

5A.8 Control of Naturally Occurring Chlorides

5A.8.1 Description of Option

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. However, as the Brazos River flows to the Gulf, inflows from tributaries decrease the concentration of dissolved minerals and salts, which in turn improves the quality of water.

The primary sources of the natural salt pollution 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 Region (Figure 5A.8-1).

A substantial part 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 pollution producing area is a semi-arid region of salt and gypsum encrusted hills and 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 base. 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 flats. Wherever there is a joint of 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 surrounds the salt flats and streams. The Brazos River receives a tremendous salt load when local rainfall is sufficient to dissolve the deposited salt and washes it out of the salt flats.

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

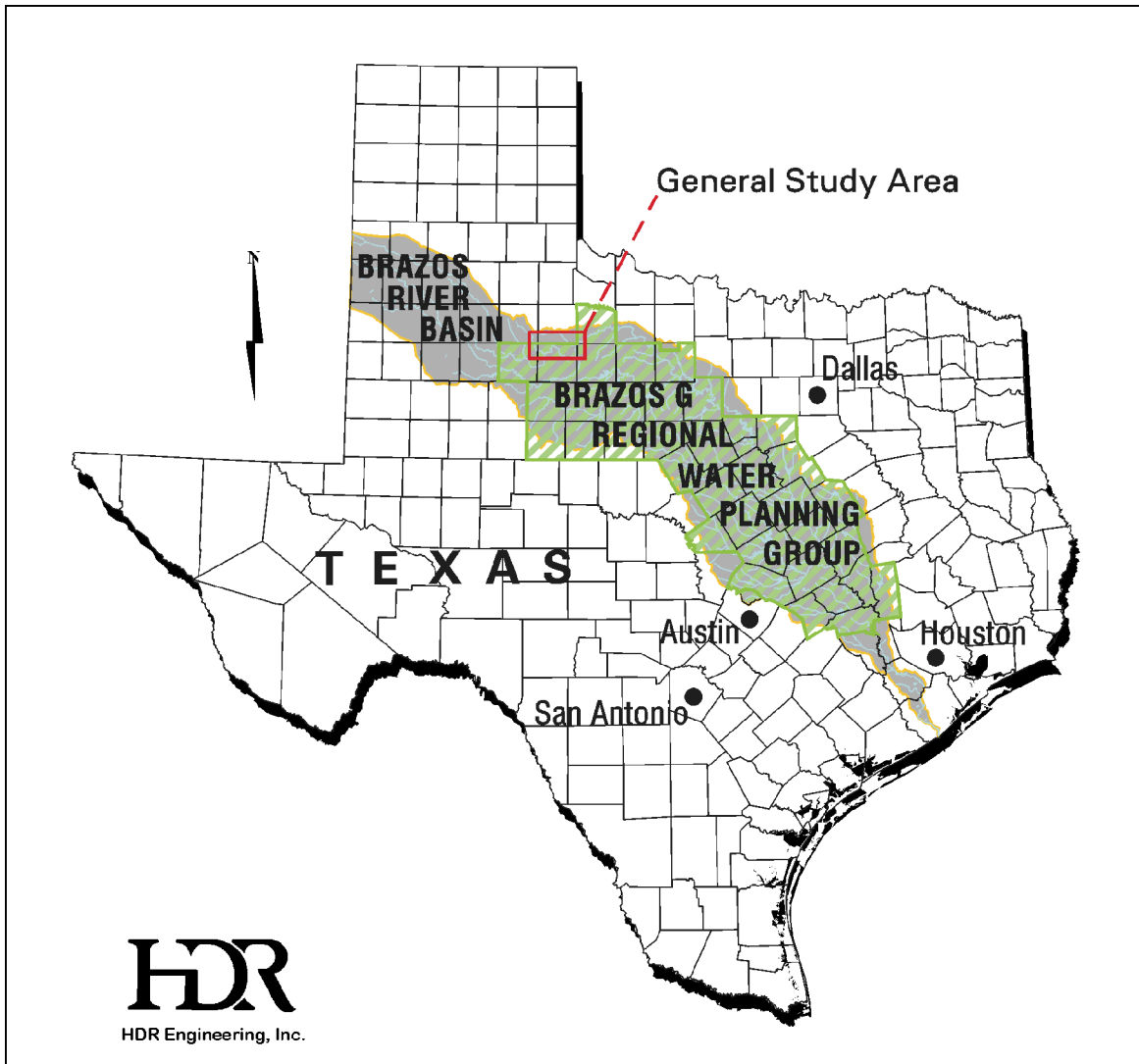


Figure 5A.8-1. Chloride Control Study Area

The watershed above Possum Kingdom reservoir contributes an average of 14 to 18 percent of the Brazos Rivers' flow. This same watershed produces approximately 45 to 55 percent of the total dissolved solids (TDS) and 75 to 85 percent of the chloride and 65 to 75 percent of the sulfate measured in the Brazos River at Richmond, in the lower portion of the basin.

The Chloride Control Projects consist of three options: Figure 5A.8-2 shows the location of Option 1, Figure 5A.8-3 shows the location of Option 2, and Figure 5A.8-4 shows the location

of Option 3. All three options require brine recovery well fields that penetrate the saline aquifer in the area, lowering the piezometric surface of the water table, thereby eliminating brine springs and seeps in the area. Option 1 would dispose of the recovered brine in a deep well injection system. Phase 1 would dispose of brine from the Dove Creek Salt Flats in the deep well injection system. Phase 2 of Option 1 would dispose of additional brine from an area to the west, Hot Springs Canyon and Short Croton Creek. The additional two areas each would require brine recovery wellfield and the brine would be pumped to the deep well injection facility. Option 2 would dispose of the brine in a reservoir that would serve as permanent impoundment for the recovered brine. Phase 1 and Phase 2 of Option 2 would remove brine from the same areas as Phase 1 and Phase 2 of Option 1. Instead of disposing of the brine in a deep well injection facility, it would be pumped to a permanent impoundment, Kiowa Peak Reservoir. Option 3 would convey the recovered brine to the Brine Utilization and Management Complex (BUMC), where it would be converted into marketable NaCl salt products and potentially high quality fresh water. The feasibility of Option 3 was first studied when, in 1995 Stonewall County applied for and was awarded a Texas Water Development Board funded Grant entitled *Evaluation of Economic and Reliable Methods of Brine Management (TWDB Contract No. 95-483-142)*. During the period of performance of this grant work, the consultants for Stonewall County made contact with United Salt Corporation (USC) of Houston, Texas in an effort to gain an understanding of the economics, marketing and technical aspects of the salt business. It was this initial contact and the interest indicated by USC that led to the concrete idea of the BUMC.

In February of 1998, Stonewall County was awarded a grant funded 75 percent by the Economic Development Administration (EDA) of the U.S. Department of Commerce, and 25 percent by local sources for the purpose of preparing a feasibility study for the BUMC. The proceeds of the grant have made possible the preparation of a substantial compilation of descriptive and preliminary cost information regarding the BUMC by the project consultants and have also very recently contributed to the funding of two successfully completed brine test wells. The final report on this study will be submitted to EDA at the end of calendar year 2000, and an indication of the positive feasibility of the BUMC project is currently anticipated.

The intended purpose of the BUMC is threefold; To control naturally occurring chlorides in the Upper Brazos River Basin by the most cost effective means available, to provide opportunity for the transfer of the technology to be utilized in the BUMC to other geographical areas faced with the need for desalination projects and/or similar projects for which the proper

disposal of brine is significant, and to provide opportunities for badly needed job creation in and around Stonewall County through the development of business ventures related to the production and sale of various NaCl salt products and potentially high quality water.

5A.8.1.1 Previous Studies

Since the first studies were performed by the State Health Department and USGS in the early 1940s defining the source and extent of the natural salt pollution problem and developing a feasible solution to control the pollution has been investigated. The most extensive review of possible control measures was performed by the U.S. Army Corps of Engineers.⁸ Table 5A.8-1 shows a brief summary of control methods investigated by the Corps of Engineers and potential solutions suggested in other reports.

5A.8.1.2 Project Yields

The watershed above Possum Kingdom Reservoir is estimated to produce on average about 1,127 tons per day of chloride,⁹ which is about 79 percent of the chloride in the Brazos River at Richmond. Each of the chloride control options results in a different amount of chloride removal, based on the number and type of removal facilities utilized by the option, and the aerial extent to the project.

