, "Irrigation Water Requirements," 1993.

11.2 Description of Salinity Control Project

Three salinity control project options were studied in the 2001 Brazos G Regional Water Plan. All three options included brine recovery well fields that penetrate the saline aquifer, lowering the piezometric surface of the water table, thereby eliminating brine springs and seeps in the area. Option 1 involved disposal of the recovered brine in a deep well injection system. Option 2 involved disposal of the brine in Kiowa Peak Reservoir, which would serve as a permanent impoundment for the recovered brine. Option 3, which has evolved into the project studied further herein, conveys the recovered brine to a utilization and management complex (BUMC) where it would be converted into marketable sodium chloride (NaCl) salt products and potable water. Stonewall, Garza, and Kent Counties have formed a local government corporation called the Salt Fork Water Quality (SFWQ) Corporation to work on advance planning for the project in cooperation with the Brazos River Authority.

The currently proposed project configuration is shown in Figure 11-8. Project components are located in Kent, Stonewall, Dickens, and King Counties and include ten brine recovery wells, a brine conveyance pipeline, the BUMC, and three water supply pipelines. The proposed brine recovery well field is located in the Dove Creek Salt Flat/ Panther Canyon Area, adjacent to salt springs contributing flows to Salt Croton Creek. Dual ten inch diameter transmission lines will convey the brine from the Panther Canyon well field to a battery of ground storage tanks located immediately upstream of the proposed BUMC. One intermediate pump station is included in the transmission system. The proposed BUMC is located in Kent County approximately 5.5 miles northwest of Jayton and 55 miles north of Snyder and consists of a Dynamic Vapor Recompression (DyVaR) Plant, an evaporative desalination plant developed by Salttech, and remineralization facilities. The DyVaR system will produce desalinated water and dry salts with little to no waste. Product water will be remineralized, converted to potable water, and delivered to users in Kent, Stonewall, and Garza Counties via the proposed water supply lines. The salt byproduct will also be sold and revenues are expected to cover annual operation and maintenance costs and help offset the price of treated water. Costing for the rehabilitation of BNSF rail spur and transportation system improvements are included in this evaluation. The rail spur will facilitate long distance shipping of salt products.

Figure 11-8. Project Layout Map



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11.3 Evaluation of the Potential Effectiveness of the Salinity Control Project

11.3.1 Modeling Approach

Evaluating the potential effectiveness of the salinity control project involved modeling TDS concentrations in the Brazos River Basin under the hydrologic, water use, and reservoir operating policies of the 2070 Brazos G Water Availability Model (WAM). Model simulations were developed to represent conditions with and without the salinity control project, and the resulting TDS concentration frequency data were compared. Work by Wurbs and Lee (2009)[13] provided salinity input data used in the modeling.

Brazos WAM WRAP-SALT Input File Without Salinity Control

Wurbs and Lee (2009)[14] used the USGS 1964-1986 sampling data to develop a TDS budget for the Brazos Basin. The budget provided estimates of TDS loads and concentrations that Wurbs and Lee then applied in preparing an input file for the WRAP-SALT[15] software. WRAP-SALT is the salinity modeling component of the Water Rights Analysis Package (WRAP).[16] The program computes loads and concentrations of conservative water quality constituents based on scenarios of water use, reservoir operating policies, and salinity control measures. The Brazos WAM is implemented with the WRAP-SIM component of WRAP and provides the water quantity data that are necessary for execution of WRAP-SALT. The Wurbs and Lee (2009) input file is designed for use with the various versions of the Brazos WAM.

Table 11-8 provides a summary of the Wurbs and Lee (2009) TDS budget. Water volumes, TDS loads, and TDS concentrations of inflows and losses to the Brazos River system are summarized by mean values over the 1964 through 1986 water year period. Inflow values are summarized at five control points representing five USGS gaging stations, and losses are summarized at the three major main stem reservoirs (Possum Kingdom, Granbury, and Whitney). The losses represent removal of salinity from the system that is not associated with a particular water management practice.

Wurbs and Lee (2009) used the TDS budget in developing the WRAP-SALT input file. The 197,402 tons/month mean net TDS inflow minus losses (Table 11-8) is the mean TDS load of flow at the Richmond gage as entered in the WRAP-SALT input file. The actual mean load at the Richmond gage (Table 11-10) for the 1964 through 1986 water year period was approximately 6,800 tons/month less than the load entered into the model. Of this difference, approximately 4,900 tons/month is accounted for by the change in reservoir storage, and approximately 1,900 is accounted for by water supply diversions from Lake

[13] Wurbs, R.A. and C. Lee, "Salinity Budget and WRAP Salinity Simulation Studies of the Brazos River/Reservoir System," Texas Water Resources Institute Technical Report No. 352, July 2009.

[14] Ibid.

[15] Wurbs, R.A, "Salinity Simulation with WRAP," Texas Water Resources Institute Technical Report No. 317, July 2009.

[16] Wurbs, R.A, "Water Rights Analysis Package (WRAP) Modeling System Reference Manual," Texas Water Resources Institute Technical Report No. 255, August 2008.

Granbury. These loads are not subtracted out of the load entered into the input file because the software computes the actual values of these loads for the water management strategies being modeled.

Components of the total Basin load are introduced at various locations throughout the Basin in the salinity simulation based on information provided by the Brazos WAM WRAP-SALT input file. The salinity computations are carried out from upstream to downstream. TDS loads entering the system at the Seymour control point and inflow concentrations entering at the Cameron control point define upstream boundaries of the salinity simulation. These boundaries are the loads and concentrations associated with total regulated flows at the Seymour and Cameron control points. The Little River is the largest low salinity tributary of the Brazos River. Although the Brazos WAM contains control points located upstream of the boundaries and computes water quantities above these points, the salinity simulation does not extend above the Seymour gage on the Brazos River and the Cameron gage on the Little River.

In addition to defining the boundary conditions, the WRAP-SALT input file defines the TDS concentrations for incremental inflows that occur throughout the Basin below the boundaries. The incremental inflow concentrations are defined at several control points. These concentrations are then automatically repeated by the model at all control points located above the given control point, until a point is encountered with a different incremental inflow concentration. Thus, incremental inflow concentrations are applied to all incremental inflows entering the model below the upstream boundaries.

Table 11-8. TDS Budget Summary

Location	*Brazos WAM Control Point ID*	*USGS Station Number*	*Mean Volume (acft / month)*	*Mean Load (tons / month)*	*Mean Load (percentage)*	*Mean Concen-tration (mg/L)*
Inflows Entering the River System						
Brazos River at Seymour	BRSE11	08082500	16,215	79,127	34.9	3,589
Brazos River at Morris Sheppard Dam near Graford	SHGR26	08088600	33,153	31,828	14.1	706
Brazos River near Whitney (Aquilla) Below Whitney Dam	BRAQ33	08092600/ 08093100	43,077	18,485	8.2	316
Little River at Cameron	LRCA58	08106500	89,374	31,134	13.7	256
Brazos River at Richmond	BRRI70	08114000	251,443	65,956	29.1	193
Subtotal			**432,262**	**226,530**	**100.0**	**385**
Losses Leaving the Reservoir System						

Table 11-8. TDS Budget Summary

Location	Brazos WAM Control Point ID	USGS Station Number	Mean Volume (acft / month)	Mean Load (tons / month)	Mean Load (percentage)	Mean Concen-tration (mg/L)
Lake Possum Kingdom	515531		2,383	19,331	66.4	5,966
Lake Granbury	515631		2,222	6,694	23.0	2,216
Lake Whitney	515731		2,233	3,103	10.6	1,022
Subtotal			**6,838**	**29,128**	**100.0**	**3,140**
Total Net Inflows Less Losses						
Brazos River Basin Total			**440,100**	**197,402**		**330**
Source: Wurbs, R.A. and C. Lee, “Salinity Budget and WRAP Salinity Simulation Studies of the Brazos River/Reservoir System,” Texas Water Resources Institute Technical Report No. 352, July 2009.						

Table 11-9 is excerpted from Wurbs and Lee (2009) and lists the locations at which TDS is input to the system, and describes how these inputs are defined. The Seymour boundary consists of a series of TDS loads for each month of the simulation period. The loads are combined in WRAP-SALT with the WAM regulated flow output to compute the concentrations at the boundary. The observed loads from the 1964 through 1986 dataset at the Seymour gage are adopted for that time period in the input file. Because the Brazos WAM simulation period extends from 1940 to 1997, loads were synthesized for the 1940 through 1939 and 1987 through 1997 periods. Wurbs and Lee (2009) synthesized the missing data by interpolating loads for the Brazos WAM naturalized flows from the observed loads and flows in the 1964 through 1986 dataset. This approach differs from simply developing a load-discharge regression equation from the observed data and using that equation to compute the load for the given naturalized flow. The approach used involves interpolating loads from the observed load-discharge data points after they have been ranked in order of increasing discharge. While these data do generally show increasing load with increasing discharge, for a given pair of data points the greater discharge point may not be associated with a larger load. Wurbs and Lee (2009) note that compared to a regression equation, the interpolation method preserves some of the variability of the observed discharge-load data.

Table 11-9. TDS Data in WRAP-SALT Input File

Control Point ID	Control Point Location	Input File Data
BRSE11	Brazos River at Seymour	Load series for total regulated flows
SHGR26	Brazos River at Morris Sheppard Dam near Graford	Concentration series for incremental inflows
BRAQ33	Brazos River near Whitney (Aquilla) Below Whitney Dam	Concentration series for incremental inflows
LRCA58	Little River at Cameron	Constant 256 mg/L for total regulated flows
BRRI70	Brazos River at Richmond	Concentration series for incremental inflows
BRGM73	Brazos River at Gulf of Mexico	Constant 339 mg/L for incremental inflows

Source: Wurbs, R.A. and C. Lee, "Salinity Budget and WRAP Salinity Simulation Studies of the Brazos River/Reservoir System," Texas Water Resources Institute Technical Report No. 352, July 2009.

At the Cameron boundary, a constant TDS concentration of 256 mg/L is established for regulated flows. This concentration is applied to the regulated flow at this control point in each month of the simulation. The 256 mg/L value is equal to the 1964 through 1986 mean concentration at the Cameron gage.

In addition to the two upstream boundaries, TDS inputs are defined at the Graford gage, Whitney gage, Richmond gage, and at the Basin outlet at the Gulf of Mexico. The inputs at the Graford, Whitney, and Richmond gages are defined with time series of TDS concentrations for incremental inflows. The time series provide the incremental inflow concentrations for each month of the simulation period. The series consist of the 1964 through 1986 observed concentrations along with synthesized data for the remainder of the period. Similar to the synthesized loads at the Seymour gage, concentrations of incremental inflows were synthesized by linear interpolation of load-discharge datasets developed from the salinity budget.

A constant incremental inflow TDS concentration is defined at the basin outlet at the Gulf of Mexico. This constant value is applied for all months of the simulation period and is equal to the 1964 through 1986 mean concentration at the Richmond gage of 339 mg/L.

