TRANS–TEXAS WATER PROGRAM

SOUTHEAST AREA

Technical Memorandum

Desalination Report

February 20, 1998

Sabine River Authority of Texas
Lower Neches Valley Authority
San Jacinto River Authority
City of Houston
Brazos River Authority
Texas Water Development Board

Preface

This document is a product of the Trans-Texas Water Program: Southeast Area. The program's mission is to propose the best economically and environmentally beneficial methods to meet water needs in Texas for the long term. The program's four planning areas are the Southeast Area, which includes the Houston-Galveston metropolitan area, the North-Central Area (including Austin), the South-Central Area (including Corpus Christi) and the West-Central Area (including San Antonio).

The Southeast Area of the Trans-Texas Water Program draws perspectives from many organizations and citizens. The Policy Management Committee and its Southeast Area subcommittee guide the program; the Southeast Area Technical Advisory Committee serves as program advisor. Local sponsors are the Sabine River Authority of Texas, the Lower Neches Valley Authority, the San Jacinto River Authority, the City of Houston and the Brazos River Authority.

The Texas Water Development Board is the lead Texas agency for the Trans-Texas Water Program. The Board, along with the Texas Natural Resource Conservation Commission, the Texas Parks & Wildlife Department and the Texas General Land Office, set goals and policies for the program pertaining to water resources management and are members of the Policy Management Committee.
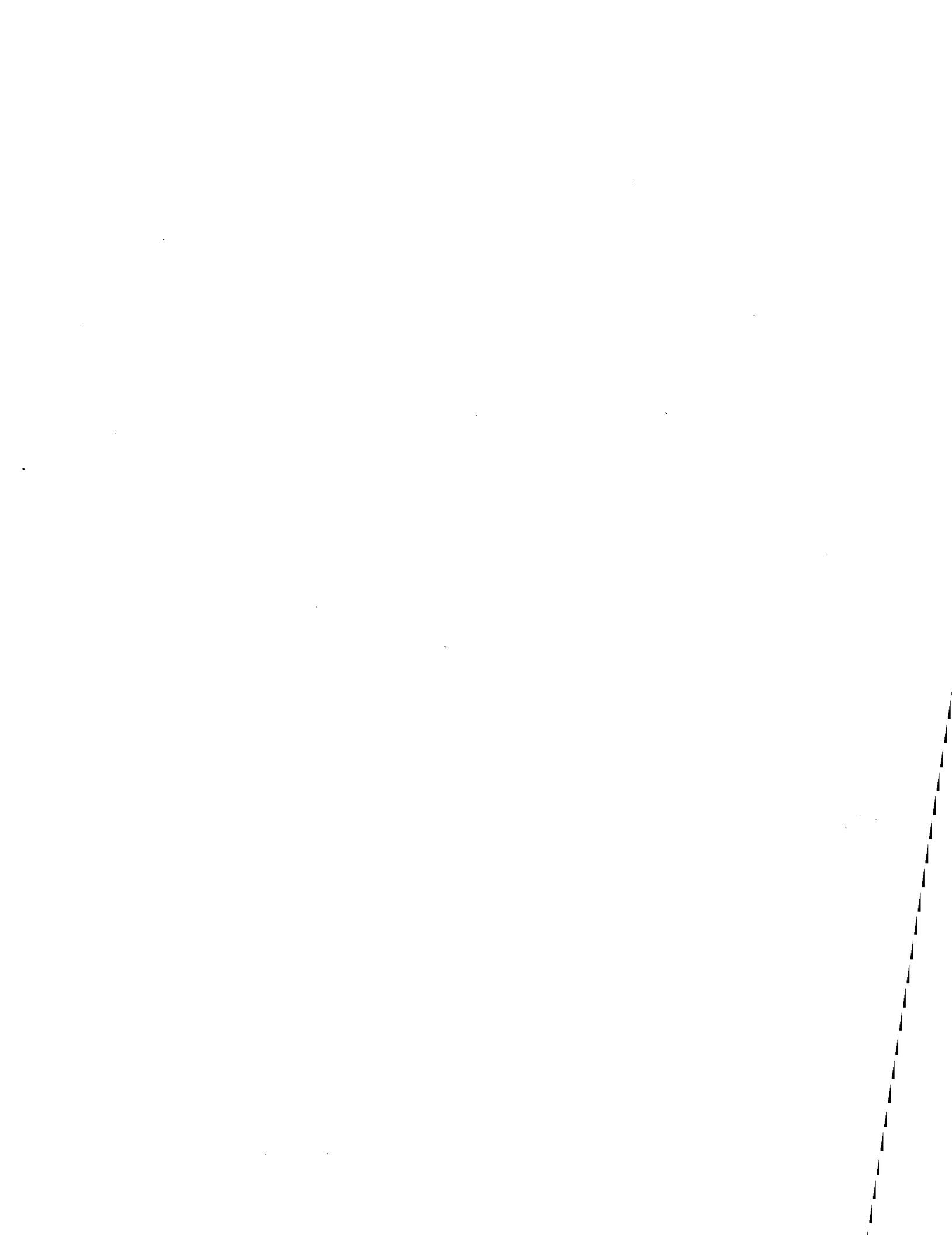
This is a final version of this document.

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1. Introduction

The Trans-Texas Water Program (TTWP) Southeast Area Phase I Report identified seven water management alternatives for possible inclusion in its final TTWP Southeast Area Water Management Plan. This current memorandum analyzes the viability of implementing one of these alternatives, desalination of brackish groundwater.

Over the past 40 years, the use of desalination technology to produce potable water has developed from an idea to a major industry. Total global desalting capacity at the end of 1989 exceeded about 3.5 billion gallons of freshwater per day produced from over 7,500 facilities. Of this total, more than one-quarter of all capacity is in Saudi Arabia, followed by 12% in the United States, 10.5% in Kuwait, and 10% in the United Arab Emirates. While desalination provides a substantial part of the water supply in certain oil-rich Middle Eastern nations, desalination provides just one one-thousandth of total world freshwater use.

The U.S. federal government has taken up the cause of desalination. The Water Desalination Act of 1994 authorizes $5 million for desalination research for fiscal 1995 and another $10 million per year for five years. An additional $50 million has been allotted to carry out demonstration and development efforts on a 50 percent cost-sharing basis with local and regional water agencies. These projects will be the first major government sponsored efforts since the U.S. Department of the Interior closed its Office of Saline Water in the late 1970s, essentially abandoning desalination research.

The Phase I Study concluded that desalination is feasible only if the required future water demand cannot be met by other, more conventional water supply methods. High capital costs, high energy requirements, high costs of operation and maintenance and brine disposal costs result in desalting production costs several times higher than other conventional water supply sources. The Phase I Report however, did not specifically evaluate the concept of desalination of brackish groundwater. Studies performed by others for the Texas Water Development Board suggest that this specific desalination source water method may have merit and deserves review.

This Desalination memorandum therefore analyzes this concept in relation to the overall TTWP Southeast Area water management program. This Desalination Memorandum is structured to discuss the following:

- Desalination Processes
- Desalination Strategy
- Environmental Impacts
- Desalination Costs
- Water Supply and Availability
- Conclusion

The U.S. Office of Technology Assessment, in a 1985 Background Paper on Desalination Technologies, defined desalination as "processes used to remove salt and other dissolved minerals from water." Other contaminants in water (e.g., dissolved metals, bacteria, and organics) may also be removed by some desalination processes.

The selection of the most appropriate desalination technology depends on the composition of the feed water (prior to desalination) and the desired quality of the product water. The following definitions are useful in evaluating desalting processes:

Freshwater - water with levels of dissolved salts and other minerals that are low enough (typically less than 1,000 ppm) to make desalination unnecessary for most uses. However, depending on its quality, freshwater may require treatment in some way prior to use.

Potable water - water suitable for drinking that generally has less than 500 ppm of dissolved minerals (including salt).

Seawater - water that is withdrawn from the ocean (with about 35,000 ppm salt and dissolved solids).

Brackish water - water containing significant levels (i.e., greater than 1,000 ppm) of salt and/or dissolved solids, but less than that found in seawater (35,000 ppm dissolved solids).