Estimated daily average chloride production from the salt seeps and springs to the Dove Creek Salt Flats is 388 tons per day. Estimated average chloride production for the Croton Creek Watershed is 75 tons per day and 50 tons per day from the North Croton Creek Watershed. Therefore, total chloride production within the general area is 513 tons per day (or about 46 percent of the salt production in the Brazos River above Possum Kingdom Reservoir).

Table 5A.8-2 lists the potential chloride removal rates for each option.

5A.8.2 Environmental Issues

5A.8.2.1 Chloride Control Option 1 — Brine Recovery with Subsequent Deep Well Injection

Environmental impacts could include:

- Possible low to moderate negative impact on quantity of stream flows below well fields;
- Possible low to moderate positive impact to water quality in streams below well fields;

⁸ Natural Salt Pollution Control Study, Brazos River Basin, Texas, Volumes 1-4, U.S. Army Corps of Engineers Fort Worth District, 1973.

⁹ Wurbs, R., 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 5A.8-1.
Investigated Control Methods**

Control Method	Description	Advantages	Disadvantages
Flow Suppression	Seeps and springs can be kept underground by imposing a hydrostatic head at the source of the flow, (i.e., ring dike).	Low Maintenance Downstream water quality improvement	Extremely site specific
Total Impoundment	Capture all flow on a stream including the 100-year flood.	Downstream water quality improvement	Cost
Low Flow Impoundment	Detain stream flow with low water dams and inflatable weirs and divert flows to a total impoundment.	Downstream water quality improvement	Cost
Diversion Impoundment	Detain all fresh water stream flows and divert flows into the Brazos River downstream.	Downstream water quality improvement	Cost
Dilution	Mixing water of low salt concentrations to flow to lower the high naturally occurring salt concentrations (i.e., import fresh water to mix with the brine water).	Increased water supply Downstream water quality improvement	Cost
Desalination	The mechanical removal of ions from water.	Highly effective on site removal	Cost (However, recent and current advances in membrane technology is reducing the cost of this alternative)
Deep Well Injection	Injection of brine water into a sub surface strata (disposal method only, requires other control method to collect brine water)	Downstream water quality improvement	Used in conjunction with a collection alternative Break out of brine from deep formation
Export to Gulf	Move brine water from source to Gulf	Downstream water quality improvement	Cost
Evaporation	Solar evaporation, climatological fact and in incorporated into the design of many alternatives	Reduces brine water storage capacity	Topographic and soil characteristics were unacceptable for shallow impoundments with large surface areas
Distribution-Import	Re-distribute available supplies to areas where constraints on water use are greatest.	Provide potable water supply to upper and middle Brazos Basin	No water quality improvements
Pipeline Distribution	Complex pipeline system	Provide potable water supply to upper and middle Brazos Basin	No water quality improvements
Tributary Supply	Construct new reservoirs on fresh water tributaries to supply upper and middle Brazos basin	Provide potable water supply to upper and middle Brazos Basin	Cost No water quality improvement
Shallow Well Recovery – Deep Well Injection	Install a series of shallow brine recovery wells to reduce the piezometric head in the brine aquifer and injection of recovered brine water into a sub surface strata.	Downstream water quality improvement	Cost
Plugging springs	Fill springs with grout	Downstream water quality improvement	Artesian pressure would cause spring to break out elsewhere

- Possible moderate to high negative impact to existing aquatic habitat for high-saline adapted species;
- Possible low to moderate positive impact to aquatic habitat quality for non-saline adapted species below well fields on Salt Croton Creek and Croton Creek.

A summary of environmental issues is presented in Table 5A.8-3.

Table 5A.8-3.
Environmental Issues: Chloride Control
(Option 1 – Brine Recovery with Subsequent Deep Well Injection)

Water Management Option	Chloride Control (Option 1 – Brine Recovery with Subsequent Deep Well Injection)
Implementation Measures	Development of well fields in brine springs area, brine pumped via pipeline to proposed deep injection wells
Environmental Water Needs / Instream Flows	Possible low to moderate negative impact on quantity of stream flows below well fields; possible low to moderate positive impact to water quality in streams below well fields
Bays and Estuaries	Negligible impacts
Fish and Wildlife Habitat	Possible moderate to high negative impact to existing aquatic habitat for high-saline adapted species at brine springs; possible low to moderate positive impact to habitat quality for non-saline adapted species below well fields on Salt Croton Creek and Croton Creek
Cultural Resources	Possible low impact
Threatened and Endangered Species	Negligible impact
Comments	Deep well injection requires TNRCC permit; abandoned oil or gas wells cannot be used

5A.8.2.2 Chloride Control Option 2 — Brine Recovery with Subsequent Disposal in Kiowa Peak Reservoir

Environmental impacts could include:

- Possible low to moderate negative impact on quantity of stream flows below reservoir; possible low to moderate positive impact to water quality in streams below reservoir;
- Possible moderate to high negative impact to fish and wildlife habitat from reservoir inundation of 9,622 acres; possible moderate to high negative impact to existing aquatic habitat for high saline-adapted species;
- Possible low to moderate positive impact for waterfowl and wetland dependent wildlife as a result of reservoir construction; possible low to moderate positive impact to habitat quality for non-saline adapted species below well fields on Salt Croton Creek and Croton Creek;
- Mitigation costs could be substantial due to compensation required for habitat lost from reservoir construction;

A summary of environmental issues is presented in Table 5A.8-4.

**Table 5A.8-4.
Environmental Issues: Chloride Control
(Option 2 - Brine Recovery with Subsequent Disposal in Kiowa Peak Reservoir)**

Water Management Option	Chloride Control (Option 2 - Brine Recovery with Subsequent Disposal in Kiowa Peak Reservoir)
Implementation Measures	Development of brine recovery well fields, brine recovered and pumped through 30-mile pipeline to the proposed 9,622-acre Kiowa Peak Reservoir on North Croton Creek and Pen Branch in King and Stonewall Counties
Environmental Water Needs / Instream Flows	Possible low to moderate negative impact on quantity of stream flows below reservoir; possible low to moderate positive impact to water quality in streams below reservoir
Bays and Estuaries	Negligible impact
Fish and Wildlife Habitat	Possible moderate to high negative impact to fish and wildlife habitat from loss of 9,622 acres; possible moderate to high negative impact to existing aquatic habitat for high saline-adapted species; possible low to moderate positive impact for waterfowl and wetland dependent wildlife as a result of reservoir construction; possible low to moderate positive impact to habitat quality for non-saline adapted species below well fields on Salt Croton Creek and Croton Creek
Cultural Resources	Possible low to moderate negative impact
Threatened and Endangered Species	Negligible impact
Comments	Uncontrolled spills during flooding rains could produce a surge of highly saline water downstream to the Brazos River; mitigation requirements for habitat loss from reservoir construction could be substantial

5A.8.2.3 Chloride Control Option 3 — Shallow Well Recovery and Salt Croton Creek Low Flow Diversion with Beneficial Use of Brine at BUMC plant

Environmental impacts could include:

- Possible moderate to high negative impact on quantity of base flow immediately downstream of the well fields and low flow diversion structure;
- Probable low to moderate positive impact on water quality of stream flows downstream of the well fields and low flow diversion structure;
- Possible low negative impact on existing aquatic habitat for high saline adapted species;
- Possible low to moderate positive impact on aquatic habitat quality for non-saline adapted species downstream of well fields and Salt Croton Creek low flow diversion structure;

A summary of environmental issues is presented in Table 5A.8-5.