The TDS budget summarized in Table 11-8 shows losses from the system that are not associated with a particular water management practice. To account for these losses in the WRAP-SALT simulations, the input file includes coding to reduce inflow loads to the Lake Possum Kingdom, Granbury, and Whitney control points by 17.42%, 6.59%, and 3.00% respectively. These losses are not repeated at any other control points.

The WRAP-SALT simulation requires initial storage and TDS concentrations for each reservoir located below the upstream boundaries. In both the Brazos WAM and the salinity simulation, all reservoirs are assumed to be full at the beginning of the simulation period. Possum Kingdom Lake, Lake Granbury, and Lake Whitney are assigned initial TDS concentrations of 1,626 mg/L, 1,302 mg/L, and 1,062 mg/L, respectively. These values are the mean 1964 through 1986 TDS concentrations for each lake as computed in the salinity budget. Reservoirs upstream of Possum Kingdom, Granbury, and Whitney are assigned initial TDS concentrations of 800 mg/L, 400 mg/L, and 300 mg/L respectively. Reservoirs upstream of the Brazos River at the Gulf of Mexico and below Whitney are assigned initial TDS concentrations of 250 mg/L.

Brazos WAM WRAP-SALT Input File with Salinity Control

Wurbs and Lee (2009) used WRAP-SALT with the input file described in the previous section to assess the salinity reduction that would be achieved by construction of salinity control impoundments on Croton Creek, Salt Croton Creek, and North Croton Creek. The impoundment project has been previously studied by the U.S. Army Corps of Engineers.[17,18] Wurbs and Lee (2009) modeled the impacts of the impoundments by assuming that all flows and loads entering the system above the impoundments would be removed. A similar approach was used in the present study to assess the effects of the groundwater pumping salinity control project.

Table 11-10 provides a summary of loads and discharges at USGS gages in the upper Brazos River Basin prepared by Wurbs and Lee (2009). Not all the gages listed in Table 11-10 have complete water year 1964 through 1986 records. The table therefore provides 1969 through 1977 means that are based on measured data as well as 1964 through 1986 means that are based on records which were filled as necessary by regression analysis.

To model the effects of the salinity control impoundments, Wurbs and Lee (2009) reduced TDS loads at the Seymour gage in the WRAP-SALT input file using the information provided in Table 11-10. In doing so, the authors assumed that all discharges and loads entering above the impoundments would be removed. The Seymour gage is the upstream boundary for the salinity calculations on the Brazos River and therefore it follows that the effects of the impoundments, which lie upstream of this location, would be entered in the model at Seymour. Wurbs and Lee (2009) reduced the naturalized flow volumes by 12.7% and the TDS loads by 41.8%, which are the 1962 through 1968 average volume and load contributions of the impounded tributaries.

Figure 11-9 shows the location of the previously proposed brine recovery well fields in relation to major brine springs and USGS stream gages. Prior work has indicated that the brine recovery well system proposed in the 2016 Plan would reduce the TDS loads in the Brazos River above Possum Kingdom Lake by 41%.[19] If the Dove Creek Salt Flat / Panther Canyon Area well field eliminated the TDS load from Salt Croton Creek and the Short Croton Salt Flat well field eliminated the TDS load from Croton Creek, an average of 901 tons per day would be eliminated from the system, based on the 1964 through 1986 mean TDS loads (Table 11-10 and Figure 11-9). The TDS load of Salt Creek is approximately 10% of the load of the Salt Fork of the Brazos River near Peacock[20], or approximately 68

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[17] U.S. Army Corps of Engineers Fort Worth District, "Natural Salt Pollution Control Study, Brazos River Basin, Texas," Volumes 1-4, 1973.

[18] U.S. Army Corps of Engineers, Fort Worth District, "Brazos Natural Salt Pollution Control, Brazos River Basin, Texas, Design Memorandum No. 1, General Phase 1 – Plan Formulation," 1983.

[19] James, W.P., "Water Quality Improvement along the Brazos River," prepared for the Salt Fork Water Quality District, Stonewall, Kent, and Garza Counties, Texas, Open-file Report, 2007.

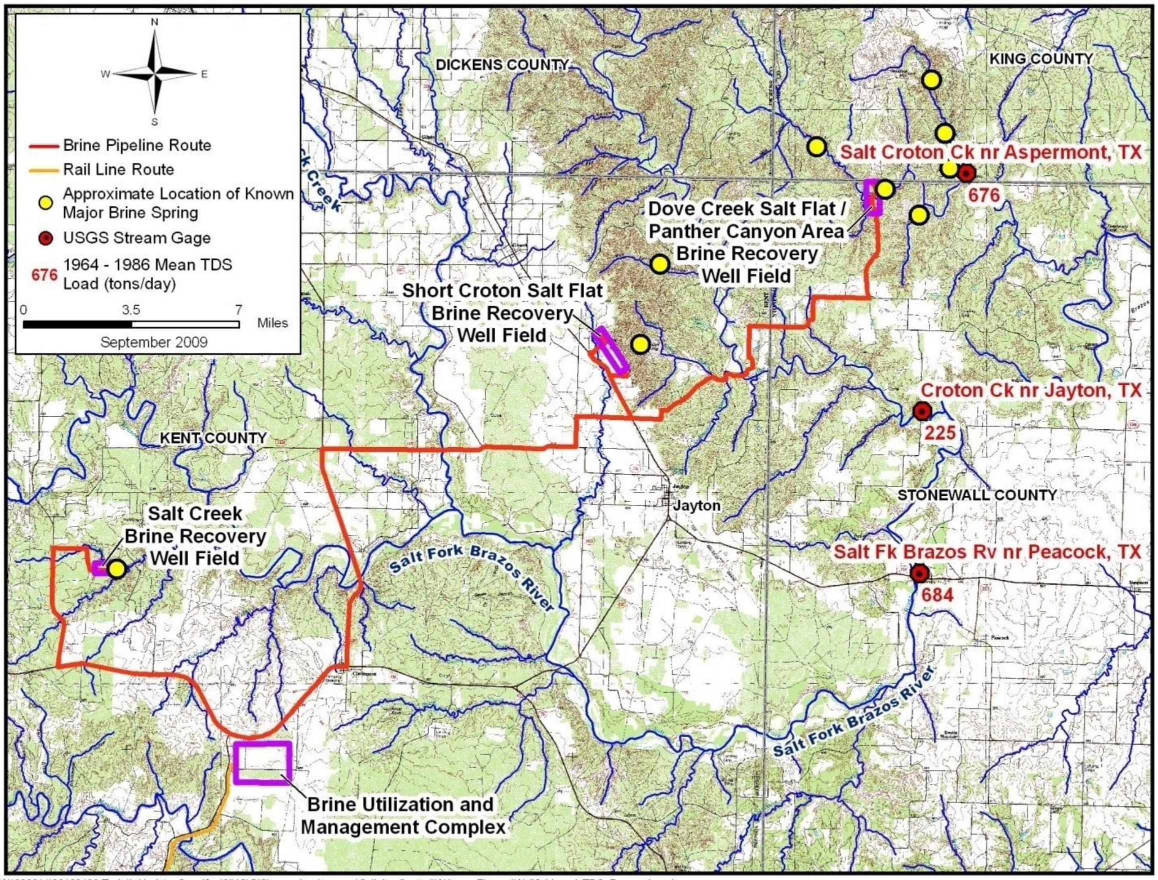
[20] Rodgers, R.W., "Natural Chloride Salt Pollution Control in the Upper Brazos River Basin," prepared for the Salt Fork Water Quality District, Stonewall, Kent, and Garza Counties, Texas, 2008.

tons per day based on the 1964 through 1986 mean load at the gage near Peacock (Table 11-10 and Figure 11-9). If the Salt Creek well field eliminated this load, the total mean TDS load eliminated by the project would be approximately 969 tons per day, which is approximately 37% of the 1964 through 1986 mean load of the Brazos River at Seymour. This value agrees reasonably well with the reported 41% load reduction. A WRAP-SALT input file representing conditions with the well fields in place was therefore developed that includes a provision to multiply the TDS loads at the Seymour boundary by a factor of 0.60 for a 40% reduction.

Table 11-10. Flows and Loads in the Upper Brazos River Basin

USGS Gaging Station	*USGS Station Number*	*Mean Flow (cfs)*	*Mean Load (tons / day)*	*Mean Concen-tration (mg/L)*	*Mean Flow (%)*	*Mean Load (%)*
October 1968 through September 1977 (Water Year 1969 through 1977)						
Salt Fork of Brazos River near Peacock	08081000	41	594	5,380	16.3	22.1
Croton Creek near Jayton	08081200	12	200	6,030	4.8	7.4
Salt Croton Creek near Aspermont	08081500	4	673	56,920	1.6	25.0
Salt Fork of Brazos River near Aspermont	08082000	63	1,548	9,090	25.1	57.5
North Croton Creek near Knox City	08082180	11	163	5,400	4.4	6.2
Brazos River at Seymour	08082500	251	2,693	3,980	100.0	100.0
October 1963 through September 1986 (Water Year 1964 through 1986)						
Salt Fork of Brazos River near Peacock	08081000	40	684	5,780	14.9	26.3
Croton Creek near Jayton	08081200	13	225	6,540	4.8	8.7
Salt Croton Creek near Aspermont	08081500	5	676	54,560	1.9	26.0
Salt Fork of Brazos River near Aspermont	08082000	62	1,660	10,000	23.0	63.8
North Croton Creek near Knox City	08082180	17	211	4,720	6.3	8.1
Brazos River at Seymour	08082500	269	2,601	3,590	100.0	100.0
Source: Wurbs, R.A. and C. Lee, "Salinity Budget and WRAP Salinity Simulation Studies of the Brazos River/Reservoir System," Texas Water Resources Institute Technical Report No. 352, July 2009.						

Figure 11-9. Previously Proposed Project Layout and TDS Loads



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It has been proposed that a total groundwater pumping rate of 500 gallons per minute (gpm) would effectively lower the piezometric surface on the brine aquifer such that the Dove Creek Salt Flat / Panther Canyon Area springs will cease to flow.[21] If the other two well fields were pumped at a similar rate, the total rate of groundwater pumping would be approximately 1% of the discharge of the Brazos River at Seymour. Given that a portion of this discharge would be lost to natural process in the channel between the springs and the Seymour gage, it was assumed for modeling purposes that the flow removed by the well fields would constitute an inconsequential fraction of the total discharge of the Brazos River at Seymour, and therefore the discharge at Seymour was not reduced in the model. As further justification for this assumption, the well pumping rate required to sufficiently lower the water table would likely exceed the total spring discharge. This would mean that the flow volume reduction in the upper Brazos River due to the project would be less than the total well pumping rate.