Moderately brackish water - water containing between 3,000 ppm and 10,000 ppm dissolved solids that usually requires desalination prior to use.

Highly brackish water - water containing between 10,000 ppm and 35,000 ppm dissolved solids that would probably require a level of treatment comparable to seawater.

Brine - salty wastewater that is produced by desalination operations and that requires disposal. Salt concentrations in brine can exceed 50,000 ppm.

There are essentially four types of desalination process categories:

- thermal
- mechanical
- chemical
- hybrid

Within each category are specific process types that have associated advantages and disadvantages in terms of operability, energy usage and pre- and post-treatment requirements. This discussion will provide an overview of each of the processes but focus on those processes that are best suitable for the treatment of brackish groundwater. A brief discussion of each process type is presented below.

2.1 Thermal Processes

Thermal processes remove pure water, in the form of water vapor, from feed water. Salt and mineral-free water can be separated from seawater by vaporizing some of the water from the salt solution and then condensing the water vapor on a

cooler surface. Vaporization is accomplished by heating the brine to its boiling point. To maximize the efficiency of the distillation process, the heat given up during condensation is used to heat the incoming feed water or to reheat the unvaporized brine.

Distillation plants typically have high capital costs since plant designs are quite complicated. To withstand exposure to high temperatures, corrosive brines and chemicals, high-cost metals such as titanium and copper-nickel alloys, are typically used. Operating a distillation plant requires highly skilled workers, continuous monitoring of plant operations, and maintenance every four months. Otherwise, major and very costly breakdowns can occur.

Two major processes are currently used to distill water on a commercial scale. Multi-stage flash (MSF) distillation and multiple-effect (ME) evaporation involve boiling the brine in adjacent chambers at successively lower vapor pressures. Since reducing the vapor pressure is less costly than adding heat to the brine, commercial distillation processes usually include boiling the brine at successively lower vapor pressures without adding heat.

Multi-stage flash distillation delivers high quality freshwater with a salt concentration of only 10 ppm. Typical MSF systems consist of many evaporation chambers arranged in series, each with successively lower pressures and temperatures that cause sudden (flash) evaporation of the feed water, followed by condensation on tubes in the upper portion of each chamber. A typical MSF plant may have 20 to 50 stages. Technological advances in distillation have made the MSF process obsolete.

Multiple-effect (ME) evaporation is a much more efficient technology to recapture heat when steam is condensed. A multiple-effect evaporator does not consume heat -- it reduces it from a high temperature to a lower temperature. The incoming heat is used over and over to convert seawater into freshwater, and is slightly degraded to a lower temperature each time.

ME reuses the heat of vaporization by placing evaporators and condensers in series and is based on the principle that vapor produced by evaporation can be condensed in a way that uses the heat of vaporization to heat brine at a lower temperature and pressure in the following chamber.

About 3.5% of desalinated water in the world is produced by ME. The low-temperature, horizontal aluminum tubed ME concept is marketed principally by Israel Desalination Engineering. They have placed in operation about a dozen moderate-sized plants over the last 15 years, mostly in the Caribbean. Sidam (French) also markets the ME concept but prefers to use more conservative materials such as titanium and copper-nickel alloys.

A third process, solar distillation, typically occurs inside a glass enclosure, similar to a greenhouse, where water vapor rising from sun-heated feed water condenses on the cooler inside surfaces of the glass. The droplets of distilled water that run down the glass are collected in troughs along the lower edges of the glass.

Such technology is appropriate in Third World countries where large expanses of

land are readily available, saltwater and brackish water are available and a minimum of mechanical equipment is preferred. Of the total stream of water passing through the system, 12 to 15 percent is made into potable water.

The largest solar desalination plant in operation by the end of 1991 was a 0.15 million gallons per day (mgd) system in Libya, designed to be powered by wind turbines. The small scale and inefficiency of solar distillation units makes them impractical for the large potable water demands projected within the TTWP.

2.2 Mechanical Processes

Mechanical processes are designed to separate dissolved salts and minerals from water. These processes include:

- vapor compression
- freeze distillation
- reverse osmosis
- electrodialysis

With vapor compression (VC), water vapor from salty feed water is collected and compressed thereby condensing the vapor. The heat for evaporating the saline feed water comes from the compression of vapor rather than the direct exchange of heat from steam produced in a boiler. In VC units, the heat given off during condensation is transferred back to the feed water to enhance its evaporation. In this process, the major energy input is provided by the compressor, which not only compresses the vapor, but also reduces the vapor pressure in the vaporization chamber.

VC units account for about 2 percent of the world's capacity with unit sizes generally being less than 0.1 mgd. These units

are typically diesel-powered and may be used on ships, offshore oil rigs, at remote construction sites, and at hotels in water-limited regions of the world. Again, due to the small scale of these units, they appear impractical for use within the TTWP.

Freeze desalination was developed on a small commercial scale in the late 1960s. When saltwater freezes, the ice crystallizes from pure water leaving the dissolved salts and other minerals in pockets of higher salinity brine. Freeze desalination has the potential to concentrate a wider variety of waste to higher concentrations with less energy than any distillation process. Significant operational problems, however, limit the practicality of this process, and it has generally fallen out of use.

In Reverse Osmosis (RO), saltwater on one side of a semi-permeable membrane is subjected to pressures of 200 to 500 lb./sq.in. for brackish water, and 800 to 1,200 lb./sq.in for seawater. Pure water will diffuse through the membrane, leaving behind a more salty concentrate containing most of the dissolved organic and inorganic contaminants. Brackish water RO plants typically recover 50 to 80 percent of the feed water, with 90 to 98 percent salt rejection. For seawater, recovery rates vary from 20 to 40 percent, with 90 to 98 percent salt rejection.

RO membranes are manufactured in the form of hollow, hair-like fibers; or several alternating layers of flat-sheet membranes and open "spacer" fabric which is rolled into a spiral configuration. Membrane selection depends largely on feed water characteristics and membrane costs.

At the beginning of 1992, the largest RO plant in the world was located at Yuma,

Arizona, to desalt the irrigation return flow from 74,100 acres of farmland in the southwestern United States. This plant was designed and constructed specifically to fulfill water quality obligations under an international treaty between the United States and Mexico on the Colorado River, and has a capacity of about 70 mgd.

In electrodialysis (ED), brackish water is pumped at low pressures between several hundred flat, parallel, ion-permeable membranes that are assembled in a stack. Membranes that allow cations to pass through them are alternated with anion permeable membranes. A direct electrical current is established across the stack by electrodes positioned at both ends of the stack. This electric current "pulls" the ions through the membranes and concentrates them between each alternate pair of membranes. Partially desalted water is left between each adjacent set of membrane pairs. Typical freshwater recovery rates for ED range from 80 to 90 percent of the feed water volume.

Scaling or fouling of the membranes, the most common problem encountered with ED, is prevented by operationally reversing the direction of the electrical current. This process is called electrodialysis reversal (EDR) and is an automatic, self-cleaning process. Reversing the flow of ions through the membranes results in the spaces collecting concentrated brine to begin collecting less salty product water. Alternating valves in the water collection system automatically direct the flow in the proper direction depending on the direction of the current. Typical freshwater recovery rates for EDR range from 80 percent to 90 percent of the feed-water volume.

A typical ED plant can range in size from 0.05 to 0.5 mgd. The largest installation is an 8 mgd plant in Iraq. One American company, Ionics, Inc., continues to dominate the market for ED units throughout the world.

2.3 Chemical Processes

Ion exchange (IX), uses resins to exchange undesirable ions in the feed water for desirable ions. For example, cation exchange resins are typically used in homes and municipal water treatment plants to remove calcium and magnesium ions in "hard" water, and by industries in the production of ultrapure water. The higher the concentration of dissolved solids in the feed water, the more often the resins will need to be replaced or regenerated. With rising costs for resins and for disposing of regeneration solutions, IX is competitive with RO and ED only in treating relatively dilute solutions containing a few hundred ppm of dissolved solids. Brackish groundwater concentrations will tend to exceed the treatment capabilities of this process.