**Table 5.A8-5.
Environmental Issues: Chloride Control
(Option 3: Shallow Well Recovery and Salt Croton Low Flow
Diversion with Beneficial Use of Brine at BUMC Plant)**

Water Management Option	Chloride Control Option 3-Brine Recovery Wells and Low Flow Diversion Structure in Conjunction with Beneficial Use of Brine at BUMC Plant
Implementation Measures	Development of brine recovery well system west of brine springs area and diversion structure located downstream. Brine pumped via pipeline to proposed BUMC plant site for evaporation of water and commercial salt production.
Environmental Water Needs — Instream Flows	Possible moderate to high negative impact on quantity of stream flow immediately downstream of brine recovery well system and Salt Croton Creek low flow diversion structure; probable low to moderate positive impact on water quality in stream downstream of well system and low flow diversion structure
Bays & Estuaries	No impact
Fish and Wildlife Habitat	Possible moderate to high negative impact on existing aquatic habitat for high-saline adapted species at brine springs and low flow diversion structure. Possible low to moderate positive impact on non-saline adapted species downstream from brine recovery well system and Salt Croton Creek low flow diversion structure.
Cultural Resources	Possible low impact
Threatened and Endangered Species	Negligible impact
Comments	Salt Croton Creek diversion structure is designed to intercept low-flow high salinity brine only. Low salinity/high water flows will not be affected, but rather will pass to downstream.

5A.8.3 Engineering and Costing

The Chloride Control Projects consist of three options. Figure 5A.8-2 shows the location of Option 1, Figure 5A.8-3 shows the location of Option 2, and Figure 5A.8-4 shows the location of Option 3. All three options require brine recovery well fields that penetrate the saline aquifer in the area, lowering the piezometric surface of the water table, thereby eliminating brine springs and seeps in the area. Option 1 would dispose of the recovered brine in a deep well injection system. Option 2 would dispose of the brine in a reservoir that would serve as permanent impoundment for the recovered brine. For Option 3, the brine collected would be conveyed to a reservoir (solar salt pond complex) and then be put to beneficial use at the BUMC plant site, in the production of salt products.

The following elements would be included in each option:

5A.8.3.1 Option1

- Brine Recovery well field & collection piping;
- Above ground storage tank & booster station;
- Pipeline facilities; and
- Deep Well Injection System including treatment facilities

5A.8.3.2 Option2

- Brine Recovery well field & collection piping;
- Aboveground storage tank & booster station;
- Pipeline facilities;
- Reservoir; and
- Stilling basin

5A.8.3.3 Option3

- Brine Recovery well field and collection piping;
- Salt Croton Creek Low Flow Diversion Structure and Water Quality Monitoring Station;
- Pump Stations and Storage Tank for Brine Water;
- Pipelines for Transmission of Brine Water;
- Reservoir (Solar Salt Pond Complex);
- Facilities for solar salt production, processing and storage;
- Facilities for upgrading of electrical power infrastructure; and
- Site development improvements

Chloride Control Option 1 consists of building a brine recovery well field in the area of the Dove Creek Salt Flats, located in the upper reaches of the Brazos River Basin. The preliminary design of the well field and cost estimate is based on previous work done on the project and updated where necessary.¹⁰ The brine recovery well field will consist of 10 wells with spacing determined by the geophysical survey and with an average depth of 210 feet. A pumping capacity of approximately 75 gpm would be required for each of the 10 wells in the well field. A collection piping system would transport the recovered brine to a storage tank, from which a booster station would pump the brine through a pipeline to the deep well injection system. The deep-well injection system would consist of a pre-injection treatment facility to remove any solids from the recovered brine, by use of corrosion resistant filters. After treatment, the brine would be stored in storage tanks, from which four high-pressure pumps would inject

brine into a 7,000 foot deep well, to the Ellenburger Formation, which was estimated could accept up to 2 cfs of brine without substantial long term pressure changes in the formation. Table 5A.8-6 lists the sizes of the required facilities.

**Table 5A.8-6.
Required Facilities — Option 1 Phase 1**

Facility	Description
1 Recovery Well Field	10 Wells, Spacing determined by Geophysical Survey, Average Depth~210 feet, Pumping Rate 75 gpm/well
1 Collection Piping System	500 feet of 4-inch pipe, 4,500 feet of 6-inch pipe, 4,500 feet of 8-inch pipe, 4,500 feet of 10-inch pipe
1 Storage Tank	40,000 gallons
1 Booster Station	20 hp
Pipeline	10,560 feet of 10-inch pipe
Deep Well Injection Facilities	Plant contains 4-550 hp high-pressure pumps

To the west, two other areas in the Croton Creek Watershed contain brine springs and seeps, one such area is located in Hot Springs Canyon, and the other is located on the Short Croton Creek. Phase 2 of Option 1 includes a brine recovery well field, collection piping, storage tanks, and a booster station at each site. A pipeline would take the recovered brine from the storage tank at Short Croton Creek to the storage tank at Hot Springs Canyon, from which another segment of pipeline would take the recovered brine to the Dove Creek Salt Flat pumping and storage facilities, which would be enlarged to handle the additional recovered brine. The deep-well injection facilities would also be enlarged to handle the additional recovered brine, requiring additional storage, pumping capacity, and another injection well. According to a 1994 report¹¹, the Ellenburger formation is the recommended formation to accept recovered brine, but the Strawn formation could also accept up to 2 cfs of brine without significant long-term pressure increases in the formation. Table 5A.8-7 lists the required facilities.

¹⁰ Brazos Chloride Study, Brazos River Basin, Texas, Phase II, June 1995, United States Army Corps of Engineers, Fort Worth District

¹¹ "Evaluation and Partial Control of Natural Salt Springs and Seeps in the Dove Creek Area, Upper Brazos River Basin, Texas, Part II," Texas Engineering Experiment Station, Texas A&M University, James and Spongberg, February 1994.

**Table 5A.8-7.
Required Facilities - Option 1 Phase 2**

Facility	Description
3 Recovery Well Fields	10 Wells, Spacing determined by Geophysical Survey, Average Depth~210 feet, Pumping Rate 75 gpm/well
3 Collection Piping Systems	1,500 feet of 4-inch pipe, 13,500 feet of 6-inch pipe, 13,500 feet of 8-inch pipe, 13,500 feet of 10-inch pipe
3 Storage Tanks	40,000 gallons; 80,000 gallons; 120,000 gallons
3 Booster Stations	20, 125, 125 hp
Pipeline	16,404 feet of 10-inch pipe, 49,209 feet of 12-inch pipe, 10,560 feet of 14-inch pipe
Deep Well Injection Facilities	Plant contains 12-550 hp high-pressure pumps

Chloride Control Option 2 would consist of the same brine recovery well-field near the Dove Creek Salt Flats as Option 1, but instead of disposing of the recovered brine by deep-well injection, it would be transported by pipeline to Kiowa Peak Reservoir, sized for permanent impoundment. The preliminary design and cost estimate of Kiowa Peak Reservoir was completed by the United States Army Corps of Engineers and was updated to complete this evaluation.⁶ Kiowa Peak Reservoir has a maximum storage capacity of 659,650 acft, which equates to a surface area of 13,100 acres, and a maximum flood pool elevation of 1605.0 feet above mean sea level. The top of the brine pool (also the spillway crest) has a storage capacity of 423,500 acft, a surface area of 9,455 acres, and a pool elevation of 1584.5 feet above mean sea level. Table 5A.8-8 lists the required facilities for Phase 1 of Option 2.

**Table 5A.8-8.
Required Facilities - Option 2 Phase 1**

Facility	Description
1 Recovery Well Field	10 Wells, Spacing determined by Geophysical Survey, Average Depth~210 feet, Pumping Rate 75 gpm/well
1 Collection Piping System	500 feet of 4-inch pipe, 4,500 feet of 6-inch pipe, 4,500 feet of 8-inch pipe, 4,500 feet of 10-inch pipe
1 Storage Tank	40,000 gallons
1 Booster Station	30 hp
Pipeline	57,417 feet of 10-inch pipe
Reservoir	Max Elevation = 1605.0 ft above msl, Maximum Capacity = 659,650 acft. Maximum Area = 13,100 Acres

Phase 2 of Option 2 would recover brine from Hot Springs Canyon, Short Croton Creek, and the Dove Creek Salt Flats in the same way that it was recovered and transported in Option 1, Phase 2, but disposed of in the same reservoir as Option 2. Table 5A.8-9 lists the required facilities.