Several assumptions are inherent in the modeling approach described above. The approach assumes that the groundwater flows eliminated by the well fields provide the only salinity sources to the receiving creeks and that any salt stored in the system would

[21] James, W.P., "Chloride Concentration in the Possum Kingdom Reservoir," prepared for the Salt Fork Water Quality District, Stonewall, Kent, and Garza Counties, Texas, Open-file Report, 2005 cited in Rodgers, R.W., "Natural Chloride Salt Pollution Control in the Upper Brazos River Basin," prepared for the Salt Fork Water Quality District, Stonewall, Kent, and Garza Counties, Texas, 2008.

be flushed out within a finite time period. Previous work by others has indicated that significant improvement in water quality of the Brazos River would occur within three to five years of implementation of the brine recovery well system, depending on the amount of rainfall that occurs in the watershed.[22] It was also assumed that brine discharges from existing desalination plants do not contribute a significant amount of additional salinity to the system; desalination discharges were therefore not explicitly modeled.

Two other assumptions in the approach are highlighted by Wurbs and Lee (2009). First, the approach assumes that there are no natural salinity losses occurring between the sources and the Seymour gage. Second, the WRAP-SALT program assumes that salinity load losses due to flow volume losses in the channel are linearly proportional to the volume losses. Wurbs and Lee (2009) note that underestimation of natural load losses would tend to cause overestimation in the effectiveness of salinity control measures.

The first assumption noted by Wurbs and Lee (2009) appears to be reasonable, as the sum of the mean 1964 through 1986 TDS loads at the Double Mountain Fork of the Brazos River near Aspermont (USGS gage 08080500), the Salt Fork of the Brazos River near Aspermont (USGS Gage 08082000), and North Croton Creek near Knox City (USGS Gage 08082180) is 2,451 tons per day (580 tons per day plus 1,660 tons per day plus 211 tons per day from Table 11-3 and Table 11-10), while the mean load at the Brazos River at Seymour (USGS Gage 08082500) is about 6% greater at 2,601 tons/day. If the load at Seymour were less than the sum of the loads at these three gages, it would be a clear indication that significant losses do occur. With regard to the second assumption noted by Wurbs and Lee (2009), study of the relationship between flow and salinity load losses is beyond the scope of this planning level study.

11.3.2 Model Output Modifications

Adjustments have been made to the proposed SFWQ salinity control project since the 2016 Planning Cycle. Most notably, the 2016 Plan describes three brine collection well fields (Figure 11-9) while the current project considers only one (Figure 11-8 and Figure 11-10Figure 11-1). As shown in Figure 11-9 and Figure 11-10, the currently proposed Dove Creek Salt Flat/Panther Canyon well field and upstream area host the bulk of major known brine springs. Therefore, based on flow and load data (Table 11-10) it is assumed that the project will reduce TDS in the Brazos River near Seymour by 26%, a 14% reduction from the originally simulated scenario. To account for this change, model results representing implementation of the 2016 proposed project were multiplied by a factor of 1.14. Multiplying the model output by 14% is reasonable for planning purposes and because WRAP-SALT is a mass balance model.

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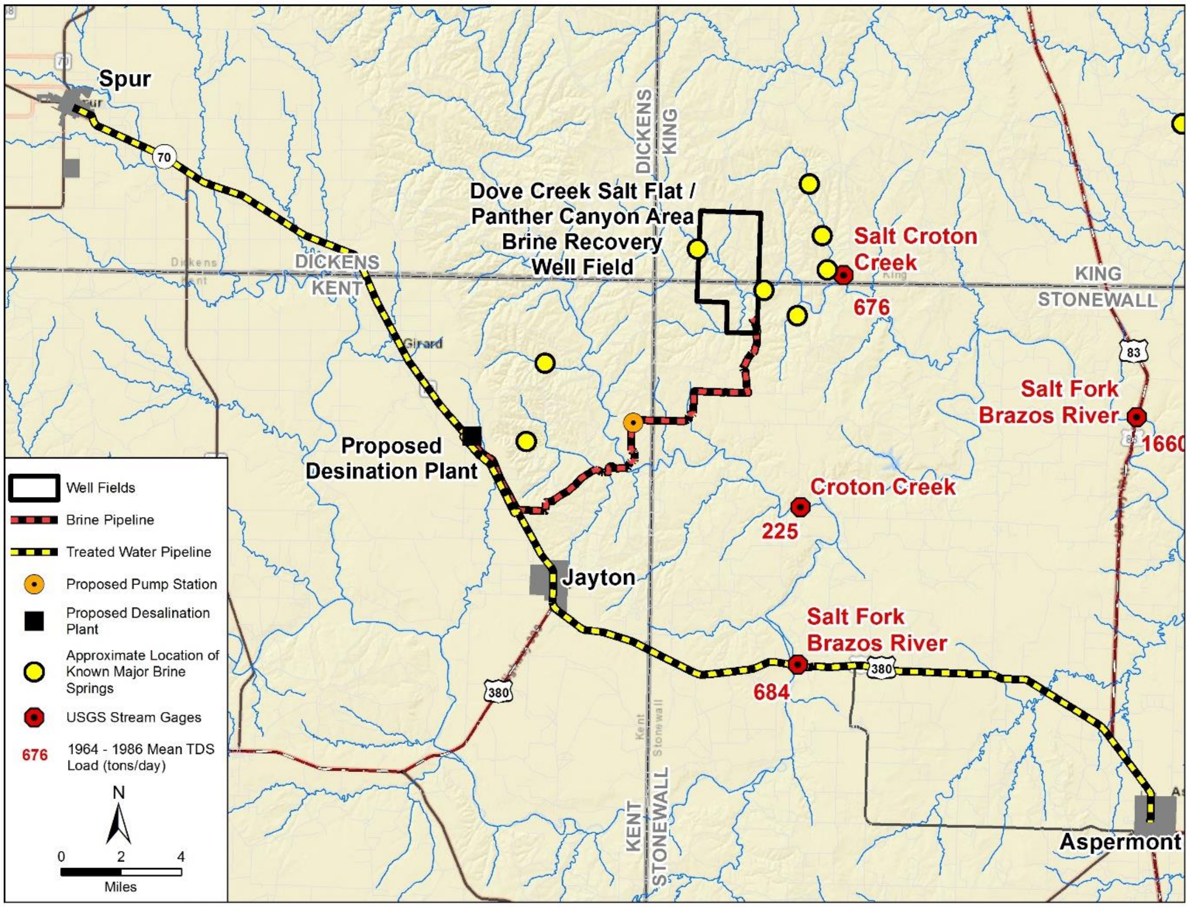
[22] James, W.P., "Water Quality Improvement along the Brazos River," prepared for the Salt Fork Water Quality District, Stonewall, Kent, and Garza Counties, Texas, Open-file Report, 2007.

Figure 11-10. Well Field and TDS Loads



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11.3.3 Comparison of Model-Predicted TDS Concentrations With and Without Salinity Control Project

The WRAP-SALT input files representing conditions with and without the salinity control project were executed with the 2070 version of the Brazos G WAM, which models reservoirs at their projected year 2070 capacity. Table 11-11 and Figure 11-11 through Figure 11-16 summarize the results of the WRAP-SALT analysis at key locations in the Brazos River Basin. The tables and figures provide TDS concentrations for regulated outflows from the Seymour, Bryan, and Richmond model control points and reservoir storage concentrations at Possum Kingdom Lake, Lake Granbury, and Lake Whitney. Presented values are based on the monthly concentration output for the 696 months of the 1940 through 1997 Brazos WAM simulation period.

Table 11-11 provides mean TDS concentrations at each location, computed as the arithmetic average of the concentrations for the 696 simulation periods, both with and without the salinity control project. The last row in Table 11-11 lists the percent reductions in mean concentrations that result from the project. The reduction percentages show that the effects of the project are most pronounced at the upstream model limit (Seymour), and diminish with distance downstream. Wurbs and Lee (2009) explain that this is due to the effects of load losses in the channel and reservoirs.[23] There is a 32% reduction in mean TDS concentration at Seymour, while reductions of 19% to 13% are computed at the three reservoirs. With the removal of two of the three well fields proposed in the 2016 Plan, benefits of the salinity control project are not realized further downstream no reduction in TDS concentrations at Bryan or Richmond.

Table 11-12 lists exceedance frequencies without and with the salinity control project for applicable water quality limits. The data are based on the model-predicted concentration-duration curves presented on Figure 11-11 through Figure 11-16. The water quality limits are also plotted in Figure 11-11 through Figure 11-16 for comparison to the concentration-duration curves. The effects of the project are demonstrated by the reduction in percentage of months a water quality limit is exceeded. For example, the percentage of months where the TCEQ secondary TDS standard is equaled or exceeded in Lake Whitney is reduced by approximately 18% (36.2% - 18.5% = 17.7%). Of the locations shown in Table 11-12, Lake Whitney is the location with the greatest reduction in time exceeding the TCEQ standard. The greatest reduction in time exceeding the industrial limits is also seen in Lake Whitney, at about 6%, while the greatest reduction in time exceeding agricultural limits is 2% at Lake Granbury.

Table 11-11. Mean Model-Predicted TDS Concentration-Duration Curves With and Without Project

	Seymour (mg/L)	Possum Kingdom Lake (mg/L)	Lake Granbury (mg/L)	Lake Whitney (mg/L)	Bryan (mg/L)	Richmond (mg/L)
TDS Without Project (mg/L)	6,398	1,751	1,374	936	551	449
TDS With Project (mg/L)	4,376	1,415	1,140	815	551	449
Percent Reduction in Mean	32	19	17	13	0	0

[23] Wurbs, R.A. and C. Lee, "Salinity Budget and WRAP Salinity Simulation Studies of the Brazos River/Reservoir System," Texas Water Resources Institute Technical Report No. 352, July 2009.