2.4 Hybrid Processes

Continuing research in desalination technologies have resulted in the development of hybrid processes that combine the features of two or more processes.

A research project in El Paso, Texas, features a 24-stage MSF distillation unit powered by a 0.83 acre solar pond. The desalination unit is designed to produce 5,000 gallons per day (19 m³/d) of freshwater from brackish groundwater. The El Paso Solar Pond has been operating as a research, development and demonstration project for ten years. Another example of a solar-powered MSF distillation plant

was installed in La Paz, Mexico, as a joint venture between the Mexican company Digaases, the German company Doonier GmbH, and the Federal Republic of Germany. The system has a 10-stage MSF distillation unit and is designed to produce 2,640 gal/d of freshwater. A solar-assisted ME desalting system is currently under design in Kuwait, one of the largest producers of desalted water in the world.

The most common type of solar-powered desalination uses RO, in which photovoltaic cells regenerate electricity for driving high pressure pumps. In North America, solar powered-RO units have been designed or built in Vancouver, British Columbia; Concepciòn del Oro, Mexico; and at the Florida Solar Energy Center. In the United States, a significant amount of solar energy water desalination work has been conducted by the Soleras project under the auspices of the United States-Saudi Arabian Joint Commission on Economic Cooperation.

Due to significant recent developments in the production of medium to large (approximately 50-500 kW) wind turbines, wind-generated electricity can also be used to power several types and designs of desalination plants. One of the first desalination projects to design a wind-powered desalination system was carried out under a joint program between Digaases and the German companies AEG-Telefunken and GKSS. This study was based on the use of a 6 kW wind turbine combined with modular RO units. The combined system was designed to produce about 1,600 gal/d.

The most promising research using renewable energy was the Soleras project described earlier which yielded the design of hybrid solar systems that included both solar thermal and wind energy inputs to a large-scale RO desalination plant. Such systems were found to have particular advantages due to the complementary aspects of the two energy resources.

2.5 Desalination Applications

By the beginning of 1990, worldwide desalination capacity exceeded 3 billion gallons of freshwater per day produced by over 7,500 desalination plants (excluding shipboard units). Nearly two-thirds of this capacity uses the multi-stage flash distillation process; much of the remainder uses reverse osmosis. More than half of all reverse osmosis plants are in the United States, Saudi Arabia, and Japan. Electrodialysis, vapor-compression, and multiple effect evaporation each produce less than 264 million gallons per day.

The majority of distillation plants are installed in Saudi Arabia, Kuwait and the United Arab Emirates; most reverse osmosis plants and vapor compression plants are in the United States. The trend over the last decade shows a steady shift toward the construction of reverse osmosis facilities. Sixty-five percent of all desalination capacity is used to treat seawater and nearly 27 percent to treat brackish water.

The United States ranks second in the world in the number of desalination plants, but ranks fourth in capacity with approximately 10 percent of world production. Between 70 and 80 percent of this capacity is provided by reverse osmosis plants located in 44 states. About 70 percent of the desalination plants in this country are used for industrial purposes. There are also more small RO units (i.e., producing less than 25,000 gpd) than

large plants in the United States, but their combined capacity is relatively low. These units are used by hospitals, small industries, pleasure boats, merchant ships, off-shore drilling rigs, and the military.

2.6 Brackish Water Desalting

Selection of the most appropriate desalination technology depends on several site-specific factors including:

- concentrations of organic and inorganic material in the feed water

- the desired quality of the finished water

- the method of brine disposal.

Table 1: Potable Water Production, summarizes typical applications for desalinating technologies based on the salt content of the feed water.

Reverse osmosis and electrodialysis are generally the most economical processes for desalinating brackish water with salinities of less than 10,000 ppm. There are approximately 750 membrane process plants in the United States with a combined capacity of >200 mgd, producing desalted water for industry and, to a lesser extent, potable water. By 1986, in Florida

alone there were about 100 RO plants with a total capacity of approximately 40 mgd that were being used for public water supply.

In 1993, the Texas Water Development Board funded the investigation of geo-pressured/geothermal water resources in the Lower Rio Grande Valley. The purpose of this study was to investigate the existence of reservoirs of hot, pressurized saline water beneath Cameron, Hidalgo and Willacy counties and assess the development potential. The results of this research indicate that desalination of this brackish groundwater using geothermal heat as the energy source is feasible provided brine disposal cost can be eliminated by the sale of marketable by-products. Much more research is needed to verify valid, reliable cost estimates at any specific location.

Also in 1993, the Sweetwater Authority in Chula Vista, California, conducted a feasibility study on desalting brackish groundwater as a supplemental source of supply that would allow the Authority to be less dependent on imported water. Using reverse osmosis, the unit cost of treated groundwater was projected to be low enough to make a project economi-

Table 1: Potable Water Production

Process	Slightly Brackish Water (1,000-3,000 ppm)	Moderately Brackish Water (3,000-10,000 ppm)	Highly Brackish Water (10,000-35,000 ppm)
Distillation	N.E.	S	P
Electrodialysis	P	S	N.E.
Reverse Osmosis	P	P	P
Ion Exchange	P	-	-

Key: P = *Primary application*
S = *Secondary application*
N.E. = *Technically possible, but not economical*

Source: *Office of Technology Assessment, 1987*

Table 2: Brine Generation by Process

Process	Percent Recovery of Feed Water	Percent Disposal as Brine
Brackish Water RO	70 to 80	20 to 30
Seawater RO	20 to 40	60 to 90
Electrodialysis	80 to 90	10 to 20
Distillation	25 to 65	5 to 75

Source: Office of Technology Assessment, 1987

cally viable in 2-3 years. Brine disposal will be to brackish coastal wetlands to provide opportunities for mitigation of project environmental impacts.

For potable water purposes, taste considerations determine the salt content allowable for finished water quality purposes. As shown previously, according to Safe Drinking Water Act criteria, potable water can have a maximum concentration of approximately 500 ppm of TDS. In general, consumers can readily taste a TDS concentration above 500 ppm. In the Houston region, groundwater from the Chicot and Evangeline aquifers and untreated surface water maintain typical TDS concentrations of 250 ppm while chloride concentration is typically in the range of 35 ppm.

The main impediment to routine use of desalting is finding suitable methods for disposal of the brine produced as part of every desalting process. The brine carries away the salts and other substances removed from feed water. The characteristics of the brine will vary depending on the process and feed water used.

The fraction of feed water that becomes brine concentrate depends on the desalination process used and the feed water composition. The greater the percentage of feed water recovered, the smaller the amount of brine that must be disposed of, but the higher the concentration of salt and other dissolved chemicals. The composition of the waste concentrate generally makes it unsuitable for most subsequent industrial, municipal, or agricultural uses.

Because of its high salt content, brine disposal cannot easily occur without affecting local groundwater, waterways, or lands. Disposal methods include discharge to freshwater streams or lakes, the ocean, and saline aquifers (by injection wells); irrigation; and dilution in domestic wastewater systems. It can present a major difficulty in inland areas and the costs associated with disposal can be very high.

Table 2: Brine Generation by Process, summarizes brine characteristics for typical desalination processes.

3. TTWP Desalination Strategy

The proposed brackish groundwater desalination water management strategy is based on a review of several conclusions outlined within the TTWP Planning Information Update report. These conclusions are related to:

- location of greatest supply need

- timing of need for additional supply

Additional assumptions shaped this strategy including:

- required desalting plant capacity

- brackish groundwater source potential

The following sections will discuss each of these subjects.

3.1 Location, Schedule, and Quantity of Need

The Planning Information Update report concluded that:

- The eight county Houston Metro Region has the greatest demand shortfall within the entire TTWP Southeast Area region. Additional supply is principally needed within the Brazos and San Jacinto watersheds, particularly within Fort Bend, Harris and Montgomery counties.

- The Houston region coastal areas, Trinity-San Jacinto basin (Cedar Bayou area) and the San Jacinto-Brazos basin (southern Harris, Galveston and Brazoria counties) also will need smaller amounts of additional supply.