**Table 5A.8-9.
Required Facilities - Option 2 Phase 2**

Facility	Description
3 Recovery Well Fields	10 Wells, Spacing determined by Geophysical Survey, Average Depth~210 feet, Pumping Rate 75 gpm/well
3 Collection Piping Systems	1,500 feet of 4-inch pipe, 13,500 feet of 6-inch pipe, 13,500 feet of 8-inch pipe, 13,500 feet of 10-inch pipe
3 Storage Tanks	40,000 gallons; 80,000 gallons; 120,000 gallons
3 Booster Stations	20, 125, 125 hp
Pipeline	16,404 feet of 10-inch pipe, 49,209 feet of 12-inch pipe, 57,394 feet of 14-inch pipe
Reservoir	Max Elevation = 1605.0 ft above msl, Maximum Capacity = 659,650 acft. Maximum Area = 13,100 Acres

For Option 3, the brine recovery well system would be supplemented by a low flow diversion system on Salt Croton Creek, with the primary objective of the combination of recovery wells and diversion from Salt Croton Creek being (1) to result in a comparatively higher rate of total chloride removal, and (2) to have the low flow diversion system serve as a “fail safe” mechanism in the event one or more of the wells is shut down for maintenance or repair. As illustrated in Figure 5A.8-4, the brine collected from both the wells and the low flow diversion system would be conveyed to a reservoir (solar salt pond complex) and then be put to beneficial use at the BUMC plant site. Table 5A.8-10 lists the required facilities for option 3.

Table 5A.8-11 summarizes the costs for Option 1, Option 2, and Option 3. For Option 1, only Phase 1 was determined to be economically justified. Based upon a unit cost of \$/ton of chloride removed per year, it was not economically feasible to consider Phase 2. The springs and seeps at the Dove Creek Salt Flats produce more chloride (approximately 388 tons per day) than do the springs and seeps at Hot Springs Canyon and Short Croton Creek combined (approximately 75 tons per day). The cost to remove the chloride in Phase 2 is greatly increased due to increased deep-well injection facilities and annual energy costs. The total capital costs for Option 1, including recovery well fields and collection systems, storage tanks, and booster

stations, pipelines, and deep-well injection are \$4,574,000. Considering engineering, legal costs, contingencies, environmental studies, land acquisition, surveying, and mineral rights, the estimated total project cost is \$7,634,000. Annual costs including debt service, operation and maintenance, and annual energy total \$1,354,000.

**Table 5A.8-10.
Required Facilities — Option 3**

Facility	Description
Recovery Well Field	10 Wells, Spacing determined by geophysical surveys; average depth of 210 feet and average pumping rate of 75 gpm/well
Collection Piping System, Ground Storage tank(s) and Automated Data Acquisition System	11,000 feet of 8-inch pipe; 1,000 feet of 4-inch pipe; 2 @ 108,000 gallon each storage tanks and data acquisition system
Booster Stations	1 station just south of well field and 1 station at junction of 8-inch and 10-inch lines. 40 HP pumps at both stations
Pipelines	82,000 feet of 8-inch pipe; 74,000 feet of 10-inch pipe and appurtenances
Salt Croton Creek Low Flow Diversion System & Water Quality Monitoring System	125 HP Submersible Pump Station at Low Flow Diversion Structure and USGS Monitoring Equipment
Reservoir (Solar Salt Pond Complex)	For brine storage and conversion to solar salt; total capacity of 800 to 1000 ac/ft to accommodate salt production capacity of approximately 200,000 tons/yr. Dikes with 3 feet of freeboard and rip rap protection of embankments with 3:1 side slopes
Facilities for production, processing and storage of solar salt products	Facilities include equipment, machinery warehouse and related to accommodate capacity of approximately 200,000 tons/year of solar salt production
Facilities for upgrade of electrical power infrastructure	As per South Plains Electric Cooperative and consists of both upgrading of substation and line extensions
Site development improvement	Includes facilities for water and wastewater services and site paving, grading and fencing improvements

For Option 2, both Phase 1 and Phase 2 were determined to be economically justified, since the disposal of brine from the additional sites only requires added facilities, but the cost of the reservoir remains the same, which is the bulk of the cost for Option 2. The total capital costs for Option 2, Phase 2, including recovery well fields and collection systems, storage tanks, and booster stations, pipelines, stilling basin, and reservoir facilities are \$151,932,000. After considering engineering, legal costs, contingencies, environmental studies, land acquisition, mineral rights, and surveying, a total project cost of \$302,129,000. Annual costs including debt service, operation and maintenance, and energy total \$22,763,000.

For Option 3, the total capital costs, including recovery well field and collection system, storage tanks, booster station, pipeline, low flow diversion, facilities for production, processing, storage of solar salt, facilities for upgrade of electrical power infrastructure, and site development improvements, and solar salt reservoir are \$19,477,000. After considering engineering, legal costs, contingencies, environmental studies, land acquisition, mineral rights, and surveying, a total project cost of \$28,673,000. Annual costs including debt service, operation and maintenance, and energy total \$2,427,000. Total annual revenues from the sale of salt products are estimated at \$600,000 per year. The net annual cost is \$1,827,000.

5A.8.3.4 Comparison of Chloride Control Benefits and Desalination Treatment

This section reviews the benefit and cost effectiveness of implementing chloride control to reduce water treatment costs of demineralization in the Brazos River. The effectiveness of the chloride control project on water quality in the Brazos River are determined. The cost of desalination treatment of municipal water with and without chloride control is compared to the cost of implementing the chloride control project.

Concentration-duration curves for total dissolved solids (TDS) were developed by Ralph Wurbs et. al' at five different locations on the Brazos River. These five locations within the basin are the USGS Gaging Stations at Seymour, at Possum Kingdom Dam near Graford, near Whitney, near College Station and at Richmond, and are shown in Figure 5A.8-5. The