Figure 11-11. Model-Predicted TDS Concentration-Duration Curve at Seymour

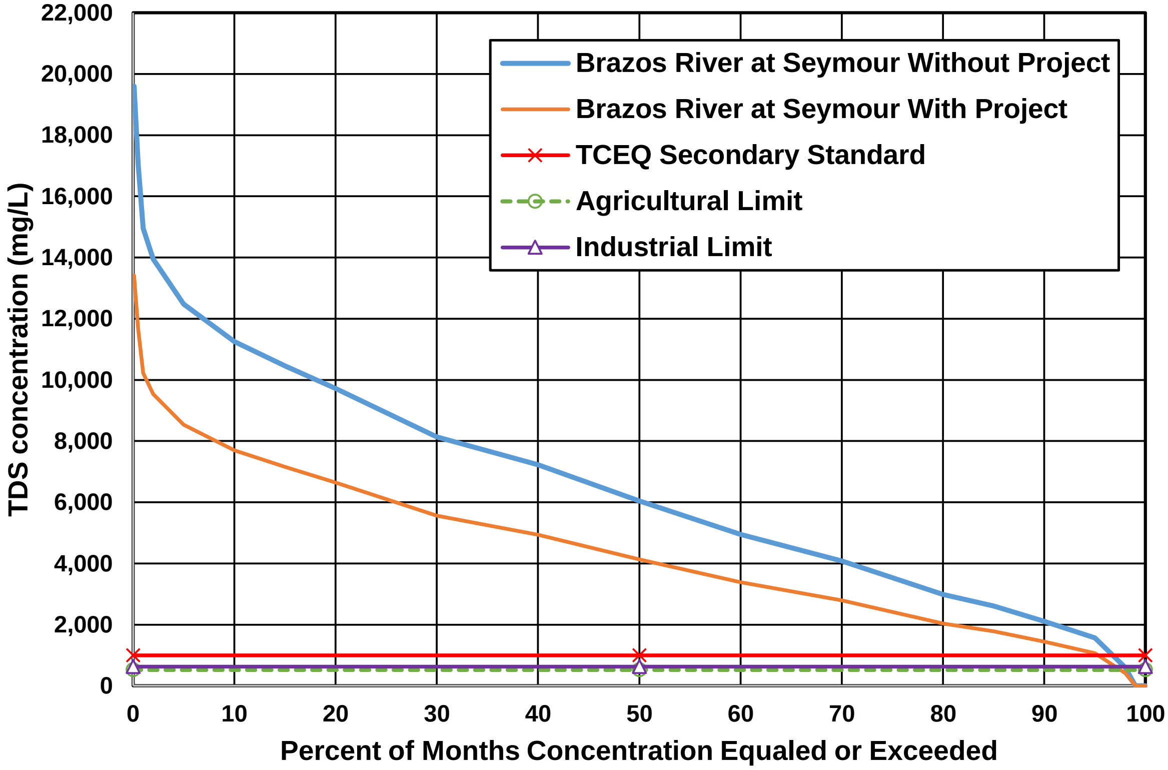

Figure 11-12. Model-Predicted TDS Concentration-Duration Curve at Possum Kingdom Lake