- Additional supply within Fort Bend county is needed by approximately year 2020, while Harris and Montgomery counties will require additional supply by approximately 2030. The coastal basins will need additional supplies by approximately year 2040.

- Through year 2050, the following amount of demand needs are projected to exist in each basin:

Trinity-San Jacinto	25,400 afy
San Jacinto	186,000 afy
San Jacinto-Brazos	44,600 afy
Brazos	162,100 afy

(afy = acre-feet per year)

Based on these conclusions, the desalination strategy should be configured to address any or all of these areas of future need. Additionally, based on the availability of existing supplies, it appears that the potential implementation schedule of a desalination project should vary based on the location of the facility. The earliest date that a desalting facility might be implemented is in year 2020 in the Fort Bend county region. If configured to exist in the coastal basin of southern Harris, Galveston or Brazoria counties, a desalting project would not be needed until approximately year 2040.

The only existing desalting plants in the U.S. that have capacities of over 23 mgd (25,400 afy) have utilized the reverse osmosis treatment process. For this study, the RO process will therefore be used for study purposes.

In terms of desalting facility capacity, while it is technically feasible to construct desalting facilities of sufficient capacity to meet the above stated demand needs, it should be noted that even a 25,400 afy (~23 mgd) desalting facility is outside the norm of presently existing facility capacities throughout the world. As previously stated, the largest RO facility in the world is the Yuma Arizona plant at approximately 70 mgd. This facility is not currently in use due to the availability of an alternative supply at a lower cost. The excessive capital, operations and maintenance costs have priced the supply from the Yuma plant above all other current supply alternatives. The typical RO desalting plant is less than 10 mgd in capacity.

3.2   Brackish Groundwater Sources

The location and extent of brackish groundwater will also define the location, capacity and configuration of the proposed desalting facility.

A study of hydro-geologic data in the Houston Gulf Coast region shows that brackish groundwater exists at depths of approximately 3,000 feet and lower beneath the ground surface. The Chicot aquifer exists within 10 feet of the ground surface. Freshwater contained within the Chicot and Evangeline aquifers typically range in depth from near the ground surface to approximately 2,800 feet below ground. Notably, no significant locations of brackish groundwater exist in the Houston region near the ground surface.

Brackish groundwater strata exist below the Chicot and Evangeline freshwater bearing sand strata. These freshwater sands are the common groundwater supply sources in the Houston metropolitan region. Brackish groundwater exists within the lowest section of the Evangeline aquifer and within the Jasper aquifer which is separated from the Evangeline aquifer by the Burkeville aquiclude. The Burkeville unit, which is approximately 200 to 400 feet in thickness, consists of compressible clay strata which confines and separates the Evangeline from the Jasper aquifers.

Aquifer formations in the Houston Gulf Coast region move down dip from the northwest towards the coast. This means that the aquifer sand strata tend to increase in thickness as the aquifer moves from the northern regions toward the coast. Sands nearer the coast, therefore, have the ability to transmit larger volumes of water; however, because of the larger sand thickness, this water exists further beneath the ground surface. Conductivity, and therefore aquifer yield, also trends from higher volumes near the coast to lesser amounts as you move inland. Also, sand strata generally become more fine within the lower Evangeline and Jasper units from inland areas to the coast resulting in lower aquifer yields from north to south.

In terms of water quality, salinity increases with depth within the Evangeline and Jasper aquifers. Salt constituents, including Chlorides and Total Dissolved Solids (TDS), are in higher concentrations near the coast. Concentrations of salt chemicals decrease as you move north from the coast. Well log data indicate that the TDS and Chloride concentrations within the lower Evangeline and Jasper units are approximately 10,000 ppm near the coast and reduce to approximately

1,000 ppm TDS by the middle of Harris county.

Were brackish groundwater to be pumped from the lower Evangeline aquifer, the potential risk for increased subsidence is great, especially in the quantities needed for the TTWP. It is unlikely that the Harris-Galveston Coastal Subsidence District (HGCSD) would issue permits for any type of groundwater well that could potentially contribute to land subsidence. For this reason, this study assumes that the Jasper aquifer is the only potential location that may not contribute to subsidence.

No existing potable groundwater wells have been drilled in the Jasper unit to depths in excess of 3,000 feet in Harris and Galveston counties. Well data have been compiled of Evangeline freshwater wells and Jasper aquifer waste reject injection wells. Data suggest that a significant quantity of brackish groundwater is potentially in existence within the Jasper. The water quality however, appears to limit the potential location of a brackish groundwater wellfield. Within the Houston region, it appears that only near southern Harris county is it possible to achieve a balance of reasonable brackish groundwater withdrawal rates and associated minimum concentrations of TDS and chlorides. Preliminary review of well data suggest that each brackish water well may provide approximately 750 to 1000 gpm with an associated chloride concentration of approximately 1,300 ppm. The TDS concentration of these waters is approximately 2,300 ppm. The data suggest that well capacity substantially decreases as aquifer quality improves within the middle and northern sections of Harris county. The Jasper aquifer has a very

steep down dip gradient throughout Harris county.

3.3 Desalination Facility Design

Based on the characteristics of the brackish groundwater aquifers in the Houston region, the only potential location for implementing a desalination strategy is within the San Jacinto-Brazos basin near the Houston Ship Channel. A desalting plant sized to meet the San Jacinto-Brazos basin demand is proposed for study. The desalting plant will be sized to deliver 44,600 afy (40 mgd) to southeastern Harris and northern Galveston counties. Construction of this facility would begin in approximately year 2038 to come online to meet demand shortfalls in year 2040.

In an effort to minimize costs associated with this strategy, the desalination plant is assumed to be sited to deliver water directly into a city's distribution system and also situated to discharge brine concentrate directly into the Houston Ship Channel. This location would require the least capital cost in terms of potable water transmission mains and waste concentrate discharge facilities.

A total of thirty-one (31) separate 1,000 gpm (1.4 mgd) brackish groundwater wells would be needed to supply average daily demands of 40 mgd. A relatively significantly sized well field including well collection mains would be necessary to develop 31 wells. A minimum well spacing of 1,500 feet is assumed for this study.

The following preliminary design parameters are used for the 40 mgd RO desalting plant:

- Influent TDS   2,300 ppm

- Influent Chlorides   1,300 ppm
- Finished Water TDS   250 ppm
- Finished Water Chlorides   35 ppm
- Feed Water Recovery Rate   85%
- Membrane Salt Rejection   98%

Figure 1 shows the process flow diagram

water) TDS concentration is 59 ppm and the Chlorides concentration is 34 ppm. The brine concentrate TDS concentration is approximately 15,300 ppm, which is highly brackish water. Approximately, 300 tons per day of concentrate salt waste would be produced.
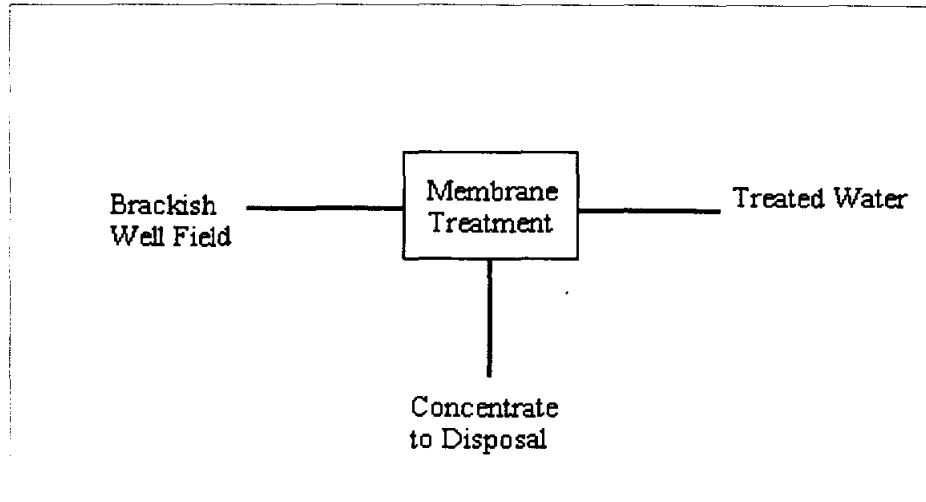
Parameter Being Investigated   **TDS**

Reverse Osmosis	Flow (MGD)	Concentration (mg/l)		
Total Influent (Groundwater Supply)	**47.0**	**2340**		
Membrane Actual Influent	47.0	2340		
Membrane Concentrate	7.1	15269	98%	Removal by Membrane
Membrane Permeate	40.0	59	85%	of Membrane Influent as Permeate
Treated Water to System	40.0	59	44840	Treated Water Required, Ac ft/yr
Waste Solids Production	4.7	15269	300	TPD Concentrate Waste to Disposal
(of concentrate)(on avg. daily basis)				Tons (Dry weight basis)

Figure 1: Desalination Analysis - Mass Flow Diagram

for the proposed desalting plant. As shown, the computed permeate (finished

4. Environmental Impacts

The potential environmental effects of constructing a brackish groundwater desalination facility adjacent to the Houston Ship Channel are related principally to aquatic species impacts resulting from discharge of the waste brine concentrate and the potential for land subsidence resulting from additional groundwater pumpage.