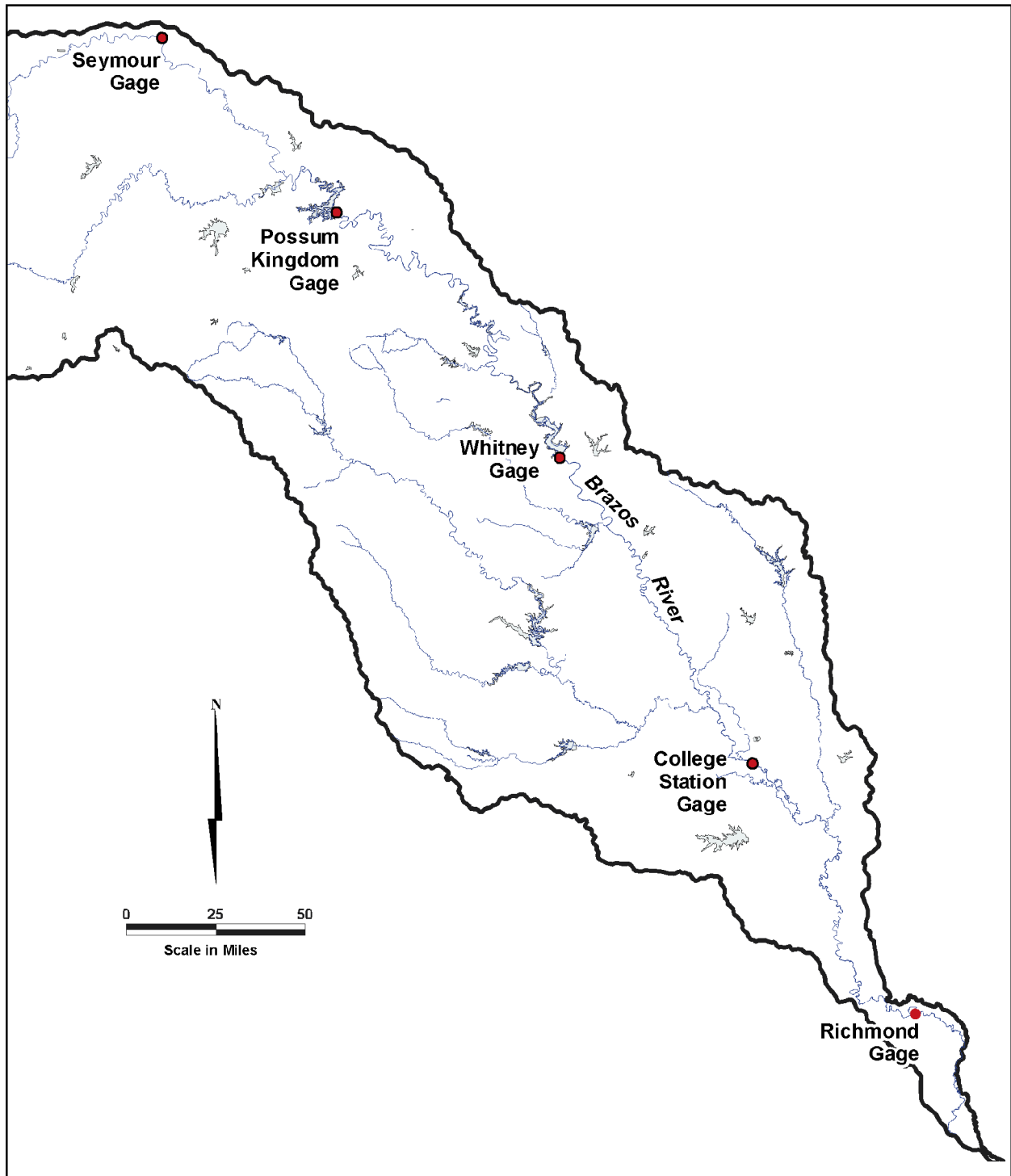
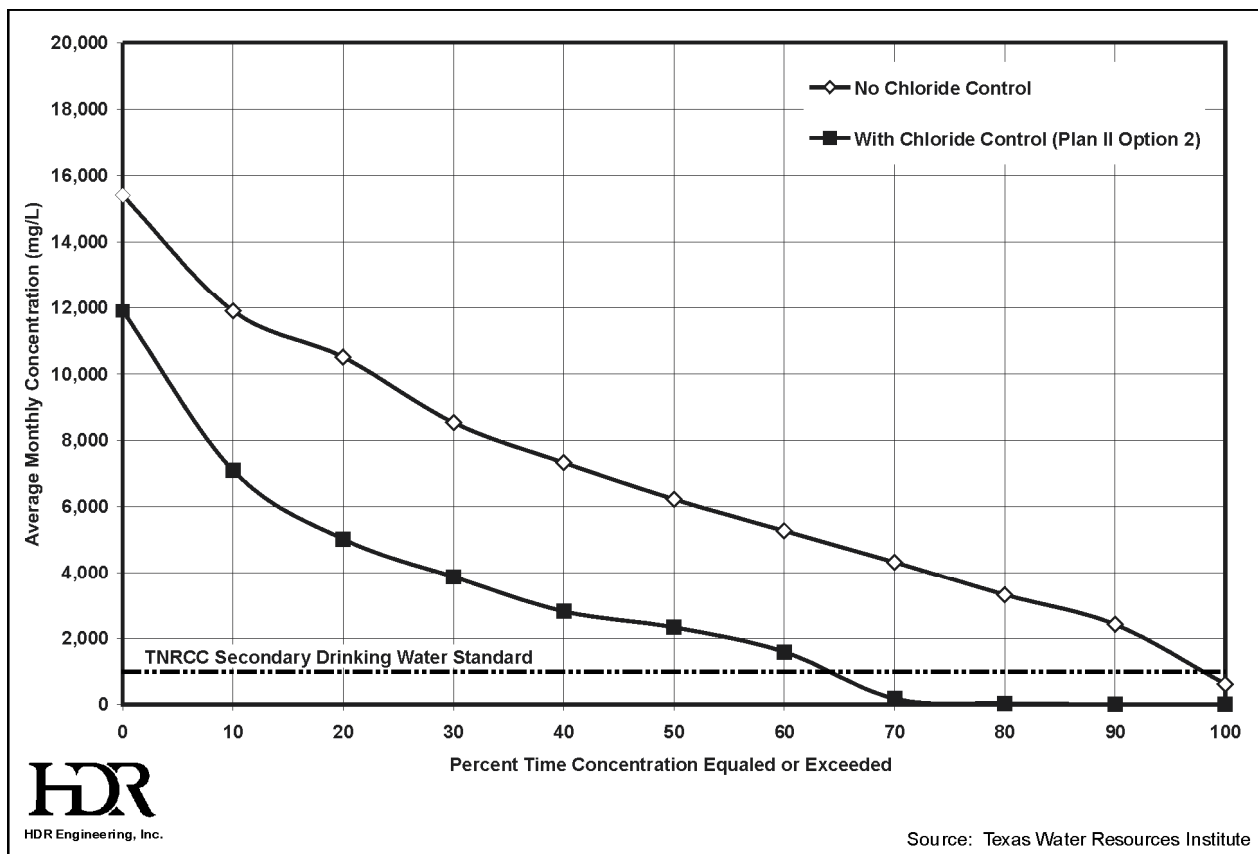


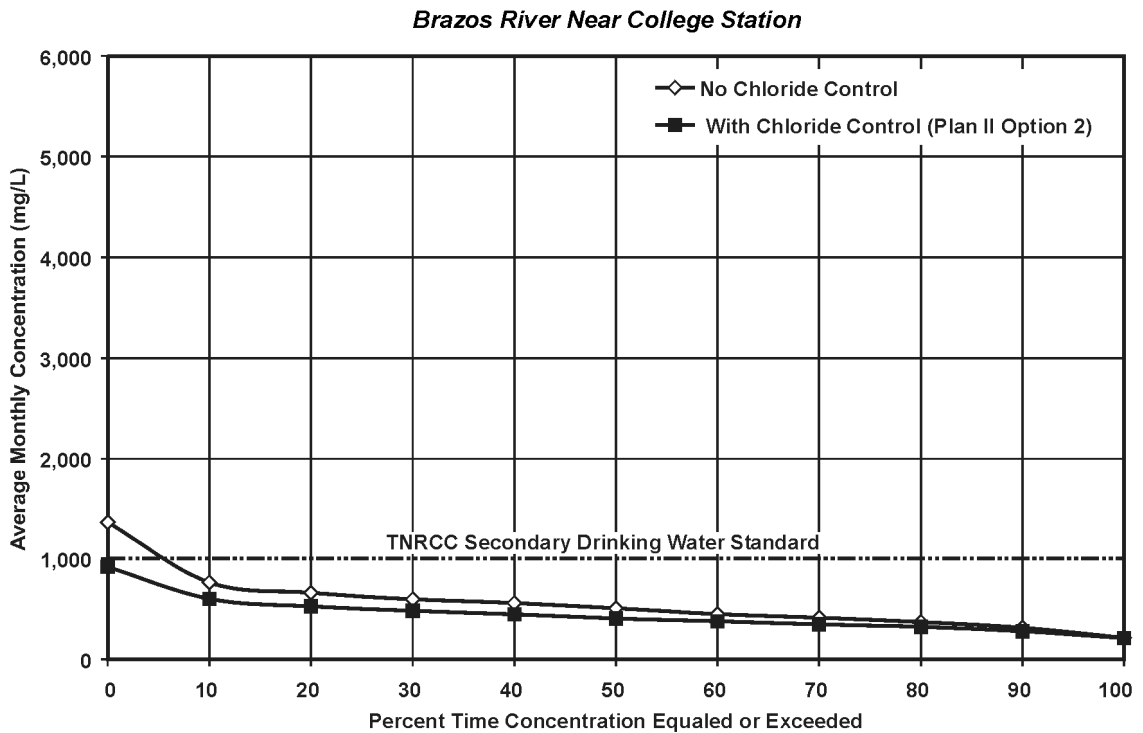
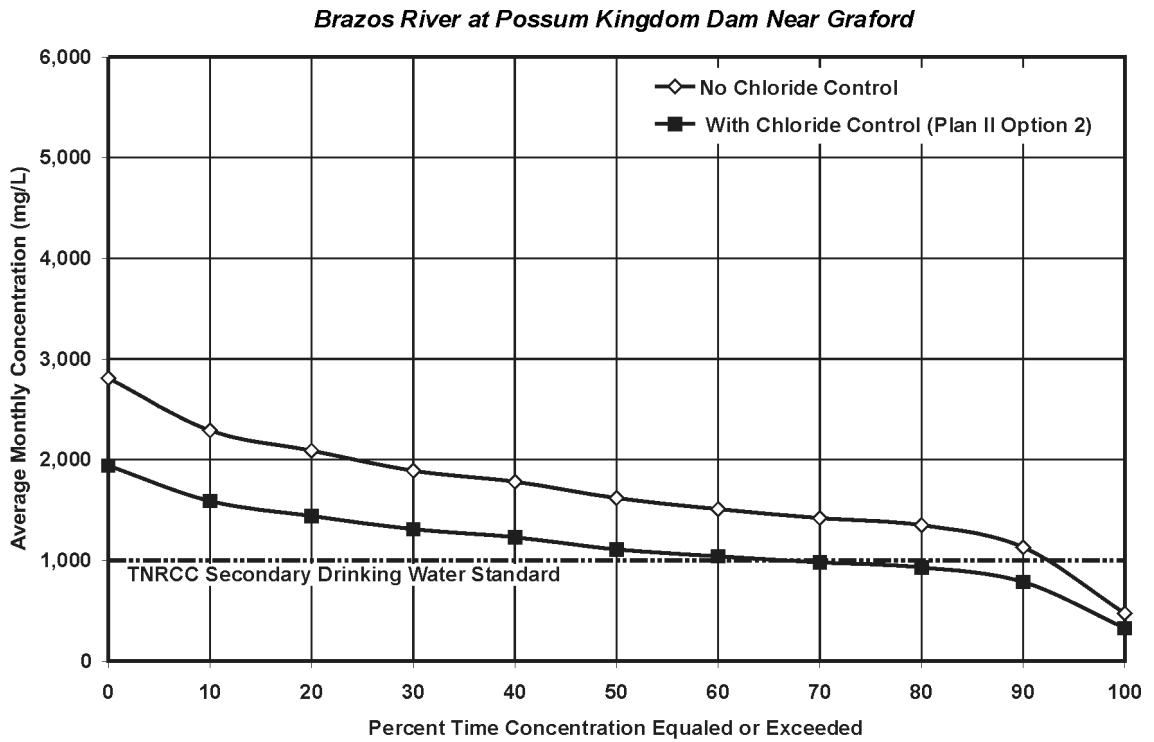
Figure 5A.8-5. Brazos River Stream Gaging Locations