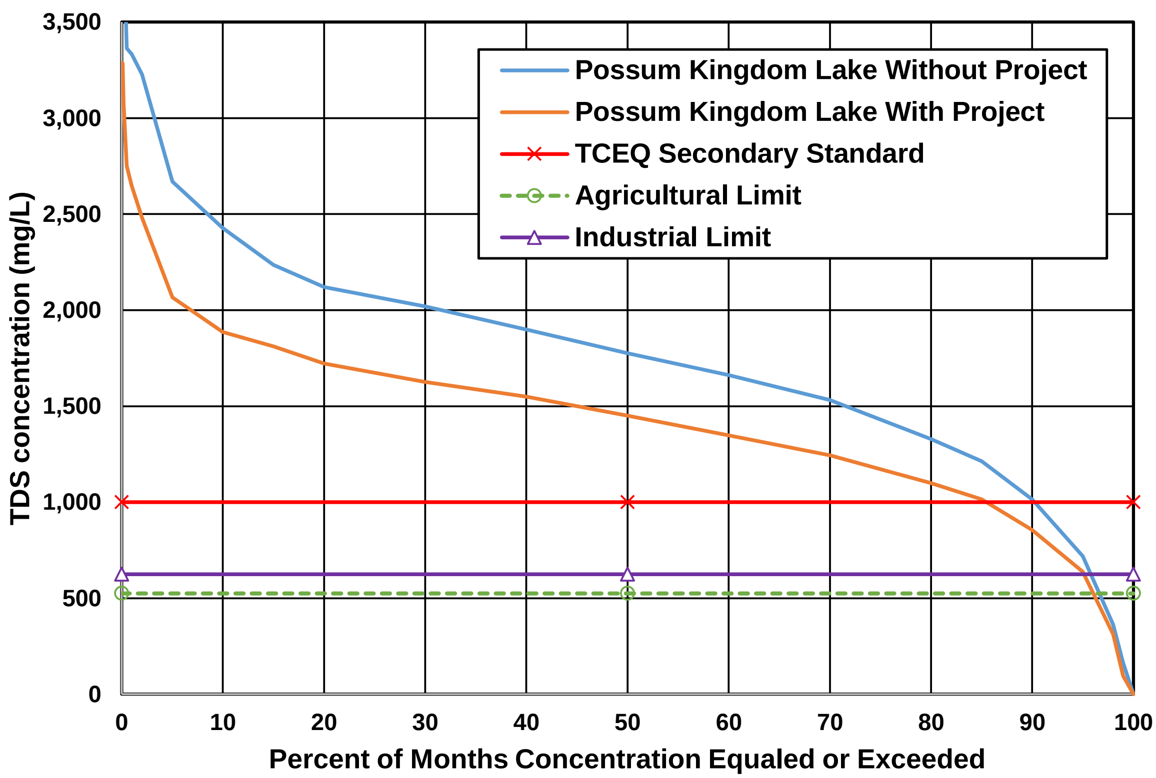

Figure 11-13. Model-Predicted TDS Concentration-Duration Curve at Lake Granbury

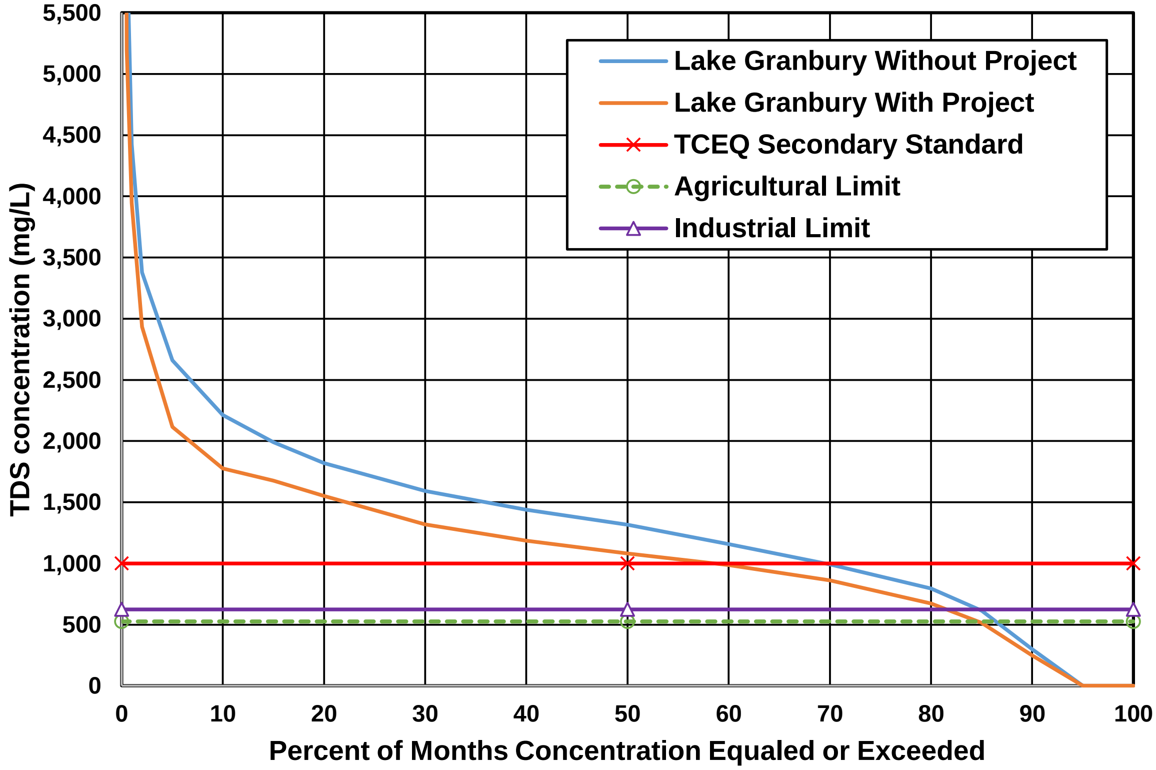

Figure 11-14. Model-Predicted TDS Concentration-Duration Curve at Lake Whitney

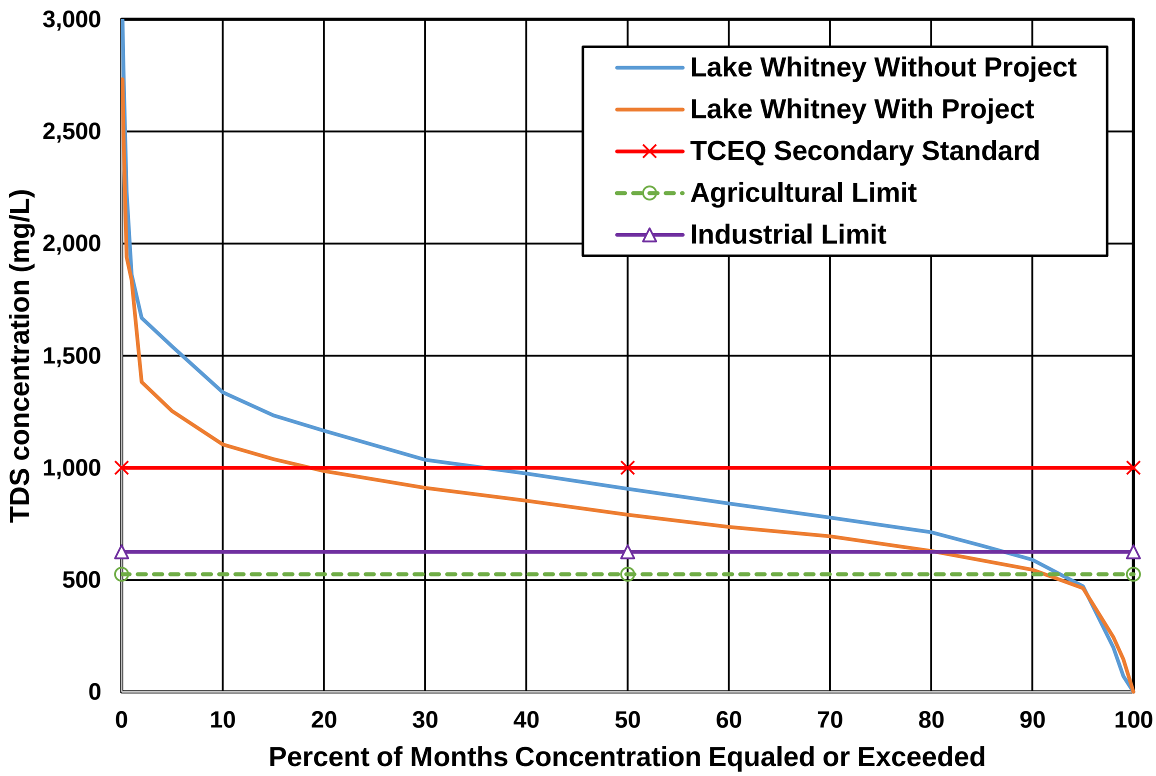

Figure 11-15. Model-Predicted TDS Concentration-Duration Curve at Lake Bryan

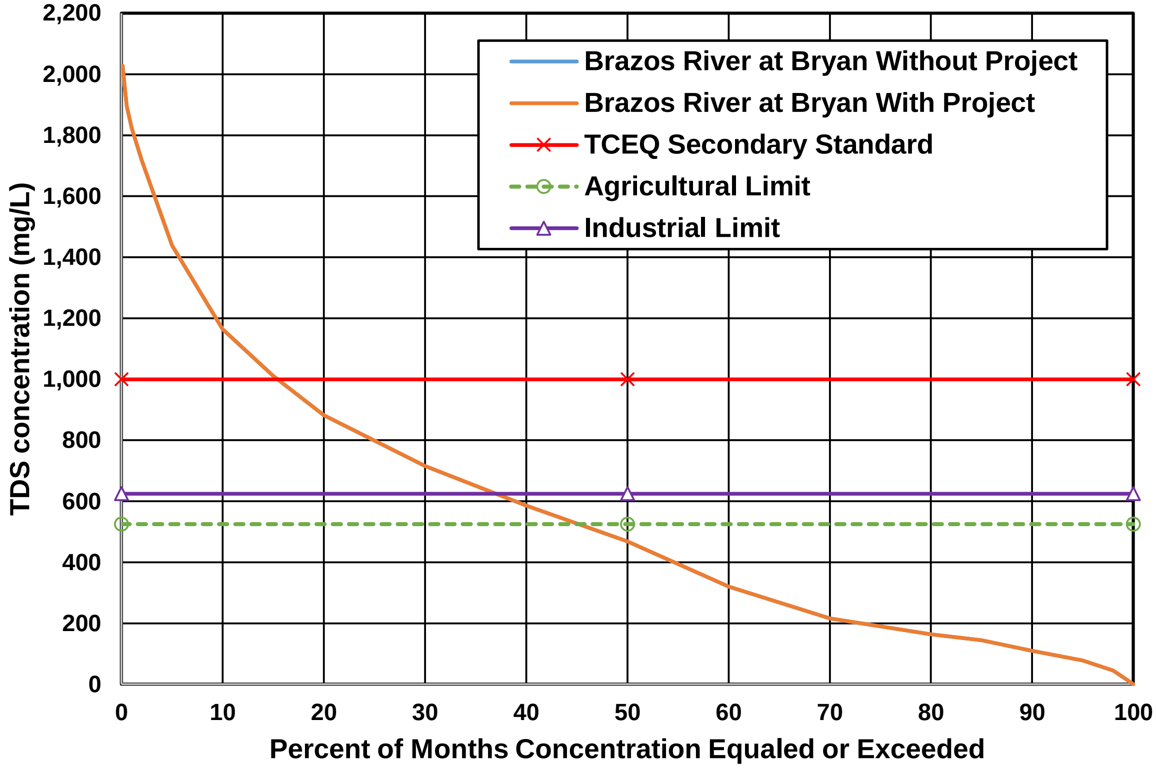

Figure 11-16. Model-Predicted TDS Concentration-Duration Curve at Richmond

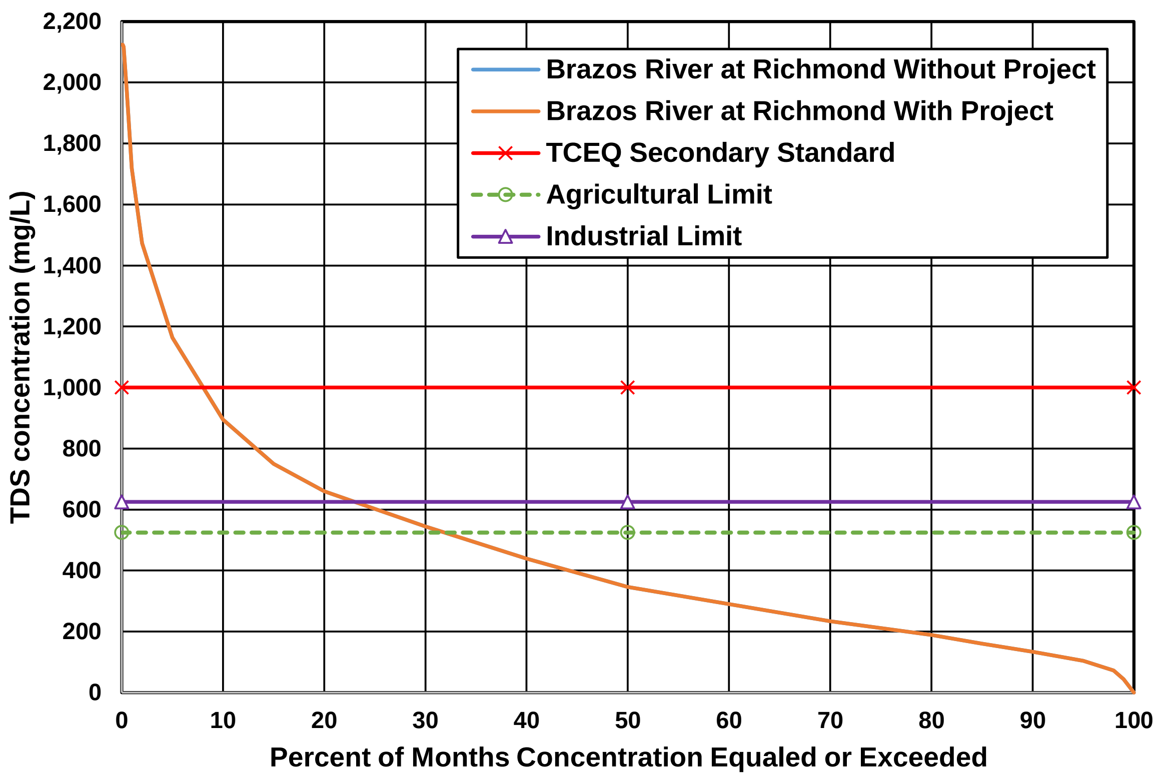

Table 11-12. Model-Predicted Exceedance Frequencies for Applicable Water Quality Limits Without and With Project

Application	TDS Concen-tration Limit (mg/L)	Percentage of Months in Which TDS Concentration Limit was Equaled or Exceeded					
		Seymour	Possum Kingdom Lake	Lake Granbury	Lake Whitney	Bryan	Richmond
Without Project							
TCEQ Secondary Standard	1,000	97.6	90.5	69.9	36.2	15.6	7.0
Agricultural	525	98.1	97.2	86.7	93.1	45.4	31.3
Industrial	625	97.9	96.5	84.6	87.2	37.1	21.6
With Project							
TCEQ Secondary Standard	1,000	96.4	86.2	58.4	18.5	15.6	7.0
Agricultural	525	97.7	96.6	84.9	91.8	45.4	31.3
Industrial	625	97.6	95.2	81.5	80.8	37.1	21.6
Difference (Without Project – With Project)							
TCEQ Secondary Standard	1.2	4.3	11.5	17.7	0	0	1.2
Agricultural	0.4	0.6	1.8	1.3	0	0	0.4
Industrial	0.3	1.3	3.1	6.4	0	0	0.3

The TDS concentration frequency results for the without project scenario can be compared to the concentration frequency curves developed by Wurbs et. al.[24] from the stream gage data. Differences between these two frequency datasets result from both the modeling methodology and the difference between the water use and reservoir storage scenario in the 2070 Brazos G WAM, and conditions that actually existed during the 1964 through 1986 data collection period. The 1964 through 1986 dataset shows that the TCEQ standard was equaled or exceeded 99.7%, 93.6%, 40.0%, and 0% of the time at Seymour, below Possum Kingdom Lake, below Lake Whitney, and at Richmond respectively. In the

[24] Wurbs, R.A., A.S. Karama, I. Saleh, and C.K. Ganze, “Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin,” Texas Water Resources Institute, 1993.

model results, the TCEQ standard is exceeded 97.6%, 90.5%, 36.2% and 7.0% of the time at comparable locations. Although the exceedence frequencies for the observed and modeled datasets are different (as would be expected), the relative similarities in the frequencies provide some confidence that the model produces reasonable results.

Integration with Other Water Management Strategies

This strategy is recommended for the Brazos River Authority as part of their main stem system. The implementation of this strategy would benefit the BRA and its main stem customers the most by reducing the salt concentration in the Brazos River and the BRA main stem supply reservoirs.

11.4 Environmental Issues

The proposed project area is located in the upper Brazos River Basin east of the Llano Estacado Region within portions of Kent, King, and Stonewall counties in north-central Texas. The primary environmental issues related to the development of the salt control water management option are the construction of ten brine recovery wells, a brine conveyance pipeline, the BUMC, and three water supply pipelines.

11.4.1 Environmental Setting

The study area is located in the Southwestern Tablelands Ecological Region as designated by the Texas Parks and Wildlife Department (TPWD).[25] This region is characterized by canyons, mesas, badlands, and dissected river breaks. Little cropland occurs within this area, with much of the region consisting of sub-humid grassland and semiarid rangeland. Vegetation within this area is characterized by grama-buffalograss with some mesquite-buffalograss in the southeast portion of the Region, juniper-scrub oak-midgrass savannah on escarpment bluffs, and midgrass prairie with low oak brush along portions of some rivers. This region is bordered on the south by the Edwards Plateau Ecological Region, on the west by the High Plains Ecological Region, and on the east by the Central Great Plains Ecological Region.

The study area is located in the Rolling Plains Vegetational area.[26] This area is characterized gently rolling hills with rangelands that are dissected by streams and rivers which flow from west to east. Vegetation within this area is characterized by mixed and short grass prairies, shinnery oak grasslands, and mesquite savannah grasslands. Within this area redberry juniper, mesquite, and Eastern red cedar are considered aggressive invasive species.

The original prairie vegetation found within the Rolling Plains Vegetational Area included medium-tall grassland with a sparse shrub cover. The dominant vegetation within this area is native grasses including little bluestem (*Schizachyrium scoparium* var. *frequens*), blue grama (*Bouteloua gracilis*), sideoats grama (*Bouteloua curtipendula*), Indiangrass (*Sorghastrum nutans*), and sand bluestem (*Andropogon gerardii* var. *paucipilus*), and

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[25] Texas Parks and Wildlife Department, 2005.

[26] Gould, F.W., G.O. Hoffman, and C.A. Rechenthin, "Vegetational areas of Texas," TX Agri. Ext. Serv. L-492.

various forbes. Within areas of sandier soils with broad rolling relief you will find shin oak (*Quercus sinuata* var. *breviloba*) grasslands, with additional groups of various oaks occurring in the mixed grass prairie. In areas containing clay and clay loam soils the predominant vegetation is the mesquite savannah grasslands. These usually occur on flat to gently rolling lands and are characterized by an open canopy of larger mesquite trees, a midstory composed of shrubs such as lotebush (*Zizyphus obtusifolia*), succulents including prickly pears (*Opuntia* spp.) and ephedra, and an understory of grasses and forbs. Bottomland areas found along larger streams contain American elm (*Ulmus Americana*), button willow (*Cephalanthus occidentalis*), pecan (*Carya illinoensis*) and cottonwood (*Populus* spp.). Historically these natural communities were maintained by a combination of severe weather events, drought and fire. Invasion of the rangeland areas in this region by annual and perennial forbs, legumes, and woody species has been facilitated by historic livestock grazing practices and a lack of naturally occurring fire in the area. The limestone ridges and steep terrains of this area produce a greater diversity of woody plants and wildlife habitat than would normally be expected within this area.