4.1 Brine Concentrate Impacts

The approximate location of the waste concentrate discharge would be to designated Stream Segment No. 1006-"Houston Ship Channel." This segment consists of the Houston Ship Channel from its confluence with the San Jacinto River upstream to just upstream of Greens Bayou. This stream segment is designated for two use types: Industrial Water Supply and Navigation. Currently, Segment No. 1006 maintains a stream classification as "Water Quality Limited" which requires that wastewater discharges use advanced wastewater treatment processes. Texas Clean Rivers Program data indicate that historically, there has been some concern regarding heavy metals and dioxin in this segment. Segment No. 1006 water uses and stream standard criteria however are generally being attained.

This stream segment is a sluggish, tidally influenced bayou. The water column consists of a pronounced stagnant salt wedge under a flowing freshwater layer.

The discharge of a salt concentrate is classified as an industrial waste. It is regulated as part of the NPDES permitting program by the U.S. Environmental Protection Agency (EPA) and the Texas Natural Resource Conservation Commission (TNRCC). The discharge is subject to the provisions of Section 403c of the Clean Water Act (Ocean Discharge Criteria) and must comply with the Texas Water Quality Criteria for Marine Discharges.

The brine concentrate would have an approximate concentration of 15,300 ppm of TDS. Brine concentrate primarily consists of dissolved solids and heavy metals. Dissolved solids and metals are conservative water pollutants and, as such do not degrade into other substances once discharged into the water column. Stream Segment No. 1006 however has a salt concentration within its lower salt wedge equivalent to seawater (35,000 ppm). Impacts into the receiving stream would depend upon many factors including the season of the year, and the location and depth at which the brine concentrate is discharged. A determination of potential environmental impacts will require further analysis. The concentrations of heavy metals may however produce a negative impact into Segment No. 1006. Because of the historical concern for elevated metals, additional metal concentrations may potentially produce unacceptable mass loads. Should this strategy be pursued further, the potential for negative impacts from heavy metals should be studied in more detail.

4.2 Land Subsidence Impacts

The southeastern region of Harris county has experienced a substantial degree of

historical subsidence. Records indicate that from 1906 through 1995, in excess of nine (9) feet of ground subsidence has occurred. The impacts of this level of subsidence have included:

- additional damages from flooding

- increased faulting activity

- damages to building structures

- impacts to historical landmarks

Notably in the Houston Ship Channel area near Greens Bayou, the San Jacinto Monument has suffered the impacts of subsidence. Currently, some of the monument park land is under water as a result of subsidence.

The Harris-Galveston Coastal Subsidence District has groundwater regulatory powers within Harris and Galveston counties. Groundwater withdrawals are regulated through "use permits" evaluated by the HGCSD. The HGCSD has reported that by year 2030 an additional quantity of ground subsidence of one to two feet will occur in the Houston Ship Channel

area if groundwater pumpage is substantially increased from year 1998 levels.

The proposed desalination strategy was configured to draw brackish groundwater from the Jasper aquifer so as to eliminate the direct impacts associated with obtaining water from the Evangeline aquifer. While the potential for subsidence is lessened from use of Jasper waters, no definitive conclusion can be drawn based on existing data. There remains a potential for further land subsidence if the compressible clays within the Burkeville acquiclude suffer compaction from a combination of water withdrawal and the weight of overburden at the 3,000 foot depth. These potential impacts associated with land subsidence could cause the HGCSD to prohibit withdrawal permits of brackish groundwater. More detailed hydrogeologic analysis would be required if this strategy is to be pursued.

5. Desalination Costs

This section discusses the general cost of developing desalination projects and the specific cost of implementing the configured TTWP Southeast Area brackish groundwater desalination strategy. Review of both of these sets of data should present a complete overview of the potential for any type of desalination project development within the Houston Gulf Coast region.

5.1 General Cost Overview

Table 3 summarizes desalination costs in the United States for various processes. The cost range is taken from data published by the Office of Technology Assessment (1987) and represents a range of plant size from 1 to 25 mgd. The cost data in Table 3 should be used for comparative purposes only.

A preliminary design report published by Metropolitan Water District of Southern California (MWD) in October 1993 concluded that total treated water cost (capital recovery and operation) at a full-size (75 mgd) plant using the ME process coupled with the re-powering of a coastal power plant would be approximately $600 per acre-foot (about $1.84 per 1,000 gallons). Waste heat from the coastal power plant is proposed to power the desalination plants. This scheme significantly reduces the ME process operations cost. This price does not include delivery costs to the MWD system since these costs would depend on the site chosen.

The Office of Technology Assessment reports that the capital and operating costs for brackish water desalting tend to be very high for small-capacity plants (several hundred thousand gpd); however, costs decrease significantly as plant capacities increase to 3 mgd. Beyond 3 mgd, overall costs decrease only slightly with increasing plant size. For example, projected water production costs (per gallon) of a 100-mgd RO plant are only 10 percent less than production costs of a 10-mgd plant. The principal cost component for expansion of an RO facility is the additional membranes required. Membrane per unit costs are fixed with little economy of scale associated with addition of more units.

Table 3: Desalination Capital Costs in the United States

Process	*Unit Capital Cost ($/1,000 Gal.)*	
Brackish Water		
Reverse osmosis	1.20	- 1.70
Electrodialysis	1.20	- 1.70
Seawater		
Multi-stage flash distillation	6.10	- 9.70
Multiple-effect evaporation	5.40	- 8.30
Reverse osmosis	6.00	- 13.40

Source: Office of Technology Assessment, 1987

Desalinating seawater - using either distillation or RO - can be from three to as much as seven times more expensive than brackish water RO or ED. Distillation costs are high, regardless of the salt content, due to the large amounts of energy required to vaporize water; RO and ED costs are higher for seawater because more salt must be extracted.

Membrane processes (RO, ED) are becoming more competitive as membranes are being produced that require less feed pressure and have improved contaminant removal rates and increased stability. In the United States, the current unit membrane desalting equipment costs for brackish water systems in the 1 to 10 mgd range are reported to be $0.60 to $1.25/ 1000 gal.

General observations about desalination costs can be made:

- The cost of treating seawater is significantly higher than the cost of treating brackish groundwater.

- In addition to the treatment process cost, an additional cost must be included associated with concentrate disposal. Disposal costs can in some cases equal or exceed the treatment process capital cost.

- Historically, desalination costs have decreased markedly. This trend is the result of improvements in plant designs, fabrication techniques, heat exchange materials, scale control techniques, and plant automation.

- The costs of membrane processes should continue decreasing with improved membrane plant performance (i.e., decreased water pressure requirements, increased rejection of salt,

longer operating lifetimes, improved energy recovery, and plant automation), and improved economics associated with larger scale production of membranes.

- When comparing the costs of desalination with the costs of conventional supplies (surface water, groundwater), it is important to recognize that desalination plants typically have an operating life of 15 to 20 years. Reservoirs, water treatment plants and other conventional water production facilities have service lives of 30 to 40 years, and sometimes longer.