concentration-duration curves represent historical average monthly concentration data and the calculated average monthly concentration values as a result of implementing chloride control measures at the Dove Creek Salt Flats, and Short Croton Creek and building the Kiowa Peak Lake impoundment. The concentration-duration curves are representative of Option 2.2, which at 100 percent removal efficiency results in a reduction in chloride loading by 513 tons/day. The concentration-duration curves are shown in Figures 5A.8-6 through 5A.8-8. The concentration-duration curves are representative of a point in the future when the benefits of chloride control are fully realized and residual salt has been washed from the upland stream beds and from downstream lakes. The amount of time this will take to occur needs further study.



**Figure 5A.8-6. Concentration-Duration Curves for Total Dissolved Solids
Brazos River at Seymour**

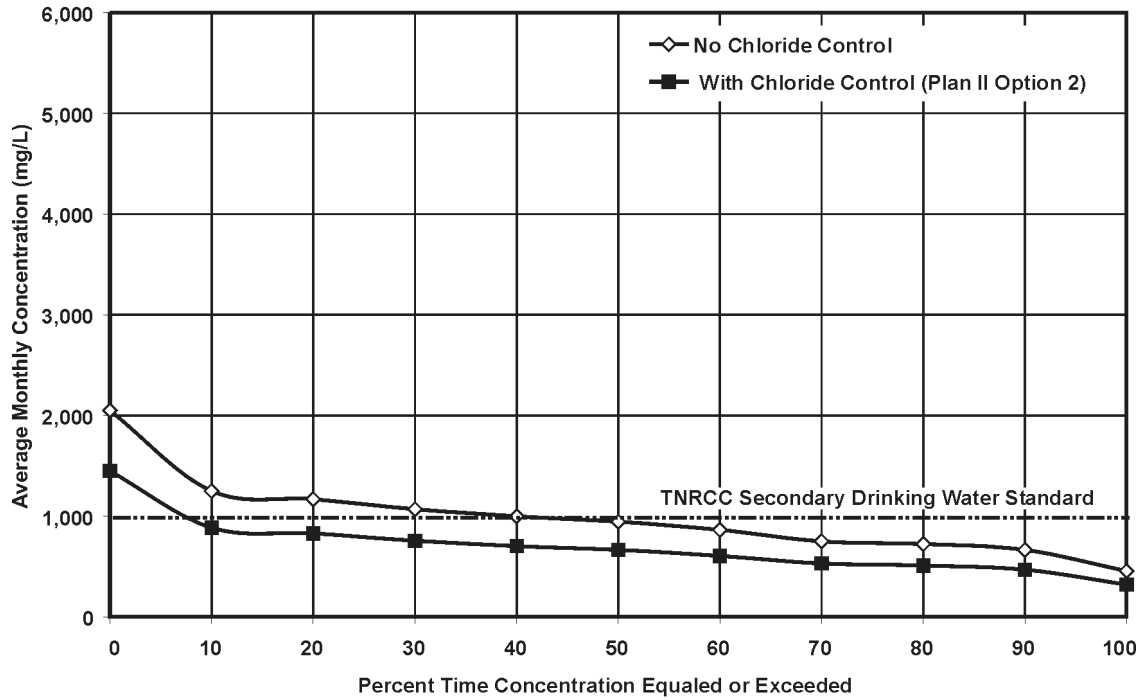
TDS is an indicator of the levels of chlorides as well as dozens of other dissolved ions that are removed by the chloride control projects and the desalination treatment process. The concentration-duration curves (Figures 5A.8-6 through 5A.8-8) show that the secondary



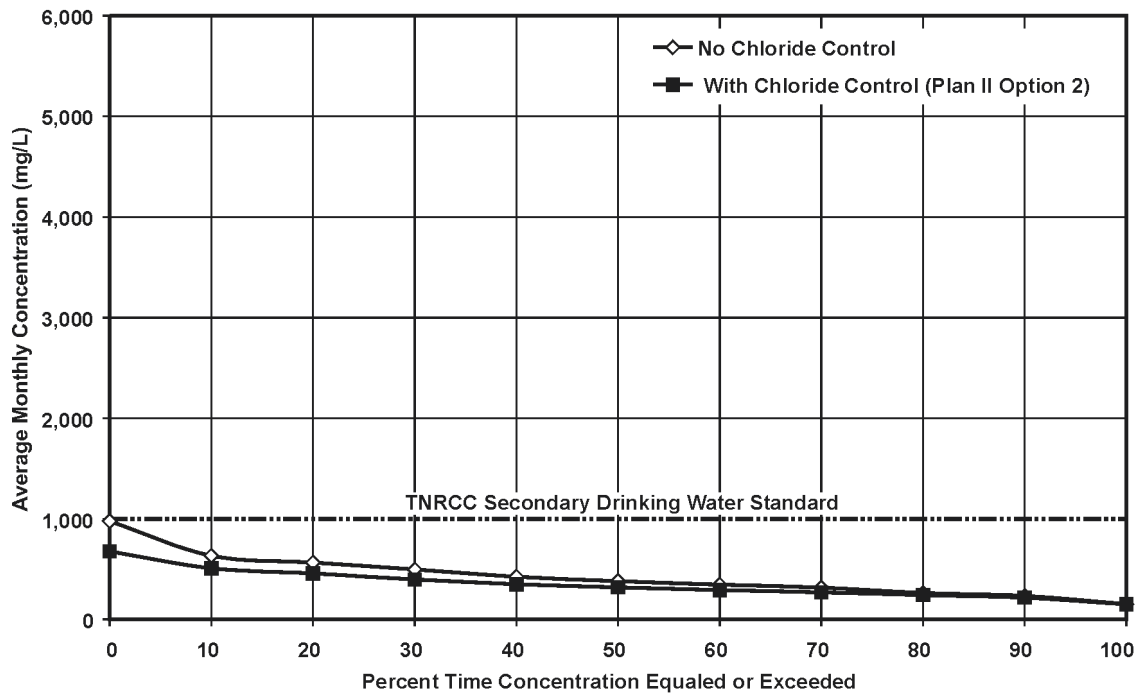
Source: Texas Water Resources Institute

Figure 5A.8-7. Concentration-Duration Curves for Total Dissolved Solids

Brazos River at Whitney Dam Near Whitney



Brazos River at Richmond



Source: Texas Water Resources Institute

Figure 5A.8-8. Concentration-Duration Curves for Total Dissolved Solids

drinking water standards for TDS of 1000 mg/L are exceeded 100 percent of the time at the Seymour Gage under baseline conditions without chloride control. However, upon implementing the chloride control measures of Option 2.2, the secondary standard was exceeded only 65 percent of the time. A similar reduction is seen at Possum Kingdom and Whitney. However, the concentration of dissolved solids at the College Station and Richmond gages seldom, if ever, exceed the 1000 mg/L TDS standard. For this reason, only the first three gage sites will be considered for comparison of desalination costs. Conventional treatment would be sufficient to treat source water from the Brazos River at College Station and Richmond.