The natural region of the proposed project area, as described by TPWD in the Vegetation Types of Texas, indicates that along the proposed brine pipeline route vegetation is generally characterized as mesquite-lotebush shrub and mesquite-lotebush brush.[27] Pockets of Havard shin oak-mesquite brush are also found within the area. The majority of the treated water pipeline would be through areas of crops, with smaller areas of mesquite-lotebush shrub and brush and Havard shin oak-mesquite brush. The majority of land found near the project area is currently used as rangeland with limited areas of dryland and irrigated crops and pastures. Land use is expected to remain primarily rural in the future. Because of the heavy salt contamination found in the area of the proposed brine wells, this portion of the project has no current landuse application.

Faunal species found within the project area include those suited to a semi-arid environment. Riparian zones along the Brazos River, and streams and their tributaries contain important wildlife habitat for the region and support populations of white-tailed deer (*Odocoileus virginianus*) and Rio Grande turkeys (*Meleagris gallopavo intermedia*). Bobwhites (*Colinus virginianus*), scaled quail (*Callipepla squamata*), mourning dove (*Zenaida macroura*), and a variety of song birds, small mammals, waterfowl, shorebirds, reptiles, and amphibians are found in this region. Mammals which occur principally in the plains area of Texas include the Texas kangaroo rat (*Dipodomys elator*), Texas mouse (*Peromyscus attwateri*), prairie vole (*Microtus ochrogaster*), plains pocket mouse (*Perognatus flavescents*), thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*), and three species of pocket gopher (*Geomys* sp.). Larger mammals include the coyote (*Canis latrans*), ringtail (*Bassariscus astusus*), ocelot (*Felis pardalis*), and collared peccary (*Tayassu tajacu*). Bison (*Bos bison*), and black-footed ferrets (*Mustela nigripes*) are historically associated with this area.

11.4.2 Threatened & Endangered Species

The Endangered Species Act of 1973 (et seq.) is designed to protect plant and animal resources from the adverse effects of development. To comply with this act, federal

[27] Texas Parks and Wildlife Department, "The Vegetation Types of Texas," Austin, Texas, 1984.

agencies are required to assess the proposed project area to determine if any threatened or endangered species or critical habitats for these species are present.

The Texas Parks and Wildlife Department (TPWD) maintains a list of Rare, Threatened, and Endangered Species of Texas by County. This list includes the federal and state listing status and a habitat description for each species which may be a resident or migrant through the county. TPWD regularly updates the listing status, range data, and habitat descriptions on their published county lists, based on the most recently available data. The current list of rare, threatened and endangered species for Dickens, Kent, King and Stonewall counties can be found at https://tpwd.texas.gov/gis/rtest/.

One listed species, the Whooping Crane, is considered endangered by both the FWS and TPWD. Portions of North Texas including the Panhandle lie within the migratory corridor the whooping cranes follow in route to and from their nesting grounds in Wood Buffalo National Park in northwestern Canada. This species is known to stop during migration at locations in Oklahoma, Kansas, and Nebraska. There have been only a few scattered confirmed ground sightings of whooping cranes within Texas with the exception of their salt marsh wintering grounds along the Texas Coastal Bend. Although these birds might occur as possible vagrants during migration periods, the likelihood of incidence within the project area is remote.

The Piping Plover and Red Knot are both state and federally-listed threatened species. The Piping Plover is a medium-distance migrant, with breeding populations along the Atlantic Coast, Great Lakes region, and central U.S. Populations who breed inland from the Atlantic coast migrate to the Gulf of Mexico or Atlantic coast for the winter. This species may be present in the project area during migratory periods. Similarly, the Red Knot is also a migratory species that may be present in the project area on its way to and from wintering grounds along the Gulf Coast.[28]

Historically, the smalleye shiner and the sharpnose shiner, both federally-listed endangered species, were found throughout the Brazos River Watershed and several of its major tributaries. They are considered at this time to be stable in the upper Brazos River Basin, but their number has declined in the middle and lower reaches of the Basin. The most serious issues threatening these species are the effects of impoundments and degradation of water quality. Current information indicates that the shiner population within the Upper Brazos drainage upstream of Possum Kingdom Reservoir is apparently stable, whereas the population within the Lower Brazos River Basins may only exist in remnant areas of suitable habitat or may be completely extirpated.

These two cyprinid species evolved to prosper in the saline and turbid conditions naturally occurring in the Brazos River Basin. The salinity control project proposed for the Upper Brazos River would convert the natural saline waters to a more favorable quality for human consumption and would modify the waters' chemical characteristics thought to be conducive to preferred shiner habitat.

After a review of the habitat requirements for each listed species, it is expected that this project will not adversely affect any federally listed threatened or endangered species, its

[28] The Cornell Lab, 2019. All About Birds. Accessed online https://www.allaboutbirds.org/news/#/_ga=2.255157576.1366775756.1574099801-1022759099.1553272842 November 18, 2019.

habitat, or designated habitat, nor would it adversely affect any state endangered species, except for possible impacts to aquatic species for which a higher salinity environment is favorable, i.e. the smalleye and sharpnose shiners, and potentially the state-threatened red river pupfish and the club shiner[29]. Although suitable habitat for several state threatened species, including the Palo Duro mouse, Texas kangaroo rat, and Texas horned lizard may exist within the project area, no impact to these species is anticipated due to the small area utilized by the wells, and the abundance of similar habit near the project area. The presence or absence of potential habitat does not confirm the presence or absence of a listed species. No species-specific surveys were conducted in the project area for this report.

11.4.3 Solar Salt Production Facility Impacts

Solar salt production would utilize the brine removed from the existing brine aquifer in Stonewall and Kent Counties. Shallow wells located along the Dove, Short Croton, and Salt Creeks would pump the brine along a 55-mile pipeline to a proposed solar salt facility located in Kent County approximately 16 miles southwest of Jayton and 29 miles north of Snyder. There the brine would be processed by solar evaporation in a series of ponds to a final crystalline salt product which would then be marketed. Modern solar salt plants can produce a pure salt product that is more than 99.7% NaCl (dry basis). Solar salt sales in the United States have increased by 50% over the last twenty years to include 5.9 million tons in 2004.[30] Factors influencing the suitability of the area for this type of production include land cost, soil type, rainfall amounts, wind velocity and direction, susceptibility to flooding, possible endangered species habitat, availability of workers, and ease of transportation of products.

11.4.4 Possible Pipeline Impacts

A number of streams in the Upper Brazos River Basin would be crossed by the proposed pipeline corridor. The brine transport system would involve the construction of a 55-mile-long pipeline which would extend through portions of Kent, Stonewall and King Counties.

The brine pipeline would begin at the Salt Creek Brine Recovery Well Field and follow Ranch Road (RR) 1081 south for approximately 6 miles, it would then turn east along U.S. Highway (US) 380 for approximately 7 additional miles and intersect with a connection to the salt facility. The pipeline would then continue east for approximately 5 additional miles along US 380, turn north along State Highway (SH) 208 for 7 miles, and then travel east paralleling RR 2320 and Farm to Market (FM) 1228 for 11 additional miles. A small portion of Kent County Roads (CR) 165 and 161 are then followed before the pipeline turns in a northwesterly direction along SH 70 for about 5 miles, terminating at the Short Croton Salt Flat Brine Recovery Well Field. From the intersection of SH 70 and CR 160 the pipeline travels northwest along CR 160, CR 350 and unnamed roadways for approximately 14 miles terminating at the Dove Creek Salt Flat/ Panther Canyon Area Brine Recovery Well Field in Stonewall County.

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[29] Texas Parks and Wildlife Department, letter commenting on the Initially Prepared 2021 Brazos G Regional Water Plan, August 25, 2020 (see Chapter 10).

[30] Salt Institute. Solar Salt Production. 2004

In general, the brine pipeline would traverse flat to gently rolling terrain and occasional surface areas designated as 100-year floodplains. Wetlands located within the pipeline right-of-way could potentially be affected by this project, and floodplains could possibly suffer a temporary change in drainage patterns. Potential wetland impacts are expected to primarily include pipeline stream and river crossings, which can be minimized by right-of-way selection and appropriate construction methods, including erosion controls and revegetation procedures. This pipeline could potentially traverse approximately eighteen stream crossings, a number of which are unnamed tributaries. Major water bodies crossed by this pipeline could include Salt Creek, T-O Creek, Duck Creek, Little Duck Creek, Croton Creek, and the Salt Fork Brazos River. Impacts to wetlands from construction possibly include destruction or alteration of vegetation/habitat along the right-of-way (ROW) and within the well field areas. Compensation for net losses of wetlands would be required where impacts are unavoidable.

There are no state or national parks, forest, wildlife refuges, natural areas, wild or scenic rivers, or other similar preserves within the proposed project area. Habitat studies and surveys for protected species and cultural resources may need to be conducted at the proposed well sites, pump locations, the desalination facility, and along all pipeline or railroad spur routes.

A review of the Texas Historical Commission Texas Historic Sites Atlas database indicated that there are no National Register Properties within the project area, however two historical markers and the Clairemont Cemetery are listed within one mile of the proposed brine pipeline. These sites should be easily avoided by adjustment of the pipeline location if necessary.

11.5 Engineering and Costing

Table 11-13 summarizes the estimated costs for the salinity control system. The majority of project costs, including operation and maintenance costs, engineering costs, land acquisition costs, and some capital costs were provided by the SFWQ Corporation’s consultants, while other costs were estimated for preparation of the regional water plan using the unified cost model (UCM). Costs calculated through the UCM are the brine transmission pump station and storage tank; treated water transmission pipelines, pump stations, and storage tanks; debt service; and interest during construction. Treated water transmission pipeline costs are based on mileage provided by the SFWQ Corporation. A two-year construction period was assumed for computing interest during construction.

The operation and maintenance costs in Table 11-13 are offset by salt revenue. The SFWQ Corporation’s consultants have prepared a pro forma analysis indicating that revenue from salt sales would cover well field, pipeline, and BUMC operation and maintenance costs. It is anticipated that once the project was constructed, a salt company would operate and maintain the facilities and generate sufficient revenue such that operation and maintenance costs to the public would be zero. The SFWQ Corporation’s consultants have also assumed that right of way costs for the brine transmission pipeline would be negligible; the pipeline would run within existing county road right of ways and the counties are participants in the project.

Overall, the estimated combined capital cost for the brine collection and transmission system and the BUMC is $57,606,000. The estimated combined total project cost for the brine collection and transmission system and the BUMC is $106,537,000, and the estimated combined annual cost is $6,194,000 – offset by salt revenue and water sales. Estimated total capital costs for the treated water delivery systems range from $1,021,000 for Jayton to $6,789,000 for White River Municipal Water District, and total annual costs range from $542,000 to $1,128,000. Note that this project is not currently recommended in the 2021 Region O Plan, but is identified as an "other" potential source of supply that can be made available to Region O.