5.2 Brackish Groundwater Desalination Cost

Table 4 shows the total cost of implementing a brackish groundwater desalination strategy for the TTWP Southeast Area. The total construction cost is estimated as approximately $ 151 million with an associated annual operations and maintenance cost of approximately $ 11 million. The annual average water cost is approximately $1,270 per acre-foot.

A life cycle cost analysis was performed to illustrate the present worth cost of this strategy. The following financial factors were used in the life cycle cost analysis:

- Capital costs were assumed to be financed over 30 years at an interest rate of 8.5 percent per year.

- The discount rate was set at 4.5 percent.

- The inflation rate was set at 4.5 percent.

Table 5 shows that the total present worth cost of the desalination strategy ranges from $1.73 per thousand gallons in the

first year of operation to $1.03 per thousand gallons in the last year.

Table 5 assumes operation of the desalting facility in year 2005. This period was used to equitably compare the total cost of this strategy to the other TTWP water resources strategies. In fact, the desalting facility would not be put in operation until approximately year 2040. A desalting facility constructed in year 2040 would have a significantly higher capital, and operation and maintenance cost than is shown in Table 5. Projecting unit cost values inflated to year 2040 for this strategy would show very large capital costs which would appear excessive in comparison to the other TTWP water strategies. The computed present value cost, shown in Table 5, represents the approximate present worth cost to begin opera

tion of the desalting facility in year 2040. The present value cost can be used to compare this strategy to other TTWP strategies.

The projected operation and maintenance (O&M) cost shown in Table 5 assume operation of the RO facility at a constant daily production rate. This assumption is a simplistic representation of the actual operation of the facility used to allow a comparison of RO with other TTWP water strategies. In reality, RO treatment facilities have high maintenance requirements and therefore are subject to operation production below the facility's design flow capacity. The relatively high maintenance requirements and subsequent impact on production and cost are additional issues to be considered when assessing the potential use of this strategy.

Table 4: Brackish Groundwater Strategy Costs

RO Plant Specifications

	Design Flow
Membrane Influent	47
Permeate Flow Rate (MGD)	40
Membrane Flux (GFD)	14.9
Membrane Element Area (SF) ea.	330
Quantity of Membrane Elements	5248
Quantity of 20:12:6:3 Arrays (41 tubes, 6 elements per tube)	32
Concentrate Flow Rate (MGD)	7

Brackish Groundwater Well Field: Wells and Collection System Cost Estimate

Item	Construction Cost	Annual O&M
Conveyance Line to Wells	$3,379,000	$68,000
31 X 1000gpm Wells	$85,250,000	$2,558,000
Ground Storage Tank (40mgd)	$7,600,000	$205,000
Sub-Total	$96,229,000	$2,831,000
Engineering & Contingency (25%)	$24,057,000	$708,000
Well Field Costs	**$120,286,000**	**$3,539,000**

RO Plant Cost Estimate

	Item	Construction Cost	Annual O & M
1	Feed Pumps	$3,206,000	$2,051,000
2	Cartridge Filters	$528,000	$204,000
3	Membrane Equipment	$4,828,000	$379,000
4	Membranes	$4,041,000	$1,358,000
5	Membrane Cleaning System	$200,000	$151,000
6	Piping & Valves	$562,000	$56,000
7	Chemical Feed Systems (pH adjustment, antiscalant)	$1,255,000	$1,022,000
8	Carbon Dioxide Stripper	$2,249,000	$225,000
10	Treatment Building	$2,587,000	$259,000
11	Lab, Administration, and Maintenance Building	$1,335,000	$134,000
12	Generator	$650,000	$46,000
13	Site Work & Yard Piping	$2,841,000	$85,000
	Sub-Total	$24,282,000	$5,970,000
	Engineering & Contingency (25%)	$6,071,000	$1,493,000
	Membrane Treatment Plant Cost	**$30,353,000**	**$7,463,000**

Concentrate Disposal Cost Estimate

Item	Construction Cost	Annual O&M
Discharge Line	$260,000	$5,000
Brine Pump Station	$170,000	$31,000
Sub-Total	$430,000	$36,000
Engineering & Contingency (25%)	$108,000	$9,000
Concentrate Disposal Cost	**$538,000**	**$45,000**

Grand Total Cost	**$151,177,000**	**$11,047,000**

Table 5: Life Cycle Cost Analysis

YEAR	YIELD (ac-ft / yr.)	BOND PAYMENTS ($1,000	O & M COSTS ($1,000)	TOTAL COSTS ($1,000)	UNIT COST ($/1,000 gal)	PRESENT VALUE (1995$ / 1,000 gal)
2005	44,600	$21,846	$17,156	$39,001	$2.68	$1.73
2006	44,600	$21,846	$17,928	$39,773	$2.74	$1.69
2007	44,600	$21,846	$18,734	$40,580	$2.79	$1.65
2008	44,600	$21,846	$19,577	$41,423	$2.85	$1.61
2009	44,600	$21,846	$20,458	$42,304	$2.91	$1.57
2010	44,600	$21,846	$21,379	$43,225	$2.97	$1.54
2011	44,600	$21,846	$22,341	$44,187	$3.04	$1.50
2012	44,600	$21,846	$23,346	$45,192	$3.11	$1.47
2013	44,600	$21,846	$24,397	$46,243	$3.18	$1.44
2014	44,600	$21,846	$25,495	$47,341	$3.26	$1.41
2015	44,600	$21,846	$26,642	$48,488	$3.34	$1.38
2016	44,600	$21,846	$27,841	$49,687	$3.42	$1.36
2017	44,600	$21,846	$29,094	$50,940	$3.50	$1.33
2018	44,600	$21,846	$30,403	$52,249	$3.59	$1.31
2019	44,600	$21,846	$31,771	$53,617	$3.69	$1.28
2020	44,600	$21,846	$33,201	$55,047	$3.79	$1.26
2021	44,600	$21,846	$34,695	$56,541	$3.89	$1.24
2022	44,600	$21,846	$36,256	$58,102	$4.00	$1.22
2023	44,600	$21,846	$37,888	$59,734	$4.11	$1.20
2024	44,600	$21,846	$39,593	$61,439	$4.23	$1.18
2025	44,600	$21,846	$41,375	$63,220	$4.35	$1.16
2026	44,600	$21,846	$43,236	$65,082	$4.48	$1.14
2027	44,600	$21,846	$45,182	$67,028	$4.61	$1.13
2028	44,600	$21,846	$47,215	$69,061	$4.75	$1.11
2029	44,600	$21,846	$49,340	$71,186	$4.90	$1.10
2030	44,600	$21,846	$51,560	$73,406	$5.05	$1.08
2031	44,600	$21,846	$53,880	$75,726	$5.21	$1.07
2032	44,600	$21,846	$56,305	$78,151	$5.38	$1.05
2033	44,600	$21,846	$58,839	$80,685	$5.55	$1.04
2034	44,600	$21,846	$61,486	$83,332	$5.73	$1.03
TOTAL	1,338,000	$655,374	$1,046,616	$1,701,990		
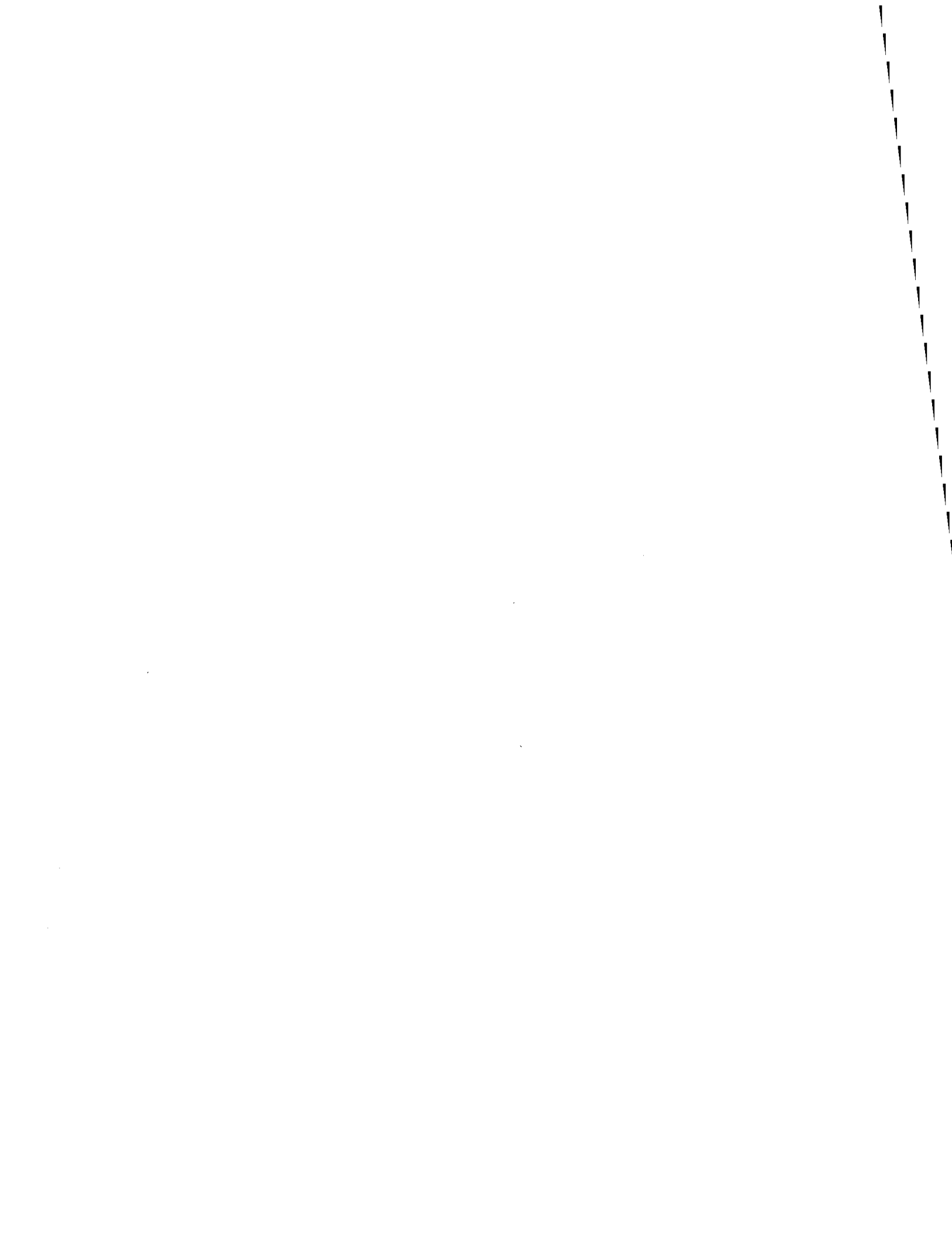
6. Water Supply and Availability