The costs of desalination treatment at Seymour, Possum Kingdom and Whitney with and without implementing chloride control are included in Tables 5A.8-12, 5A.8-13, and 5A8-14, respectively. The cost of desalination is based upon treating 10 MGD of water and the maximum and average TDS concentrations at each site as shown by the concentration-duration curves. Surface water must undergo conventional treatment prior to desalination. For comparison purposes of treatment cost for various TDS concentrations, costs shown are for desalination component only. Costs common to conventional water treatment plant are omitted. Omitted costs include intake, pump stations, conventional pretreatment, clearwell storage, and others.

The total annual cost of desalination treatment at Seymour with no chloride control is \$3,868,522, with an annual unit cost of \$345 per acft. With chloride control, the estimated annual cost of desalination at Seymour is \$3,454,818, with an annual unit cost of \$308 per acft. The desalination treatment savings at Seymour as a result of implementing the chloride control project on a unit cost basis is \$37 per acft.

The total annual cost of desalination treatment at Possum Kingdom with no chloride control is \$3,356,240, with an annual unit cost of \$300 per acft. With chloride control implemented, the estimated annual cost of desalination at Possum Kingdom is \$2,116,415, with an annual unit cost of \$189 per acft. The desalination treatment savings at Possum Kingdom as a result of implementing the chloride control project is \$111 per acft.

The total annual cost of desalination treatment at Whitney with no chloride control is \$1,811,519, with an annual unit cost of \$162 per acft. With implementation of the chloride control project, no additional desalination treatment is needed at Whitney because the secondary drinking water standard for TDS is met or exceeded over 90 percent of the time. This results in a \$162 per acft savings of desalination treatment cost.

Table 5.A.8-12.
Estimated Incremental Cost of Desalination at Seymour
with and without Implementation of Chloride Control Project

<i>Item</i>	<i>No Chloride Control</i>	<i>With Chloride Control</i>	<i>Difference</i>
Maximum TDS	11,900	7,090	
Average TDS	6,220	2,330	
% of Water Desalinated	100%	100%	
Capital Costs			
RO Desalination Plant (10 MGD) ¹	\$10,269,000	\$9,733,000	\$536,000
Concentrate Disposal	\$6,262,500	\$5,260,500	\$1,002,000
Total Capital Cost	\$16,531,500	\$14,993,500	\$1,538,000
Engineering, Legal Costs and Contingencies (35%)	\$5,786,000	\$5,248,000	\$538,000
Interest During Construction (1 years)	\$992,000	\$900,000	\$92,000
Total Project Cost	\$23,309,500	\$21,141,500	\$2,168,000
Annual Costs			
Debt Service (6 percent, 30 years)	\$1,693,000	\$1,536,000	\$157,000
Operation and Maintenance			
Desalination Water Treatment Plant	\$1,913,022	\$1,698,318	\$214,704
Concentrate Disposal	\$262,500	\$220,500	\$42,000
Total			
Total Annual Cost	\$3,868,522	\$3,454,818	\$413,704
Water Treated Annually (acft/yr)	11,202	11,202	
Annual Cost of Water (\$ per acft)	\$345	\$308	\$37
Annual Cost of Water (\$ per 1,000 gallons)	\$1.06	\$0.95	\$0.11
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 5A.8-13.
Estimated Incremental Cost of Desalination at Possum Kingdom
with and without Implementation of Chloride Control Project

<i>Item</i>	<i>No Chloride Control</i>	<i>With Chloride Control</i>	<i>Difference</i>
Maximum TDS	2,290	1,590	
Average TDS	1,780	1,110	
% of Water Desalinated	100%	60%	
Capital Costs			
RO Desalination Plant (10 MGD) ¹	\$9,198,000	\$6,446,000	\$2,752,000
Concentrate Disposal	\$5,135,250	\$3,006,000	\$2,129,250
Total Capital Cost	\$14,333,250	\$9,452,000	\$4,881,250
Engineering, Legal Costs and Contingencies (35%)	\$5,017,000	\$3,308,000	\$1,709,000
Interest During Construction (1 years)	\$860,000	\$567,000	\$293,000
Total Project Cost	\$20,210,250	\$13,327,000	\$6,883,250
Annual Costs			
Debt Service (6 percent, 30 years)	\$1,468,000	\$968,000	\$500,000
Operation and Maintenance			
Desalination Water Treatment Plant	\$1,672,990	\$1,022,415	\$650,575
Concentrate Disposal	\$215,250	\$126,000	\$89,250
Total			
Total Annual Cost	\$3,356,240	\$2,116,415	\$1,239,825
Water Treated Annually (acft/yr)	11,202	11,202	
Annual Cost of Water Treatment (\$ per acft)	\$300	\$189	\$111
Annual Cost of Water Treatment (\$ per 1,000 gallons)	\$0.92	\$0.58	\$0.34
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 5A.8-14.
Estimated Incremental Cost of Desalination at Whitney
with and without Implementation of Chloride Control Project

<i>Item</i>	<i>No Chloride Control</i>	<i>With Chloride Control</i>	<i>Difference</i>
Maximum TDS	1,250	886	
Average TDS	945	666	
% of Water Desalinated	50%	0%	
Capital Costs			
RO Desalination Plant (10 MGD) ¹	\$5,718,000	\$0 ²	\$5,718,000
Concentrate Disposal	\$2,505,000	\$0 ²	\$2,505,000
Total Capital Cost	\$8,223,000	\$0²	\$8,223,000
Engineering, Legal Costs and Contingencies (35%)	\$2,878,000	\$0 ²	\$2,878,000
Interest During Construction (1 years)	\$493,000	\$0 ²	\$493,000
Total Project Cost	\$11,594,000	\$0²	\$11,594,000
Annual Costs			
Debt Service (6 percent, 30 years)	\$842,000	\$0 ²	\$842,000
Operation and Maintenance			
Desalination Water Treatment Plant	\$864,519	\$0 ²	\$864,519
Concentrate Disposal	\$105,000	\$0 ²	\$105,000
Total			
Total Annual Cost	\$1,811,519	\$0²	\$1,811,519
Water Treated Annually (acft/yr)	11,202	\$0²	
Annual Cost of Water Treatment (\$ per acft)	\$162	\$0²	\$162
Annual Cost of Water Treatment (\$ per 1,000 gallons)	\$0.50	\$0.00²	\$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. ² With chloride control project, raw water quality at Lake Whitney meets or exceeds the secondary drinking water standard for TDS. No desalination treatment is needed.			

The reduction in TDS concentration by implementing chloride control Option 2.2 results in cost savings of desalination treatment at all three sites. In order to determine the cost effectiveness of implementing Option 2.2, the cost of desalination treatment of current municipal contracts and water rights in the Brazos River is compared to the cost of Option 2.2. The concentration-duration curves show that the relevant water quality impacts by the chloride control project are between Seymour and College Station. However, municipal water contracts and water rights exist only between Possum Kingdom Reservoir and College Station. For this reason, the benefit for municipal use is quantified along only these two segments is determined.

The reduction in TDS concentration by implementing chloride control Option 2.2 results in cost savings of desalination treatment at all three sites. In order to determine the cost effectiveness of implementing Option 2.2, the cost of desalination treatment of current municipal contracts and water rights in the Brazos River is compared to the cost of Option 2.2. The concentration-duration curves show that the relevant water quality impacts by the chloride control project are between Seymour and College Station. However, no municipal water contracts or water rights exist above Possum Kingdom Reservoir. For this reason, the benefit for municipal use is quantified for two river segments: Possum Kingdom Reservoir to Lake Whitney, and Lake Whitney to College Station.