11.6 Impacts Comparison of Desalination Costs With and Without Salinity Control Project

This section reviews the effectiveness of the salinity control project in reducing desalination costs in the Brazos River Basin. The cost of municipal desalination treatment with and without the salinity control project is compared to the cost of implementing the project.

Although the TCEQ TDS secondary standard is 1,000 mg/L, the costs presented herein assume that the desalination is implemented to reduce TDS concentrations to 500 mg/L. Actual acceptable TDS limits for water supply systems are case specific. Systems that have not historically been exposed to TDS concentrations as high as 1,000 mg/L may be subject to corrosion issues with introduction of such high TDS concentrations. The 500 mg/L treatment level was assumed as a limit that would generally be acceptable for new supplies.

Concentration-duration curves for TDS based on WRAP-SALT modeling with the 2070 Brazos G WAM are presented in Figure 11-11 through Figure 11-16 and summarized in Table 11-11. The table and figures compare TDS concentrations of regulated outflows from the Seymour, Bryan, and Richmond model control points and reservoir storage TDS concentrations at Possum Kingdom Lake, Lake Granbury, and Lake Whitney with and without the salinity control project. TDS is an indicator of the levels of chlorides and dozens of other dissolved ions that would be removed by the salinity control project and desalination treatment. The with-project concentration-duration curves are representative of a point in the future when the benefits of the project are fully realized and residual salt has been washed from the upland stream beds and from downstream lakes.

The estimated costs of desalination treatment at Seymour, Possum Kingdom Lake, Lake Granbury, Lake Whitney, Bryan, and Richmond with and without implementing the salinity control project are included in Table 11-14 through Table 11-19. The desalination cost estimates are based upon producing 10 MGD of treated water and the 90th percentile (10% equaled or exceeded) and 50th percentile (median) TDS concentrations at each location as shown by the concentration-duration curves. Varying TDS concentrations impact both the plant capital and the operating and maintenance costs. Water treatment plant capital costs are based on the 90th percentile TDS concentrations while concentrate disposal costs are based on the 50th percentile TDS concentrations. Surface water must undergo conventional treatment prior to desalination. For the purpose of comparing treatment costs for various TDS concentrations, values shown are for the desalination component only. Costs common to conventional water treatment plants are omitted. Omitted costs include intakes, pump stations, conventional pretreatment, clearwell storage, and others.

Table 11-13. Cost Estimate Summary for the Salinity Control Project

Item	Brine Utilization and Management System	White River Municipal Water District	Jayton	Aspermont
Brine Transmission Pipeline (12 in dia., 17 miles)	$14,467,000	-	-	-
Brine Transmission Pump Station(s) & Storage Tank(s)	$1,874,000	-	-	-
Treated Water Transmission Pipeline	-	$5,836,000	$579,000	$4,057,000
Treated Water Transmission Pump Station(s) & Storage Tank(s)	-	$953,000	$442,000	$1,384,000
Well Fields (Wells, Pumps, and Piping)	$839,000	-	-	-
Storage Tanks (Other Than at Booster Pump Stations)	$600,000	-	-	-
Two Water Treatment Plants (1 MGD and 1 MGD)	$34,326,000	-	-	-
Integration, Relocations, & Other	$5,500,000	-	-	-
TOTAL COST OF FACILITIES	**$57,606,000**	**$6,789,000**	**$1,021,000**	**$5,441,000**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$36,216,000	$2,084,000	$328,000	$1,702,000
Environmental & Archaeology Studies and Mitigation	$1,619,000	$150,000	$600,000	$625,000
Land Acquisition and Surveying (80 acres)	$5,541,000	-	$55,000	$55,000
Interest During Construction (3% for 2 years with a 0.5% ROI)	$5,555,000	$497,000	$111,000	$431,000
TOTAL COST OF PROJECT	**$106,537,000**	**$9,520,000**	**$2,115,000**	**$8,254,000**
Debt Service (3.5 percent, 20 years)	$7,496,000	$670,000	$149,000	$581,000
Operation & Maintenance	$7,826,000	$82,000	$17,000	$75,000
Purchase of Water (949 acft/yr @ 1,189.36 $/acft)	($1,128,000)	$214,000	$140,000	$296,000
Salt Revenue	($8,000,000)	-	-	-
TOTAL ANNUAL COST	**$6,194,000**	**$966,000**	**$306,000**	**$952,000**
Available Project Yield (acft/yr)	949	180	118	249
Annual Cost of Water ($ per acft), based on PF=1	$6,527	$5,367	$2,593	$3,823
Annual Cost of Water ($ per 1,000 gallons), based on PF=1	$20.03	$16.47	$7.96	$11.73

The project will benefit water quality but will also have an impact on the available supply to entities required to desalinate water from the main stem of the Brazos River. Influent TDS levels affect the water recovery rates at desalination water treatment plants, expressed as a percentage of influent recovered for use. Therefore, decreasing TDS in the Brazos River reduces the volume of water required for desalination and increases the overall supply by improving desalination recovery rates.

Based on the cost estimates shown in Table 11-14 through Table 11-19, the largest estimated desalination treatment unit costs savings resulting from the project would occur at Seymour. The estimated total annual cost of desalination treatment at Seymour without the salinity control project is $13,314,000, or $1,189 per acft on a unit cost basis. With the salinity control project, the estimated annual cost of desalination at Seymour is $11,497,000, or $1,026 per acft on a unit cost basis. The estimated desalination treatment savings at Seymour as a result of implementing the salinity control project on a unit cost basis is $162 per acft. At Possum Kingdom Reservoir, Lake Granbury, and Lake Whitney, the estimated desalination treatment savings as a result of implementing the salinity control project on a unit cost basis is $65, $77, and $87 per acft, respectively. With the reduction in the number of well fields from the 2016 Plan, benefits from the salinity control project are no longer realized downstream of the Lakes at Bryan and Richmond.

The cost of desalination treatment for current municipal contracts and water rights in the Brazos River can be compared to the salinity control project cost in order to determine the cost effectiveness of implementing the project. Table 11-20 includes the Brazos River Authority contract amounts and TCEQ Water Rights for municipal use between Seymour and the Gulf of Mexico as listed in the Brazos G WAM input data file. The contracts and rights total to 505,988 acft per year. Table 11-20 also includes the unit cost of desalination treatment with and without the project and the increase in municipal supply due to project. The total annual cost to desalinate water contracted or permitted for municipal use without the project is estimated to be $236,262,000. With the project, the total annual cost of desalination treatment is estimated to be $231,674,000. Therefore, implementation of the project results in reduced annual desalination costs of $4,588,000. Total annual cost exceeds downstream desalination cost savings by $1,606,000.

Table 11-14. Cost Estimate Summary for Desalination at Seymour with and without Implementation of Salinity Control Project

Item	*No Salinity Control*	*With Salinity Control*	*Cost Difference*
90th Percentile TDS	11,259	7,701	
50th Percentile TDS	6,044	4,134	
% of Water Desalinated	100%	94%	
CAPITAL COST			
RO Desalination Plant (10 MGD)[1]	$35,773,000	$32,746,000	$3,027,000
Concentrate Disposal	$13,077,000	$9,691,000	$3,386,000
TOTAL COST OF FACILITIES	**$48,850,000**	**$42,437,000**	**$6,413,000**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$17,098,000	$14,853,000	$2,245,000
Interest During Construction (4% for 1 years with a 1% ROI)	$1,814,000	$1,576,000	$238,000
TOTAL COST OF PROJECT	**$67,762,000**	**$58,866,000**	**$8,896,000**
ANNUAL COST			
Debt Service (5.5 percent, 20 years)	$4,768,000	$4,142,000	$626,000
Operation and Maintenance			
Desalination Water Treatment Plant	$7,998,000	$6,894,000	$1,104,000
Concentrate Disposal	$548,000	$461,000	$87,000
TOTAL ANNUAL COST	**$13,314,000**	**$11,497,000**	**$1,817,000**
Water Treated Annually (acft/yr)	**11,202**	**11,202**	
Annual Cost of Water ($ per acft)	**$1,189**	**$1,026**	**$162**
Annual Cost of Water ($ per 1,000 gallons)	**$3.65**	**$3.15**	**$0.50**

[1] For comparison purposes of treatment costs for various TDS concentrations, costs shown are for desalination component only. Costs common to conventional water treatment plants are omitted. Omitted costs include intake, pump stations conventional pretreatment, clearwell storage, and others.

Table 11-15. Cost Estimate Summary for Desalination at Possum Kingdom Lake with and without Implementation of Salinity Control Project

Item	No Salinity Control	With Salinity Control	Cost Difference
90th Percentile TDS	2,427	1,886	
50th Percentile TDS	1,776	1,450	
% of Water Desalinated	81%	76%	
CAPITAL COST			
RO Desalination Plant[1]	$26,908,000	$25,194,000	$1,714,000
Concentrate Disposal	$7,510,000	$6,238,000	$1,272,000
TOTAL COST OF FACILITIES	**$34,418,000**	**$31,432,000**	**$2,986,000**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$12,047,000	$11,001,000	$1,046,000
Interest During Construction (4% for 1 years with a 1% ROI)	$1,278,000	$1,167,000	$111,000
TOTAL COST OF PROJECT	**$47,743,000**	**$43,600,000**	**$4,143,000**
ANNUAL COST			
Debt Service (5.5 percent, 20 years)	$3,359,000	$3,068,000	$291,000
Operation and Maintenance			
Desalination Water Treatment Plant	$5,137,000	$4,760,000	$377,000
Concentrate Disposal	$358,000	$297,000	$61,000
TOTAL ANNUAL COST	**$8,854,000**	**$8,125,000**	**$729,000**
Water Treated Annually (acft/yr)	**11,202**	**11,202**	
Annual Cost of Water ($ per acft)	**$790**	**$725**	**$65**
Annual Cost of Water ($ per 1,000 gallons)	**$2.43**	**$2.23**	**$0.20**

[1] For comparison purposes of treatment costs for various TDS concentrations, costs shown are for desalination component only. Costs common to conventional water treatment plants are omitted. Omitted costs include intake, pump stations conventional pretreatment, clearwell storage, and others.