The TTWP *Planning Information Update* report determined the period of time for which existing water supplies (groundwater and surface water) within the Southeast Area can satisfy future projected water demands. This analysis was conducted for each river basin and shown in Table 12 of that report. Table 13 of that report then assessed the availability of existing Southeast Area water supplies to meet the future projected water demands for the state-wide TTWP region. These tables are included in Appendix A. Tables 12 and 13 support the following general conclusions:

- Current existing Southeast Area water supplies can meet all projected Southeast Area demands through year 2010.

- The Brazos river basin will experience the earliest water supply shortfalls within the Southeast Area by year 2020.

- The San Jacinto River basins (San Jacinto, San Jacinto-Brazos and Trinity-San Jacinto) within the Houston Metro area will experience initial water supply shortages by year 2030 and these shortfalls will become increasingly significant thereafter.

- East Texas river basins retain significant quantities of available supply through the 2050 planning period.

- The Southeast Area has sufficient existing water supplies to serve the statewide TTWP region.

The value of the brackish groundwater desalination strategy can be measured by assessing its ability to extend the length of time that existing available TTWP water supplies can serve projected demands. The brackish groundwater desalination strategy is evaluated by determining its impact on the above referenced Tables 12 and 13.

The desalination strategy will supply 44,600 afy beginning in year 2040 to the San Jacinto-Brazos basin. This strategy will therefore satisfy all of the projected water demand needs of the San Jacinto-Brazos basin through the year 2050 planning period. All other supply deficits shown in Table 12 of the Planning Information Update report will remain the same. Projected demand needs will continue to occur as early as year 2020 in the Brazos basin and total Houston Area demand needs will continue to be large (373,500 afy.)

Use of the desalination strategy will increase the entire Southeast Area's projected year 2050 water supply surplus from 670,400 afy to 715,000 afy (see Appendix A). For the entire State of Texas TTWP, under Scenario 1, the worst case scenario of a 600 mgd shortfall, after meeting all of the projected water demands, an additional 115,000 acre-feet per year would exist in year 2050 within the Southeast Area using the desalination strategy.

7. Conclusion

The key findings of the brackish groundwater desalination management strategy analysis consist of the following:

- If pursued, a desalination facility should be located within the Houston Metropolitan area since that area has the largest projected water supply deficit.

- A desalination facility is best located in the southeastern Harris County area in close proximity to the Houston Ship Channel. This location should provide the lowest strategy capital cost for both the finished water distribution and for brine concentrate disposal.

- A 40 mgd capacity brackish water desalination facility was investigated. This water supply facility would provide approximately 44,600 acre-feet per year of water to meet future regional water demands.

- The desalination strategy is limited to satisfying the water supply deficit within the San Jacinto-Brazos basin. The desalination strategy therefore can meet projected San Jacinto-Brazos basin water demands through the year 2050 study period, however even when coupled with existing regional water supplies, projected water deficits will exist within the Houston region as early as year 2020.

- The environmental impacts associated with a desalination strategy appear to be potentially significant. The additional salt concentrate disposal into the Ship Channel may cause localized aquatic environment impacts from the discharge of increased heavy metals. Potential land subsidence impacts could also eliminate this alternative, if such impacts proved real.

- The total capital cost of implementing the brackish water desalination strategy is approximately $ 151 million. This equates to a per unit water cost of approximately $1,270 per acre-foot.
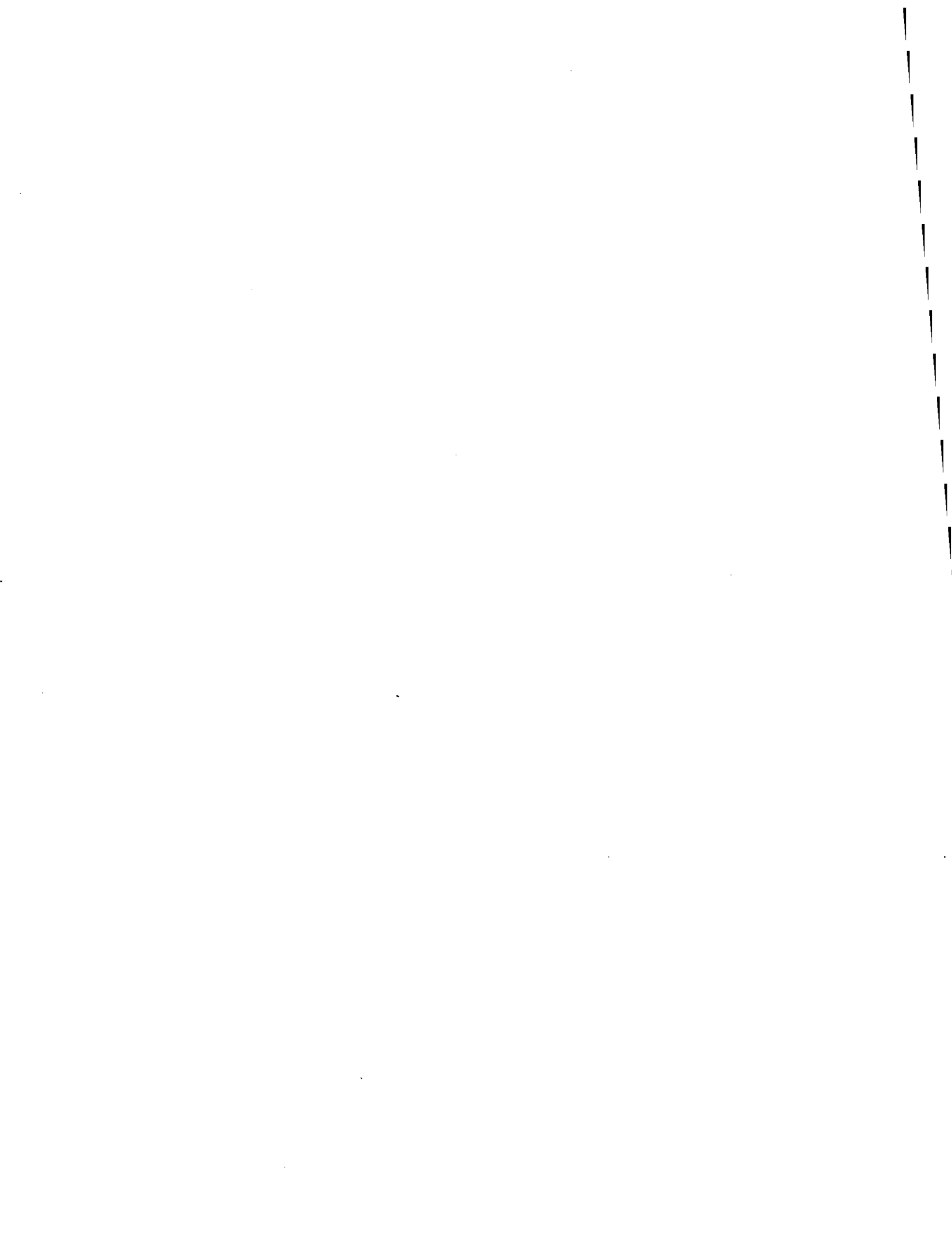
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Appendix A: Southeast Area Water Supply Availability