Table 5A.8-15 shows the current amount contracted and water rights for municipal use between Possum Kingdom and College Station is 66,171 acft/yr. Table 5A.8-15 also includes the unit cost of desalination treatment with and without chloride control Option 2.2. The total annual cost to desalinate water contracted to municipal use without chloride control Option 2.2 project is \$16,231,560 (Table 5A.8-15). With implementation of chloride control Option 2.2, the total annual cost of desalination treatment for the municipal use between Possum Kingdom and College Station is \$7,548,849 (Table 5A.8-15). Therefore, implementation of chloride control Option 2.2 results in reduced annual costs of \$8,682,711 for desalination treatment ($\$16,231,560 - \$7,548,849 = \$8,682,711$). The comparison to be made is the annual expenditure of \$22,763,000 (Table 5A.8-11) for chloride control Option 2.2 to achieve the reduced chloride concentrations to the reduced costs for desalination treatment. This comparison shows that chloride control Option 2.2 is not cost effective in terms of savings for treatment of municipal water between Possum Kingdom and College Station. However, additional benefits (although not quantified here) would accrue for industrial users requiring potable standard water, irrigation users, and to a smaller degree, for users downstream of College Station.

**Table 5A.8-15.
Determination of the Total Annual Cost of Desalination
Treatment Location with the Brazos River Basin**

	<i>Municipal Use¹</i> <i>(acft/yr)</i>	<i>Unit Cost of Desalination Treatment (\$/acft/yr)</i>		<i>Total Annual Cost of Desalination Treatment (\$/yr)</i>	
		<i>No Chloride Control</i>	<i>With Chloride Control</i>	<i>No Chloride Control</i>	<i>With Chloride Control</i>
Possum Kingdom to Whitney	39,941	\$300	\$189	\$11,982,300	\$7,548,849
Whitney to College Station	26,230	\$162	\$0	\$4,249,260	\$0
Total	66,171			\$16,231,560	\$7,548,849

¹ Includes Brazos River Authority Contract amounts and TNRCC Water Rights for municipal use.

The annual cost of implementing Option 1.1 (Shallow Well Recovery with Deep Well Injection Disposal) is \$1,354,000. For comparison purposes, if the water quality beneficial effects of Option 2.2 (as shown in Figures 5A.8-6 through 5A.8-8) and the desalination costs previously determined are estimated to be the same for Option 1.1, we can estimate the cost effectiveness of Option 1.1 relative to desalination treatment. Implementing Option 1.1 would then result in desalination cost savings of \$8,682,711 ($\$16,231,560 - \$7,548,849 = \$8,682,711$ (Table 5A.8-15)). This cost savings exceeds the annual cost of Option 1.1 by \$7,328,711 (i.e., \$8,682,711 reduced treatment cost, less Option 1.1 annual cost of \$1,354,000 (Table 5A.8-11)).

The annual cost of implementing Option 3, the Brine Utilization Management Complex (BUMC), is \$2,427,000. For comparison purposes, if the water quality beneficial effects of Option 2.2 (as shown in Figures 5A.8-6 through 5A.8-8) and the desalination costs previously determined are estimated to be the same for Option 3 (BUMC), we can estimate the cost effectiveness of Option 3 relative to desalination treatment. Implementing Option 3 would then result in desalination treatment cost savings of \$8,682,711 ($\$16,231,560 - \$7,548,849 = \$8,682,711$, Table 5A.8-15). This cost savings exceeds the annual cost of the BUMC chloride control project by \$6,256,000 (i.e., \$8,682,711 reduced treatment cost, less BUMC annual cost of \$2,427,000 (Table 5A.8-11)). This comparison does not take into account the additional revenues to be earned from the sale of salt by the BUMC project.

This evaluation indicates that implementation of Option 1.1 or Option 3 would be more cost effective than desalination treatment of municipal use water. However, to verify the water

quality effectiveness of chloride control, a detailed study would need to be performed to determine actual water quality impacts rather than using the results of the evaluation performed for Option 2.2.

Removal efficiencies are set at 100 percent for this analysis, however this will also need to be verified. Over recent years the operation and maintenance cost of desalination treatment has fallen due to the advances in technology and increased market share. It is possible to expect the cost of desalination treatment to continue to decline.

Benefits of reduced desalination treatment costs will only be fully realized at a point in the future when the effects of the chloride control project are fully realized and residual salt has been washed from upland stream beds and from downstream lakes. The amount of time this will take to occur needs further study.

5A.8.4 Implementation Issues

The water supply options have been compared to the plan development criteria, as shown in Tables 5A.8-16 through 18.

5A.8.4.1 Chloride Control (Option 1 – Brine Recovery with Subsequent Deep Well Injection):

Regulatory Permits Required

Requirements specific to pipelines needed to link brine well fields to the proposed deep well injection site will include:

- U.S. Army Corps of Engineers Section 404 permit(s) for pipeline stream crossings; discharges of fill into wetlands and waters of the United States for construction; and other activities;
- NPDES Storm Water Pollution Prevention Plan;
- TPWD Sand, Shell, Gravel and Marl permit for river crossings.

Deep well injection of brine cannot use abandoned oil or gas wells and will require:

- TNRCC injection well permit.

Mitigation Funding and Other

Mitigation requirements would vary depending on impacts, but could include vegetation restoration, wetland creation or enhancement, or additional land acquisition.

Table 5A.8-16.
Comparison of Chloride Control Option 1 to Plan Development Criteria

Impact Category	Comment(s)
A. Water Supply: 1. Quantity 2. Reliability 3. Cost	1. No increase in water supply 2. Not a reliable water supply 3. Not applicable
B. Environmental factors 1. Environmental Water Needs 2. Habitat 3. Cultural Resources 4. Bays and Estuaries	1. Low to moderate impact 2. Moderate to high impact on some species 3. Low impact 4. Negligible 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 to agriculture and natural resources
E. Equitable Comparison of Strategies Deemed Feasible	• Not considered for 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

Table 5A.8-17.
Comparison of Chloride Control Option 2 to Plan Development Criteria

Impact Category	Comment(s)
A. Water Supply: 1. Quantity 2. Reliability 3. Cost	1. No increase in water supply 2. Not a reliable water supply 3. Not applicable
B. Environmental factors 1. Environmental Water Needs 2. Habitat 3. Cultural Resources 4. Bays and Estuaries	1. Low to moderate impact 2. Moderate to high impact on some species 3. Low to moderate impact 4. Negligible 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	• Not considered for 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

**Table 5A.8-18.
Comparison of Chloride Control Option 3 to Plan Development Criteria**

Impact Category	Comment(s)
A. Water Supply: 1. Quantity 2. Reliability 3. Cost	1. No increase in water supply 2. Not a reliable water supply 3. Not applicable
B. Environmental factors 1. Environmental Water Needs 2. Habitat 3. Cultural Resources 4. Bays and Estuaries	1. Low to moderate impact 2. Moderate to high impact on some species 3. Low to moderate impact 4. Negligible 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	• Not considered for 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

5A.8.4.2 Chloride Control Project

This water supply option has been compared to the plan development criteria, as shown in Tables 5A.8-16 through 5A.8-18.

Regulatory Permits Required

Development of a brine detention reservoir may require the following permits:

- U.S. Army Corps of Engineers 404 dredge and fill permit(s) for discharges of fill into wetlands and waters of the United States for dam construction; and other activities;
- NPDES Storm Water Pollution Prevention Plan;
- GLO Easement for use of State-owned land; and
- TPWD Sand, Shell, Gravel and Marl Permit for construction in state-owned streambeds.

Permitting will require the following studies and plans:

- Habitat mitigation plan;
- Environmental study of potential impact on endangered species;
- Cultural resources study; and
- Other studies.

Requirements specific to pipelines:

- U.S. Army Corps of Engineers Section 404 permit(s) for pipeline stream crossings; discharges of fill into wetlands and waters of the United States for construction; and other activities;
- NPDES Storm Water Pollution Prevention Plan; and
- TPWD Sand, Shell, Gravel and Marl permit for construction in state-owned streambeds.

Mitigation Funding and Other

- 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.