Table 11-16. Cost Estimate Summary for Desalination at Lake Granbury with and without Implementation of Salinity Control Project

Item	*No Salinity Control*	*With Salinity Control*	*Cost Difference*
90th Percentile TDS	2,213	1,777	
50th Percentile TDS	1,316	1,081	
% of Water Desalinated	79%	74%	
CAPITAL COST			
RO Desalination Plant[1]	$26,221,000	$24,342,000	$1,879,000
Concentrate Disposal	$6,436,000	$4,951,000	$1,485,000
TOTAL COST OF FACILITIES	**$32,657,000**	**$29,293,000**	**$3,364,000**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$11,430,000	$10,252,000	$1,178,000
Interest During Construction (4% for 1 years with a 1% ROI)	$1,213,000	$1,088,000	$125,000
TOTAL COST OF PROJECT	**$45,300,000**	**$40,633,000**	**$4,667,000**
ANNUAL COST			
Debt Service (5.5 percent, 20 years)	$3,187,000	$2,859,000	$328,000
Operation and Maintenance			
Desalination Water Treatment Plant	$4,985,000	$4,526,000	$459,000
Concentrate Disposal	$306,000	$236,000	$70,000
TOTAL ANNUAL COST	**$8,478,000**	**$7,621,000**	**$857,000**
Water Treated Annually (acft/yr)	**11,202**	**11,202**	
Annual Cost of Water ($ per acft)	**$757**	**$680**	**$77**
Annual Cost of Water ($ per 1,000 gallons)	**$2.32**	**$2.09**	**$0.23**

[1] For comparison purposes of treatment costs for various TDS concentrations, costs shown are for desalination component only. Costs common to conventional water treatment plants are omitted. Omitted costs include intake, pump stations conventional pretreatment, clearwell storage, and others.

Table 11-17. Cost Estimate Summary for Desalination at Lake Whitney with and without Implementation of Salinity Control Project

Item	No Salinity Control	With Salinity Control	Cost Difference
90th Percentile TDS	1,337	1,105	
50th Percentile TDS	906	790	
% of Water Desalinated	65%	57%	
CAPITAL COST			
RO Desalination Plant[1]	$21,568,000	$19,072,000	$2,496,000
Concentrate Disposal	$4,654,000	$2,971,000	$1,683,000
TOTAL COST OF FACILITIES	**$26,222,000**	**$22,043,000**	**$4,179,000**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$9,178,000	$7,715,000	$1,463,000
Interest During Construction (4% for 1 years with a 1% ROI)	$974,000	$819,000	$155,000
TOTAL COST OF PROJECT	**$36,374,000**	**$30,577,000**	**$5,797,000**
ANNUAL COST			
Debt Service (5.5 percent, 20 years)	$2,559,000	$2,151,000	$408,000
Operation and Maintenance			
Desalination Water Treatment Plant	$4,031,000	$3,548,000	$483,000
Concentrate Disposal	$222,000	$141,000	$81,000
TOTAL ANNUAL COST	**$6,812,000**	**$5,840,000**	**$972,000**
Water Treated Annually (acft/yr)	**11,202**	**11,202**	
Annual Cost of Water ($ per acft)	**$608**	**$521**	**$87**
Annual Cost of Water ($ per 1,000 gallons)	**$1.87**	**$1.60**	**$0.27**

[1] For comparison purposes of treatment costs for various TDS concentrations, costs shown are for desalination component only. Costs common to conventional water treatment plants are omitted. Omitted costs include intake, pump stations conventional pretreatment, clearwell storage, and others.

Table 11-18. Cost Estimate Summary for Desalination at Bryan with and without Implementation of Salinity Control Project

Item	No Salinity Control	With Salinity Control	Cost Difference
90th Percentile TDS	1,164	1,164	
50th Percentile TDS	468	468	
% of Water Desalinated	60%	60%	
CAPITAL COST			
RO Desalination Plant[1]	$20,082,000	$20,082,000	$0
Concentrate Disposal	$1,980,000	$1,980,000	$0
TOTAL COST OF FACILITIES	**$22,062,000**	**$22,062,000**	**$0**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$7,722,000	$7,722,000	$0
Interest During Construction (4% for 1 years with a 1% ROI)	$820,000	$820,000	$0
TOTAL COST OF PROJECT	**$30,604,000**	**$30,604,000**	**$0**
ANNUAL COST			
Debt Service (5.5 percent, 20 years)	$2,153,000	$2,153,000	$0
Operation and Maintenance			
Desalination Water Treatment Plant	$3,740,000	$3,740,000	$0
Concentrate Disposal	$94,000	$94,000	$0
TOTAL ANNUAL COST	**$5,987,000**	**$5,987,000**	**$0**
Water Treated Annually (acft/yr)	**11,202**	**11,202**	
Annual Cost of Water ($ per acft)	**$534**	**$534**	**$0**
Annual Cost of Water ($ per 1,000 gallons)	**$1.64**	**$1.64**	**$0.00**

[1] For comparison purposes of treatment costs for various TDS concentrations, costs shown are for desalination component only. Costs common to conventional water treatment plants are omitted. Omitted costs include intake, pump stations conventional pretreatment, clearwell storage, and others.

Table 11-19. Cost Estimate Summary for Desalination at Richmond with and without Implementation of Salinity Control Project

Item	*No Salinity Control*	*With Salinity Control*	*Cost Difference*
90th Percentile TDS	895	895	
50th Percentile TDS	346	346	
% of Water Desalinated	47%	47%	
CAPITAL COST			
RO Desalination Plant[1]	$16,052,000	$16,052,000	$0
Concentrate Disposal	$1,980,000	$1,980,000	$0
TOTAL COST OF FACILITIES	**$18,032,000**	**$18,032,000**	**$0**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$6,311,000	$6,311,000	$0
Interest During Construction (4% for 1 years with a 1% ROI)	$670,000	$670,000	$0
TOTAL COST OF PROJECT	**$25,013,000**	**$25,013,000**	**$0**
ANNUAL COST			
Debt Service (5.5 percent, 20 years)	$1,760,000	$1,760,000	$0
Operation and Maintenance			
Desalination Water Treatment Plant	$2,973,000	$2,973,000	$0
Concentrate Disposal	$94,000	$94,000	$0
TOTAL ANNUAL COST	**$4,827,000**	**$4,827,000**	**$0**
Water Treated Annually (acft/yr)	**11,202**	**11,202**	
Annual Cost of Water ($ per acft)	**$431**	**$431**	**$0**
Annual Cost of Water ($ per 1,000 gallons)	**$1.32**	**$1.32**	**$0.00**

[1] For comparison purposes of treatment costs for various TDS concentrations, costs shown are for desalination component only. Costs common to conventional water treatment plants are omitted. Omitted costs include intake, pump stations conventional pretreatment, clearwell storage, and others.

Table 11-20. Cost Estimate Summary for the Total Annual Cost of Desalination Treatment within the Brazos River Basin

Strategy	Municipal Use[1] (acft/yr)	Unit Cost of Desalination Treatment ($/acft/yr)		Total Annual Cost of Desalination Treatment ($/yr)		Annual Desalination Cost Savings With Project
		Without Salinity Control Project	With Salinity Control Project	Without Salinity Control Project	With Salinity Control Project	
Seymour to Above Possum Kingdom Lake	0	$1,189	$1,026	$0	$0	$0
Possum Kingdom Lake to Above Lake Granbury	3,298	$790	$725	$2,607,000	$2,392,000	$215,000
Lake Granbury to Above Lake Whitney	35,644	$757	$680	$26,976,000	$24,250,000	$2,726,000
Lake Whitney to Above Bryan	18,975	$608	$521	$11,539,000	$9,892,000	$1,647,000
Bryan to Above Richmond	19,935	$534	$534	$10,654,000	$10,654,000	$0
Richmond to Gulf of Mexico	428,136	$431	$431	$184,486,000	$184,486,000	$0
Total	**505,988**			**$236,262,000**	**$231,674,000**	**$4,588,000**

[1] Includes Brazos River Authority Contract amounts and TCEQ Water Rights for municipal use, as of March 2015.

Comparing the desalination cost savings to the total annual cost of the project, the annual costs of the project exceed the benefits by $1,606,000. However, additional benefits not quantified here would accrue for industrial and irrigation users. Furthermore, as the amount of water contracted or permitted for municipal use increases in the future, the desalination costs savings due to the project as computed in Table 11-20 would increase, while the project cost would not.

The results of the present desalination cost evaluation are subject to the modeling assumptions utilized. In particular, it is important to note that the benefits of reduced desalination treatment costs will only be fully realized at a point in the future when the effects of the salinity control project are fully realized and residual salt has been washed from upland stream beds and from downstream lakes.

11.7 Implementation Issues

This water supply option has been compared to the plan development criteria, as shown in Table 11-21 and the option meets each criterion.

Table 11-21. Evaluation of Salinity Control Project to Enhance Water Supplies

Impact Category	Comment(s)
A. Water Supply	
1. Quantity	1. Increased water recovery rate for desalination
2. Reliability	2. Not a reliable water supply, although does increase reliable usage of existing and future main stem supplies.
3. Cost	3. High for water produced to be sold
B. Environmental factors	
1. Environmental Water Needs	1. Low to moderate impact
2. Habitat	2. Moderate to high impact on some species
3. Cultural Resources	3. Low to moderate impact
4. Bays and Estuaries	4. Negligible impact
5. Threatened and Endangered Species	5. Negligible impact
6. Wetlands	6. Low impact
C. Impact on Other State Water Resources	• Beneficial impact on water quality in much of the Brazos River Basin; no effect on navigation
D. Threats to Agriculture and Natural Resources	• Overall positive impact on agriculture and natural resources
E. Equitable Comparison of Strategies Deemed Feasible	• Generates relatively small fresh water supply. Possible significant benefit on basin water quality.
F. Requirements for Interbasin Transfers	• Not applicable
G. Third Party Social and Economic Impacts from Voluntary Redistribution	• None

The salinity control project will increase the usability of Brazos River water throughout the Brazos G and Region H Areas. Distribution of project costs to beneficiaries will not be straightforward. A summary of the implementation steps for the project is presented below.

Potential Regulatory Requirements:

- Texas Commission on Environmental Quality Water Right and Storage permits;
- U.S. Army Corps of Engineers Permits will be required for discharges of dredge or fill into wetlands and waters of the U.S. for dam construction, and other activities (Section 404 of the Clean Water Act);
- Texas Commission on Environmental Quality administered Texas Pollutant Discharge Elimination System Storm Water Pollution Prevention Plan;
- General Land Office Easement if State-owned land or water is involved; and
- Texas Parks and Wildlife Department Sand, Shell, Gravel and Marl permit if state-owned streambed is involved.

State and Federal Permits may require the following studies and plans:

- Environmental impact or assessment studies;
- Wildlife habitat mitigation plan that may require acquisition and management of additional land;
- Flow releases downstream to maintain aquatic ecosystems;
- Assessment of impacts on Federal- and State-listed endangered and threatened species;
- Aquatic Resource Relocation Plan (ARRP) and a relocation permit may be required from TPWD if a dewatering event is required during construction; and
- Cultural resources studies to determine resources impacts and appropriate mitigation plan that may include cultural resource recovery and cataloging; requires coordination with the Texas Historical Commission.

Other project issues include the following:

- Acquisition of additional land for mitigation;
- Cultural resources mitigation, including possibly extensive data recovery;
- Acquisition of rights-of-way and easements;
- Crossings of roads, railroads, creeks, rivers and other utilities; and
- Possible relocations, including residences and other structures, affected utilities and roads, etc.

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