Table 12: Southeast Area Water Supply Availability: 2000—2050

Category	Sabine	Neches	Neches -Trinity	Trinity	Trinity- San Jacinto	San Jacinto	San Jacinto -Brazos	Brazos	Total Southeast
Amount (Thousands of Acre-Feet/Year)									
2000									
In-Basin Demands	86.0	261.4	329.9	138.5	143.2	949.7	464.2	427.3	2800.2
In-Basin Supplies									
Groundwater	23.3	110.5	7.5	34.3	26.6	451.7	74.9	130.5	859.3
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	488.2	4197.6
TOTAL	1213.7	957.4	7.5	1390.7	26.6	709.4	132.7	618.7	5056.7
Transfers									
Imported Supplies	0.9	1.4	322.4	0.0	116.6	300.3	331.5	0.0	1073.1
Export Demands	1.4	280.5	0.0	582.5	0.0	60.0	0.0	142.9	1073.1
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**844.3**	**207.8**	**0.0**	**669.7**	**0.0**	**0.0**	**0.0**	**42.7**	**1764.5**
2010									
In-Basin Demands	93.9	275.4	316.6	141.0	147.9	1,030.9	497.8	463.4	2966.9
In-Basin Supplies									
Groundwater	23.3	111.6	7.9	36.6	25.7	292.3	80.9	141.9	720.2
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	487.6	4196.8
TOTAL	1213.7	958.5	7.9	1393.0	25.7	550.0	138.7	629.5	4917.0
Transfers									
Imported Supplies	1.0	2.0	308.7	0.0	122.2	540.9	359.1	0.0	1333.9
Export Demands	2.0	279.5	0.0	839.2	0.0	60.0	0.0	153.2	1333.9
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**835.8**	**196.5**	**0.0**	**412.8**	**0.0**	**0.0**	**0.0**	**12.9**	**1458.1**
2020									
In-Basin Demands	102.4	287.3	304.4	144.0	152.6	1,128.7	529.7	492.7	3141.9
In-Basin Supplies									
Groundwater	23.3	112.8	8.3	38.7	31.1	251.1	87.1	156.1	708.5
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	487.1	4196.3
TOTAL	1213.7	959.7	8.3	1395.1	31.1	508.8	144.9	643.2	4904.8
Surface Water Transfers									
Imported Supplies	1.0	2.6	296.1	0.0	121.5	679.9	384.8	0.0	1485.9
Export Demands	2.6	266.9	0.0	993.4	0.0	60.0	0.0	163.0	1485.9
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**826.7**	**199.0**	**0.0**	**257.7**	**0.0**	**0.0**	**0.0**	**-12.5**	**1271.0**

Table 12: Southeast Area Water Supply Availability: 2000 2050, Continued.

Category	Sabine	Neches	Neches -Trinity	Trinity	Trinity- San Jacinto	San Jacinto	San Jacinto -Brazos	Brazos	Total Southeast
2030									
In-Basin Demands	111.0	299.4	303.1	148.1	156.9	1,201.4	567.7	529.1	3316.7
In-Basin Supplies									
Groundwater	23.4	114.6	8.7	41.2	27.9	266.3	87.8	169.4	739.3
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	486.6	4195.8
TOTAL	1213.8	961.5	8.7	1397.6	27.9	524.0	145.6	656.0	4935.1
Surface Water Transfers									
Imported Supplies	1.0	4.1	294.4	0.0	129.0	726.2	422.1	0.0	1576.8
Export Demands	4.1	265.3	0.0	1072.6	0.0	60.0	0.0	174.7	1576.7
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**816.8**	**191.8**	**0.0**	**176.9**	**0.0**	**-11.2**	**0.0**	**-47.8**	**1126.5**
2040									
In-Basin Demands	123.1	321.7	306.7	159.3	167.0	1,298.3	617.9	583.2	3577.2
In-Basin Supplies									
Groundwater	23.5	116.3	8.8	43.8	29.6	280.5	88.8	181.1	772.4
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	486.0	4195.2
TOTAL	1213.9	963.2	8.8	1400.2	29.6	538.2	146.6	667.1	4967.6
Surface Water Transfers									
Imported Supplies	1.0	4.6	297.7	0.0	123.5	710.9	460.8	0.0	1598.7
Export Demands	4.6	268.7	0.0	1075.3	0.0	60.0	0.0	190.1	1598.7
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**804.3**	**168.3**	**0.0**	**165.6**	**-13.9**	**-109.2**	**-10.5**	**-106.2**	**898.4**
2050									
In-Basin Demands	135.8	344.8	310.6	174.5	179.9	1,386.4	668.4	639.2	3839.6
In-Basin Supplies									
Groundwater	23.6	118.3	9.0	46.7	31.0	291.8	89.7	197.3	807.4
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	485.4	4194.6
TOTAL	1214.0	965.2	9.0	1403.1	31.0	549.5	147.5	682.7	5002.0
Transfers									
Imported Supplies	1.1	5.1	301.6	0.0	123.5	710.9	476.3	0.0	1618.5
Export Demands	5.3	272.2	0.0	1075.4	0.0	60.0	0.0	205.6	1618.5
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**791.0**	**144.2**	**0.0**	**153.2**	**-25.4**	**-186.0**	**-44.6**	**-162.1**	**670.4**

Table 13: Trans-Texas Water Program Supply Availability: 2000-2050

Category	Amount (Thousands of Acre-Feet/Year)					
	2000	*2010*	*2020*	*2030*	*2040*	*2050*
Scenario 1						
Available Southeast Supply	1764.5	1458.1	1271	1126.5	898.4	670.4
West-Central Demand	-	-	150	300	450	600
Net Surface Water Availability	**1764.5**	**1458.1**	**1121**	**826.5**	**448.4**	**70.4**
Scenario 2						
Available Southeast Supply	1764.5	1458.1	1271	1126.5	898.4	670.4
West-Central Demand	-	-	-	100	200	300
Net Surface Water Availability	**1764.5**	**1458.1**	**1271**	**1026.5**	**698.4**	**370.4**
Scenario 3						
Available Southeast Supply	1764.5	1458.1	1271	1126.5	898.4	670.4
West-Central Demand	0	0	0	0	0	0
Net Surface Water Availability	**1764.5**	**1458.1**	**1271**	**1126.5**	**898.4**	**670.4**